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8 April 1946

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Torpedoes and Tubes, Article 1 - Ship and KAITEN Torpedoes.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, dealing with Target O-01 of Fascicle O-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Comdr. C. F. Edwards, RNVR, and Lieut. H. DeLacy, RNVR, assisted by Lieut. J. Quine, RNVR, as interpreter and translator.

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SUMMARY

ORDNANCE TARGETS

JAPANESE TORPEDOES AND TUBES - ARTICLE 1
SHIP AND KAITEN TORPEDOES

General: Japanese ship torpedoes can be divided into three classes, the first using 100% oxygen, the second air, and the third electricity.

Oxygen Torpedoes: The details of the most important of the 100% oxygen types are as undernoted:

Type 93, Model 1, Modification 1 (destroyers)

Speed and Range	Knots	Meters	Yards
	49	20,000	22,000
	40	32,000	35,000
	36	40,000	44,000

Explosive Charge .... 490 kg (1078 lbs)

Type 93, Model 3

Speed and Range	Knots	Meters	Yards
	49	15,000	16,400
	40	25,000	27,300
	36	30,000	32,000

Explosive Charge .... 780 kg (1700 lbs)

Type 95, Modification 1 (submarines)

Speed and Range	Knots	Meters	Yards
	49	9000	9840
	45	12,000	13,000

Explosive Charge .... 405 kg (891 lbs)

Type 95, Model 2

Speed and Range	Knots	Meters	Yards
	49	5500	6000
	45	7500	8200

Explosive Charge .... 550 kg (1210 lbs)

Air Torpedoes: During the recent war Types 02, 02 Special, and 05 air torpedoes were designed, and these are the only modern air torpedoes (apart from aircraft torpedoes) used by the Japanese Navy.

The 02 and 02 Special (1942) are 18" torpedoes which very closely resemble the Type 91 aircraft torpedo, of which they are modifications. They use an eight-cylinder, two-row, radial engine of the Whitehead type. The 02 and 02 Special were designed for small submarines and motor torpedo boats.

The Type 05 (1945) is a low-speed, short range, 11" torpedo designed for small motor torpedo boats. A five-cylinder swash plate engine operating on the wet heater cycle and developing 7 hp is used. Only two models of this type were manufactured.

Electric Torpedo: The 21" Type 92 submarine electric torpedo was designed in 1932. Research was started in 1921. Owing to its ease of manufacture, the Type 92 was used extensively during the war for submarine armament. The following performance is claimed:

Speed	28 to 30 knots
Range	7500 vards

Development of the Use of Oxygen for Torpedoes: Japanese experimental work on the use of oxygen in torpedoes was commenced in 1917 but discontinued shortly afterward. In 1928 research was reopened, and in 1933 the first 100% oxygen torpedo (24" Type 93) was designed.

The design of all subsequent oxygen torpedoes conforms to the same general plan. The 18" Type 94 oxygen aircraft torpedo has been included in the report. The main features are:

1. Use of air or carbon tetrachloride at start of run.

2. Use of sea water as diluent. This involved the design of a "buffer" chamber to smooth the flow of sea water from the diluent pump.

3. New design of generator.

4. Special precautions to avoid contact between lubricant and high pressure oxygen.

Oxygen and Fuel Vessels: The oxygen vessel bodies of earlier types of torpedoes consisted of a forged steel body with hemispherical ends. In the Type 93, Model 1, Modification 2 and subsequent torpedoes the body and after end were forged in one piece using a 4000 ton press. The forward end is turned with a plain face joint and the cover is inserted into the body and bolted to it. A copper washer is used as jointing material, the gas pressure being used to make the joint.

The fuel vessels are of a design similar to the oxygen vessels and are screwed onto them.

Repeated pressure tests to check the safety factor were carried out on three or four vessels, the tests being repeated with each change in material.

Power Unit of the Oxygen Torpedo: The engine is of the [illegible] Whitehead design, having two double-acting cylinders placed [illegible] line, with the reversing gear forming the connection between [illegible]. The engine has been modified in certain details to enable sea [illegible] as diluent and to develop the additional power required to propel [illegible] at 50 knots.

A double-acting, single-throw reciprocating pump was [illegible] engine to supply sea water for displacing the fuels and for [illegible] generator, the surplus being used to cool the engine.

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U. S. Naval Technical Mission to Japan.

JAPANESE TORPEDOES AND TUBES

ARTICLE 1

SHIP AND KAITEN TORPEDOES

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE O-1, TARGET O-01

APRIL 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

The engine operates on the "Rankine" cycle and has a theoretical efficiency of 13.8 percent. The actual efficiency of the propulsion system is 9.6 percent.

Naval Views on Oxygen Torpedoes: To obtain the general views of the Japanese naval officer on oxygen torpedoes, the opinions of the commanders of a first-class destroyer and a first-class submarine were sought. These officers stated that it is generally felt by the Japanese Navy that the excellence of the performance of oxygen torpedoes outweighed the disadvantages of handling and preparation. (See Enclosures (A) and (B)).

Ranging of Torpedoes: In order to test the validity of Japanese claims for the performance of their oxygen torpedoes, four 21" Type 95, Model 2 submarine torpedoes were ranged at DAINYU, near KURE. The performance claimed for this model was 49 knots to 6000 yards. In all, eight runs were made. One torpedo was lost at the end of its first run, but for the remaining seven runs an average performance of 49.2 knots to 5750 yards was obtained. The tracks of the torpedoes of which photographs were obtained were very slight.

In view of the lack of proper ranging facilities it was not considered feasible to range the Type 93, Model 1 for which a performance of 49 knots to 22,000 yards was claimed. As a result of their investigation, however, the authors are satisfied that Japanese claims for their oxygen torpedoes are justified.

Heads: Prior to 1940 the Japanese used a round-nosed head. In 1940 the Italian streamlined head was fitted to Japanese high-speed torpedoes. It is claimed that this head increased the speed by about two knots without increase of engine output. Subsequently Types 93 and 95 torpedoes were fitted with streamlined heads which were a modification of the Italian type.

The explosive filling used in all Japanese torpedo warheads consisted of a mixture of:

Trinitro-toluene 60%
Hexanitrodiphenylamine 40%

"Homing" Torpedoes: In an effort to develop a "homing" torpedo, the Japanese undertook experiments with hydrophone-equipped torpedoes designed to "home" on a sound source. Two principles were employed, one depending on the difference in sound intensity at two points, the other on phase difference. Only electric torpedoes (Type 92) were used for the experiments.

The research met with only limited success, and the experiments were finally abandoned.

Influence Firing Systems: Two magnetic influence firing pistols were developed and were known as the Type "M" and Type "OR", respectively. The development of the former type was completed in 1944 and accepted by the Navy after successful trials. The type "OR" was in the early stage of experiment. Trials had not been undertaken.

Turbine Torpedoes: About 1936, the Japanese undertook the development of a turbine torpedo to meet a Naval Staff requirement of 60 knots to 9000 yards. In 1936, after preliminary work at YOKOSUKA, the design of turbine units F1, F2, and F3 suitable for 24" torpedoes was undertaken.

Sea water was used as a diluent in the generator. Deposition of salt in the nozzles and on the blades was prevented by injecting a zinc chloride solution just before the induction ring. Zinc chloride lowers the melting point of common salt and prevents its crystallization at the temperature existing in the turbine.

The development was finally abandoned because of the technical difficulties involved in meeting further staff requirements.

Japanese Torpedo Production: Some data on the numbers of torpedoes produced from 1931 to 1945 was obtained from the U.S. Strategic Bomb Survey. It appears that no differentiation in type was made for the various diameters so that, except in the case of the Type 02, the total production cannot be split into types.

The numbers were small and quite inadequate for the services for which the torpedoes were intended.

KAITEN Torpedoes: The one-man KAITEN torpedo was developed by the Japanese to direct the torpedo onto the target and to obtain greater weight of explosive and greater range; the last at the expense of speed.

The first KAITEN was designed in 1944. In all, four types of KAITEN were designed - 1, 2, 4, and 10. Only Type 1 was used operationally.

Type 1: This was essentially based on the Type 93, model 3 torpedo and, in fact, the Type 93 torpedo (without head) was used almost unchanged for the propulsion system of KAITEN 1. The maximum speed of this type was 30 knots with a range of 25,000 yards at this speed. Over 3000 pounds of explosive were carried in the head. The total weight was eight tons.

Type 2: KAITEN 2 was designed in 1944 to operate on hydrogen peroxide, hydrazine hydrate and kerosene, using sea water as diluent and operating on the wet heater cycle. A new engine, known as the No. 6 Engine, was designed. It was a two-row, vertical engine with eight cylinders. A special generator was designed. The KAITEN 2 was considerably larger than KAITEN 1. The following are some of its main characteristics:

Weight	18 tons
Length	50 ft
Diameter	4 ft
Horsepower	1500
Maximum speed	40 knots
Range at 40 knots	27,000 yards
Weight of explosive	3000 lbs

The KAITEN 2 never underwent sea trials, but these were about to be carried out when the war ended.

Type 4: With an adequate supply of peroxide for KAITEN 2 in doubt, work was begun on the design of KAITEN 4. This KAITEN had the same overall dimensions and weight as Type 2, but it was designed to run on oxygen. The No. 6 Engine was used in conjunction with two Type 93 torpedo generators. Carbon tetrachloride was used for safe starting.

Trials with KAITEN 4 were disappointing. The use of two Type 93 generators was not satisfactory, and the oxygen consumption was poor. Large percentages of unburnt oxygen appeared in the exhaust.

Sea trials of KAITEN 4 were unsatisfactory. The speed realized never exceeded 25 knots.

Type 10: In the main, the KAITEN 10 consisted of the Type 92 electric torpedo with a pilot's cockpit built in. It was designed for the defense of Japanese coastal waters, but it was never used in service.

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REFERENCES

Locations of Targets:

Japanese torpedo development was carried out at YOKOSUKA, KURE, HIRO, MAIZURU, TOKYO, KANAZAWA, NAGASAKI and SASEBO.

This investigation was made mainly at the Kure Naval Arsenal, but visits were paid to establishments in TOKYO, YOKOSUKA and KANAZAWA.

Japanese Personnel Interviewed:

Admiral S. OYAGI - Graduated about 1920 from Tokyo Imperial University where he studied ordnance engineering and then went to the Torpedo Department, KURE; joined the Torpedo Experimental Department, KURE, when it was started in 1923; spent about two years (1926-27) at Whitehead Torpedo Factory, England; upon returning to Kure Experimental Department he engaged in oxygen research; was one of the pioneers responsible for the development of the oxygen torpedo, (the others were ASAKUMA, KITA and WATANABE); left KURE in 1934 to join Naval Technical Department, TOKYO on fundamental research side of torpedoes. Supplied general information on the development of the oxygen torpedo. Speaks English.

Admiral S. NARUSE - Graduated about 1920 from Tokyo Imperial University where he specialized in ordnance engineering; spent most of his career in Yokosuka Torpedo Department; visited England about 1924 as Ordnance Inspector, and spent about two years there; upon returning to YOKOSUKA he studied aircraft torpedoes and designed Type 91; undertook research on turbine engine in 1935; came to KURE in 1937 and continued turbine research with Commander HORI at the Kure Torpedo Experimental Department; in 1941 joined Yokosuka First Naval Technical Arsenal where he was engaged in the development of the aircraft torpedo. Expert in aircraft and turbine torpedoes. Speaks English.

Rear Admiral KIMOTO - Studied ordnance engineering at Tokyo Imperial University for three years; spent two years in Germany attached to Japanese Naval Representative in Berlin, as torpedo inspector; from 1939-1942 assistant to the head of Naval Technical Department, TOKYO in an administrative capacity; from Sept., 1943 to August 1945, head of Torpedo Department, KURE. Responsible for design and production of torpedoes and their supply to the fleet. Has general knowledge of the administrative side of the Naval Technical Departments.

Captain K. WATANABE - Graduated from Imperial University about 1925, specialized in Ordnance Engineering; engaged in manufacture and repair of torpedoes at YOKOSUKA; about 1930, went to Torpedo Department, KURE, where he studied torpedo design with particular reference to the oxygen torpedo; in 1934, joined Naval Technical Department, TOKYO; in 1937, visited U.S.A. as Japanese ordnance inspector, spent about two years there; in 1939, visited Italy and brought back to Japan three Italian torpedoes; returned to KURE and worked in Torpedo Experimental Department for about one year, then held the post of chief torpedo designer in Torpedo Technical Department. Has wide knowledge of design and manufacture of torpedoes and KAITEN. Supplied information on development and design of Type 93 torpedo. Speaks English.

Captain NAKAMURA - Destroyer commander. Details of career are given in Enclosure (A). Supplied information on his experience in the use of surface ship torpedoes.

Commander Y. HORI - Graduated from Tokyo Imperial University in 1932; entered Navy, taking a course of four months at Yokosuka Naval School in ordnance and general naval training, then went to Kure Torpedo Department where training in fundamental torpedo engineering was received for about one year; spent 12 months on cruisers, destroyers and submarines studying the operational use of torpedoes; from 1935, spent about five years in the design and manufacture of torpedoes and tubes and in research in the Torpedo Experimental Department; in 1940 became member of staff of Experimental Department and about 1944, became head of this Department. During his career HORI was engaged in the design of propellers and turbine engines and general engine development; was finally in charge of all torpedo and KAITEN design. Has wide knowledge of development and design of oxygen torpedo. Carried out hydrogen peroxide research in collaboration with Lt. Comdr. H. KAWASE. Supplied large amount of information on the development and detailed mechanics of Japanese torpedoes. Speaks English.

Commander R. NAGANO - Graduated from Tokyo Imperial University in mechanical engineering in 1932; entered Navy; worked at the Marine Engine Experimental Department, YOKOSUKA; went to Germany in 1937 to study Diesel engine design and in 1939 went to Italy as Naval Inspector; returned to Japan in 1940 and was appointed chief designer of diesel engines at Naval Technical Department, TOKYO; was granted Doctorate of Engineering by Tokyo Imperial University in 1943 for thesis on "Torsional Vibration of Japanese Marine Diesel Engine Shafts and its Damping". NAGANO was the designer of the No. 6 Engine for KAITEN; he supplied information on this subject. Speaks English.

Lt. Comdr. H. KAWASE - Specialized in biochemistry at Sendai Imperial University and was graduated in 1935; studied corrosion of metals at Sendai University from 1935 to 1937; entered the Navy in 1937 and studied torpedo ordnance at YOKOSUKA; spent some months studying oxygen plants and compressors; in 1939 went to KURE where he researched on the use of hard chromium plate for main shafts and slide valves of torpedoes; in 1944 conducted research on hydrogen peroxide propulsion. KAWASE supplied a great deal of information on compressors, carbon tetrachloride for starting, lubricants, fuel and KAITEN 2 research. Speaks English.

Lt. Comdr. I. FUKUDA - Graduated from Tokyo Imperial University in 1937, taking his degree in mechanical engineering and specializing in ordnance; entered Navy; studied ordnance for four months at Yokosuka Naval School; from 1940 to 1942 continued training at SASEBO where he was engaged in production and repair of torpedoes and tubes; subsequently at Kure Torpedo Department where he spent some time in the Experimental Department and then engaged in manufacture of torpedoes and KAITEN; towards end of the war was connected with the manufacture of midget submarines. Has wide knowledge of Japanese torpedoes and is expert in the preparation and ranging of oxygen torpedoes. Supplied tremendous amount of information on every aspect of the oxygen torpedo. Speaks English.

Lt. Comdr. ITAKURA - Submarine commander. Details of his career are given in Enclosure (B). Supplied information on his experience in the use of submarine torpedoes.

Lieutenant Kazuo SHIOTANI - Completed his education at the Hiroshima Technical College in 1933 and entered the Navy as soon as he left school; has worked continually in the research department of the

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INTRODUCTION

The purpose of this investigation was to obtain as much information as possible on the development, performance and operation of all types of Japanese ship and one-man KAITEN torpedoes.

The method used was to examine specimens of each type, to interrogate Japanese naval personnel, to carry out ranging trials, and to have drawings made of novel or unusual components. Fortunately specimens of practically every type were found in KURE, the principal development center. No drawings or test results were available, so much valuable information is missing which it would have been desirable to include. Quantitative data has been collected in the metric system; in many instances the English equivalent is given.

The investigation did not cover the Types 6, 8, 89 and 90, which were air torpedoes and were designed before 1931. Although these torpedoes were used in the war it was considered that the design was now obsolete.

No attempt was made to give a full appreciation of the new methods employed by the Japanese; but a detailed record of the methods has been given where the information was forthcoming. It was possible, however, to obtain the views of the Chief Experimental Designer on the lines of the future development of the torpedo which would have been adopted by the Japanese.

Since the report has been written in the field, without the usual facilities, reference books, etc., it has not been possible to verify all the figures. As far as time has permitted, as many as possible have been checked.

Inasmuch as it was not possible to prepare drawings of all the parts of all the torpedoes, the facilities available were concentrated on those details of special interest.

The authors would like to acknowledge with many thanks the following contributions:

Lt. Comdr. J. LAVERACK, RNVR - Guiding and homing torpedoes. Japanese influence firing systems.

Lt. Comdr. N. GOLDSWORTHY, GC.GM., RANVR
Lieut. L. BLACKWELL, USNR
Ensign S. BARTLETT, USNR - Exploders

Lt. Comdr. R. BROOKE, RNVR - Power unit, Type 92 electric torpedo

Lieut. J. QUINE, RNVR - Interpreting, organization of the field expeditions and production of the report

R. M. KERWIN, PhoM2c, USNR
R. F. TRAUB, PhoM3c, USNR - Photography

Finally the authors would like to express their appreciation of being permitted to work as part of a U.S. Naval Technical Mission and their pleasure in so doing.

THE REPORT

IDENTIFICATION MARKINGS ON JAPANESE TORPEDOES

Type

The type number on a Japanese torpedo generally indicates the year in which the first model of this type torpedo was designed. In order to appreciate, therefore, the full significance of type markings, one must be acquainted with the main points of difference between the Japanese calendar and the Christian calendar.

The Japanese calendar dates from the year of the founding of the Empire by JIMMU in 660 B.C. Thus, the data in the Japanese calendar, corresponding to a certain date in the Christian Era, is obtained by adding 660 to the Christian year. Hence, the year 1945 A.D. corresponds to the year 1945 plus 660 or 2605 in the Japanese calendar. The torpedo referred to as Type 05 takes its type number from the last two figures of this year, and was therefore designed in 1945 A.D. Similarly the Type 97 was designed in the Japanese year 2597 or 1937 A.D.

The following table gives a list of torpedo types which are dated according to this system;

TORPEDO TYPE	YEAR OF DESIGN	
	Japanese	Christian (A.D.)
89	2589	1929
90	2590	1930
91	2591	1931
92	2592	1932
93	2593	1933
94	2594	1934
95	2595	1935
97	2597	1937
02	2602	1942
05	2605	1945

Dating by Emperor's Reign

In addition to dating their year from the founding of the Empire, the Japanese also fix their year by naming the reign of the Emperor and numbering the years following his accession. The present reign is known as 'SHOWA', and it began when Emperor HIROHITO ascended the throne in 1926 (1st year SHOWA). Thus 1945 A.D. was the 20th year SHOWA. The previous reign was known as 'TAISHO' and the one before that, 'MEIJI'. The durations of these reigns were as follows:

	Christian Calendar (A.D.)
MEIJI	1868-1912
TAISHO	1912-1926
SHOWA	1926-

It will be noticed that the last year of an Emperor's reign coincides with the first year of the succeeding Emperor's reign. Thus 1st SHOWA and 15th TAISHO both refer to the same year, 1926 A.D. In the same way, both 1st TAISHO and 45th MEIJI refer to 1912 A.D.

The following types of torpedoes have derived their type numbers from this system of dating:

TORPEDO TYPE	YEAR OF DESIGN		
	Japanese Calendar		Christian Calendar
	Emperor's Reign	Founding of Empire	
44	44th year MEIJI	2571	1911
6	6th year TAISHO	2577	1917
8	8th year TAISHO	2579	1919

It must be remembered that the above principles fix the year of design of a particular model but do not indicate the number of years of research which may have preceded the design. For instance, the Japanese devoted a great deal of research to the development of an electric torpedo as early as 1921, but the electric torpedo used during the recent war takes its type number (Type 92) from the experimental model which was built in 1932 as the result of the previous research.

Exceptions

There are two important exceptions to the foregoing principles. Types 96 and 98 were both developed in 1942, although their type numbers suggest that their development took place in the years 1936 and 1938 respectively. This apparent anomaly will be understood, when one realizes that Type 96 is a modified form of Type 95 and therefore is not a new type torpedo. It was assigned the next type number to its 'parent' Type 95. In the same way, Type 98 (sometimes called 'Type 97, special') is a modified form of Type 97 and was consequently assigned the succeeding type number.

Subsidiary Markings

In order to differentiate between the main type of torpedo and its various models, four main identification markings are used. These are shown below, with corresponding English equivalents:

Japanese Symbol	Hepburn Spelling	English Equivalent
式	shiki	Type
型	kata or gata	Model
改	kai	Modification
號	go	Mark

Except in the case of aircraft torpedoes, the Japanese equivalent of 'Mark' is not used in any of their modern torpedoes. In general, 'Model' is used to denote a major change within the 'Type', whereas 'Modification' denotes a change of a lesser nature. Where used, 'Mark' has the same significance as 'Model'.

TRANSLATION OF SHELL MARKINGS - 24" TYPE 93 MODEL 1*

1.	T-93 Mod. 1 KURE No. Date Made	Forward end of air vessel
2.	Oxygen charging stop valve Stop valve for No. 2 air Close Open	Forward end of air vessel
3.	Oxygen charging valve	Forward end of air vessel
4.	Fuel filling plug	Center of fuel chamber
5.	Relief valve	Center of fuel chamber
6.	Fuel drain plug	Center of fuel chamber (underside)

*See Page 22 for corresponding Japanese characters and Figure 1 for locations of shell markings.

7.	Separator drain plug Fuel-separator exhaust	Center of fuel chamber (underside)
8.	Cleaning hole for fuel chamber	Center of fuel chamber (portside)
9.	Cleaning hole for fuel chamber	Center of fuel chamber (starboard)
10.	Aperture for testing relief valve lub. oil filler plug	Top of oil chamber
11.	Fuel strainer Relief valve for fuel chamber	Top of oil chamber
12.	Relief valve	Front of forebody buoyancy (top) chamber
13.	When depth dial shows 6m the marking on dial & base line of adjusting & shell must coincide	Rear of forebody b/c. (top)
	Shallow Deep	
14.	Non-return valve	Rear of forebody b/c. (top)
15.	Oxygen delivery stop valve	Rear of forebody b/c. (top)
	Close Open	
16.	Steering air stop valve	Rear of forebody b/c. (top)
	Close Open	
17.	Charging valve for steering air	Rear of forebody b/c. (top)
18.	Stop valve for 1st air vessel	Rear of forebody b/c. (top)
	Close Open	
19.	Charging valve for 1st air vessel	Rear of forebody b/c. (top)
20.	Pipe connections Exhaust from steering Air to oil chamber Fuel supply to generator Air stop valve to tube starting valve Reducer adjustment	Front of engine room (top)
21.	Water filling plug of No. 1 reducer	Engine room (top)
22.	Water filling plug of No. 2 reducer	Engine room (top)
23.	Oil filling plug of No. 2 reducer	Engine room (top)

1 九三式一型呉 No
昭和　年造
2 第二空塞気 閉↑ ↑開
3 第二空装気
4 燃料注入口
5 安全弁
6 燃料排出口
7 分離器排水口
8 燃料室手入口
9 燃料室手入口
10 安全弁気密試験口
潤滑油注入口
11 燃料濾網
燃料室排気
12 安全弁
気密試験口
13 深度6米ノ時調整片及外皮口ノ基線ガ一直線ニ合致スルコト。 浅↓ ↓深
14 戻止弁
15 第二起動 閉↑ ↑開
16 操舵空塞気 閉↑ ↑開
17 操舵空装気
18 第一空塞気 閉↑ ↑開
19 第一空装気

20 （排気 燃料 空気）
主調和器改調口
21 主調和低圧注水口
22 主調高圧注水口
23 主調低圧注油口
24 主調高圧注油口
25 加熱固定口
26 水量計螺蓋
27 発停主機発動弁
28 発停距離調整口
29 緩衝器補助室注水口
30 火管撃槌
火管遅動調整口
31 潤滑油濾網，排油口
32, 33, 34 操舵空排水口
35 第一空排水口
36 深度機及横舵機接續口
37 横舵制止目盛
38 初度目盛
39 轉子調整口，横舵機手入口
40 横舵制止
41 横舵機濾網
42 緩衝器油排出口
43, 44 気筒固縛

45 水戻止弁
46 第二 →□
47 緩衝器注入口
48 緩衝器取付口
49 第二空 ←□
潤滑油 ←
50 水 ←□
51 潤滑油 ⇄□
水
空気 ←
52, 55, 65, 67 接合 → 分離
接合ノ際ハ「接」ナル合印ヲ認メタル上更ニ緊締スルヲ要ス
53 燃料戻止弁
54 減速歯車装置接續口
56 空気濾網
57 空気発動弁
58 安全弁 気密試験口
59 呉 NO
60 横舵錘接續口
61, 62, 63 気筒排水口
64 横舵錘接續口
66 斜進改調口

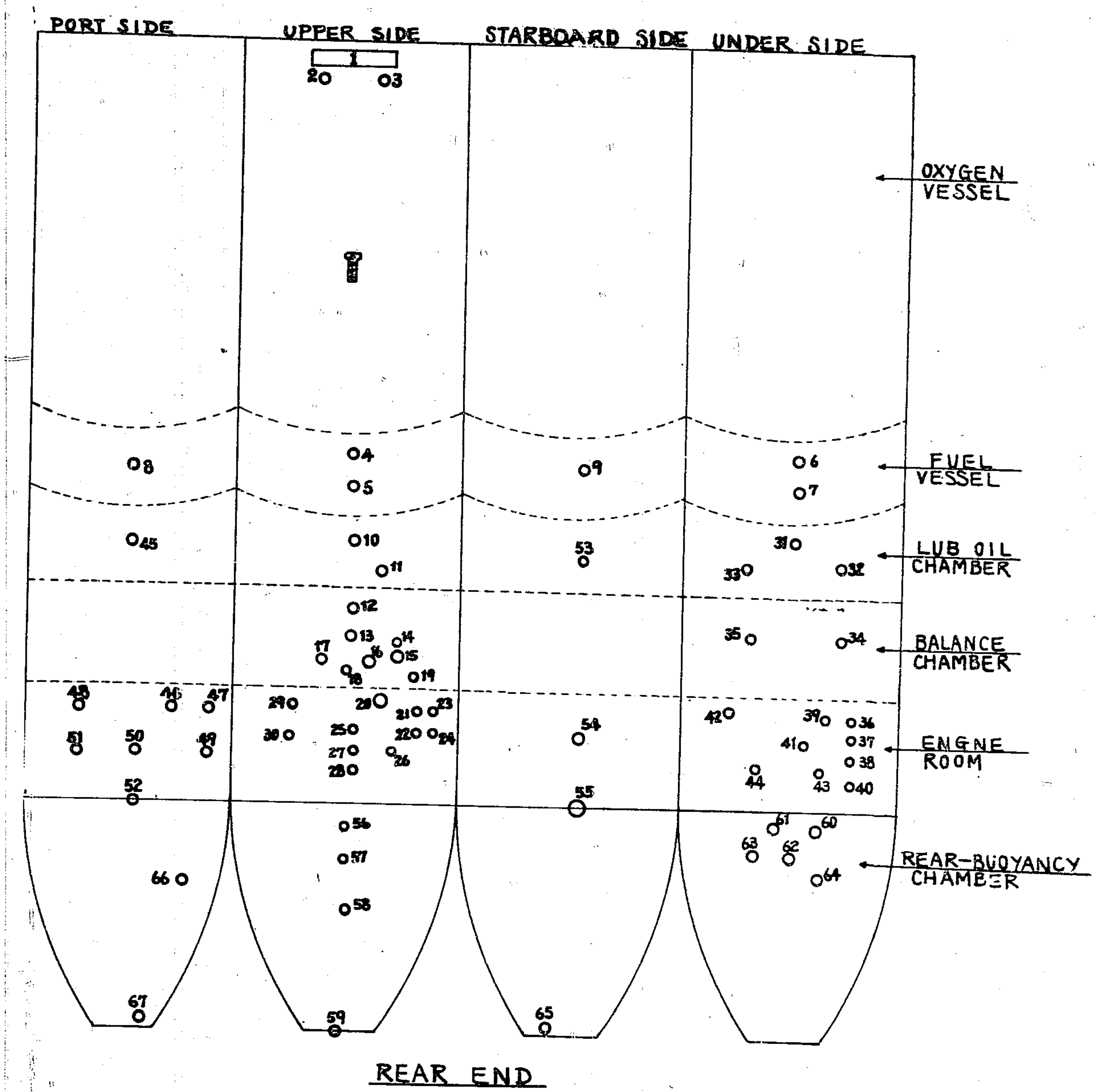


FIGURE 1
DEVELOPED VIEW OF SHELL
TYPE 93 MODEL 1

24.	Oil filling plug of No. 1 reducer	Engine room (top)
25.	Water & fuel nozzle adjustments	Engine room (top)
26.	Aperture for flow-meter	Engine room (top)
27.	Engine starting valve in group	Engine room (top)
28.	Range setting aperture	Engine room (top)
29.	Filling plug for buffer chamber	Engine room (top)
30.	Ignition delay gear IGNITER hammers	Engine room (top)
31.	Oil strainer and drain plug	Oil chamber (underside)
32.	Drain from steering air bottle	Oil chamber (underside)
33.	Drain from steering air bottle	Oil chamber (underside)
34.	Drain from steering air bottle	Balance chamber (underside)
35.	Drain plug of 1st air vessel	Balance chamber (underside)
36.	Connection between depth gear & servomotor	Engine room (underside)
37.	Dial for rudder locking	Engine room (underside)
38.	Dial of horizontal rudders	Engine room (underside)
	Down	
39.	Adjusting hole for gab rod Cleaning hole for horizontal rudder	Engine room (underside)
40.	Rudder locking gear	Engine room (underside)
41.	Air strainer for servomotor	Engine room (underside)
42.	Oil drain from buffer	Engine room (underside)
43.	Engine anchoring	Engine room (underside)
44.	Engine anchoring	Engine room (underside)
45.	Non-return valve (water)	Lub. oil chamber (portside)
46.	Pipe connection from oxygen stop valve to group	Engine room (portside)
47.	Water inlet to buffer	Engine room (portside)
48.	Securing screw for buffer	Engine room (portside)

49.	No. 2 air Pipe connection from génerator to the piston of buffer chamber	Engine room (portsdde)
	Lub. oil Pipe connection from oil pressure regulator to the piston of buffer chamber	Engine room (portside)
50.	Water Pipe connection from pump to buffer chamber	Engine room (portside)
51.	Lub. oil Pipe connection from oil chamber to oil pump Water from buffer chamber to generator Air from tube-operated starting valve to servomotor	Engine room (portside)
52.	Assembly of after body to engine room	Engine room (portside)
	Separate When assembled tighten beyond the marks	
53.	Non-return valve for fuel	Lub. oil chamber (starboard)
54.	Connecting hole for adjusting rudder locking gear	Engine room (starboard)
55.	Assembly of afterbody to engine room	Engine room (starboard)
56.	Air strainer	Rear buoyancy chamber
57.	Starting valve for steering air Relief	Rear buoyancy chamber
58.	Safety valve Aperture for air testing	Rear buoyancy chamber
59.	KURE No. KURE No.	Rear buoyancy chamber
60.	Connecting hole for rudder rods	Rear b/c underside (downside)
61.	Drain plug for cylinder	Rear b/c underside (downside)
62.	Drain plug for cylinder	Rear b/c underside (downside)
63.	Drain plug for cylinder	Rear b/c underside (downside)
64.	Connecting hole for rod of rudder	Rear b/c underside (downside)

65.	Assembly of tail	Rear b/c (starboard)
66.	Adjusting hole for gyro angling	Rear b/c (portside)
67.	Assembly of tail	Rear b/c (portside)

Above markings are as on Type 93 Modification 1. On Type 93 Modifications 2 and 3 the Japanese wording is more abbreviated but the meaning and location remain the same.

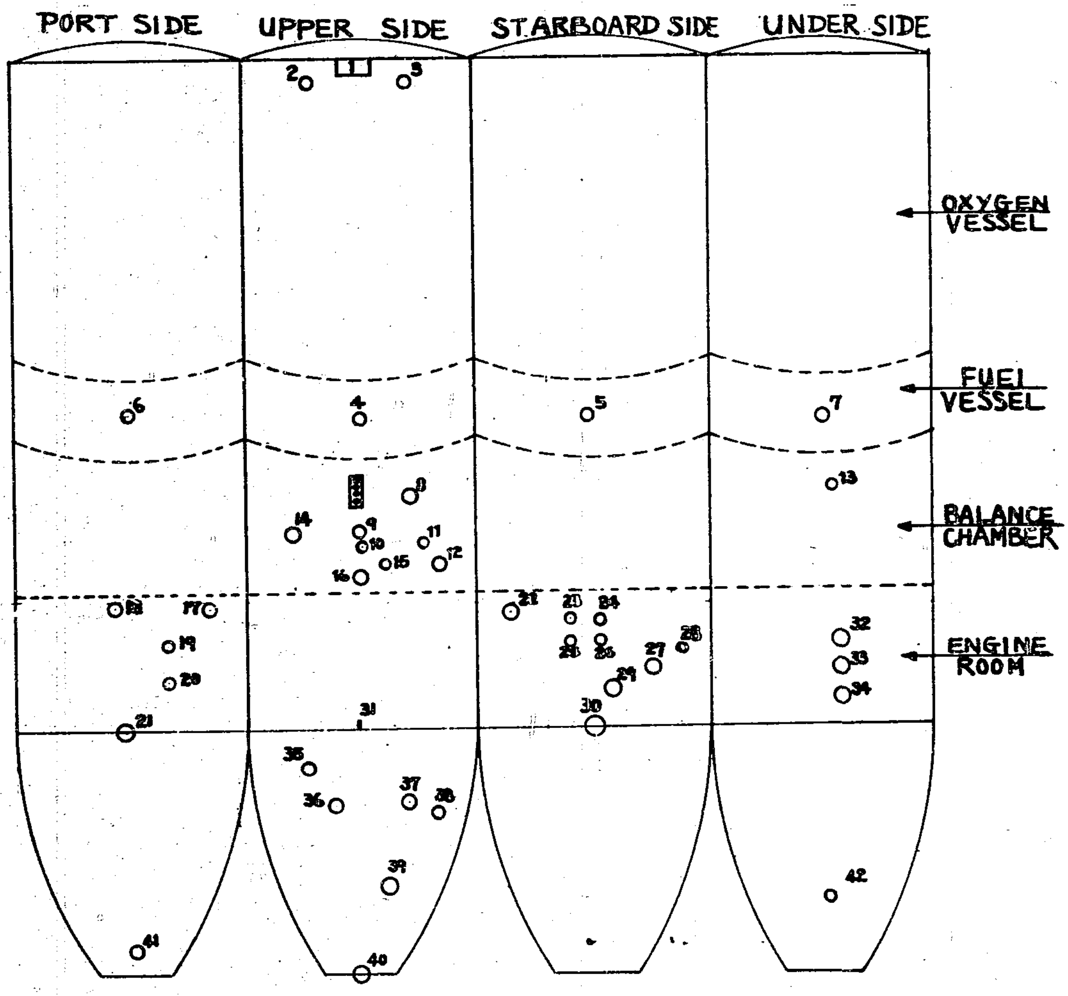
TRANSLATION OF SHELL MARKINGS - 21" TYPE 95 MODEL 2*

1.	Type 95 Model 2 factory no. Material of oxygen vessel	Forward end of vessel center top
2.	Oxygen charging valve	Forward end of vessel top port
3.	Oxygen charging stop valve	Forward end of vessel top starboard
4.	Filling plug for fuel	Center of fuel vessel top
5.	Cleaning hole for fuel vessel	Center of fuel vessel starboard side
6.	Cleaning hole for fuel vessel	Center of fuel vessel port side
7.	Fuel drain plug	Center of fuel vessel underside
8.	Forebody relief valve	Center of balance chamber top
9.	Fuel strainer	Center of balance chamber top
10.	Fuel non-return valve	Center of balance chamber top
11.	Charging valve for steering air	Rear of balance chamber top starboard
12.	Stop valve for steering air close↑ ↑open	Rear of balance chamber top starboard
13.	Steering bottle drain plug	Center of balance chamber underside
14.	Oxygen delivery stop valve	Rear of balance chamber top port
15.	Water non-return valve	Rear of balance chamber top
16.	Depth setting deep↑ ↑shallow When depth dial shows 6 meters the markings on dial and base line of shell must coincide	Rear of balance chamber center

*See Page 28 for corresponding Japanese characters and Figure 2 for location of shell markings.

17.	Fuel pipe connection from fuel vessel to generator	Port side of engine room
18.	Water pipe connection from diluent sea water pump to buffer chamber	Port side of engine room
19.	Filling plug for buffer chamber	Port side of engine room
20.	Oil pipe from distributor to buffer chamber	Port side of engine room
21.	Engine assembly assemble↑ ↑disassemble	Rear of engine room port side
22.	Oxygen pipe connection from delivery valve to group	Starboard side of engine room
23.	Oil filling plug No. 2 stage of reducer	Starboard side of engine room
24.	Water filling plug No. 2 stage of reducer	Starboard side of engine room
25.	Oil filling plug No. 1 stage of reducer	Starboard side of engine room
26.	Water filling plug No. 1 stage of reducer	Starboard side of engine room
27.	Steering air. Pipe connection from stop valve to tube-operated starting valve	Starboard side of engine room
28.	Servomotor non-return valve	Starboard side of engine room
29.	Aperture for flow meter	Starboard side of engine room
30.	Engine assembly assemble↑ ↑disassemble	Rear of engine room starboard side
31.	NAGASAKI factory number	Rear of engine room top center
32.	Rudder locking gear	Underside of engine room
33.	Dial of initial setting of horizontal rudders	Underside of engine room
34.	Steering air strainer for servomotor	Underside of engine room
35.	Rear buoyancy chamber relief valve	Rear of buoyancy chamber top port
36.	Tube-operated starting valve for steering valve	Rear of buoyancy chamber top port
37.	Lub. oil strainer	Rear of buoyancy chamber top starboard

1 九五式二型 長 2730
SFS 7R
2 ニ空装
3 ニ空塞 閉↑ ↑開
4 燃料注
5, 6 手入口
7 燃排
8 安全弁(前部用)
9 燃料濾網
10 燃料不歸弁
11 操空装
12 操空塞 閉↑ ↑開
13 操空溜排
14 起動弁, 不歸弁
15 燃料押水不歸弁
16 深度 深↑ ↑浅
深度目盛6米ノ時要具溝ハ縦軸線ニ平行ニ取付クルコト
17 燃料 □→
18 水 □←
19 緩水
20 緩油
21 接 ↷ 離 ↶
22 ←□ 主空
23 ニ調油
24 ニ調水
25 一調油
26 一調水
27 ←□ 操空
28 横舵機不歸弁
29 量水計
30 接 ↷ 離 ↶
31 長 2730
32 制止
33 初度 ↷上 ↗下
34 横空濾網
35 安全弁(後部用)
36 操空發動弁
37 濾網, 主機油
38 操空濾網
39 主機注油
40 長 2730
41 接 ↷ 離 ↶
42 主機油排



REAR END

FIGURE 2
DEVELOPED VIEW OF SHELL
TYPE 95 MODEL 2

38.	Steering air strainer for steering engine	Rear buoyancy chamber top starboard
39.	Lub. oil filling plug	Rear buoyancy chamber top
40.	Alignment mark of tail with rear buoyancy chamber	Rear buoyancy chamber top
41.	Assembly of tail	Tail top
42.	Lub. oil drain	Rear buoyancy chamber underside

MAIN CHARACTERISTICS OF JAPANESE TORPEDO TYPES

21" Type 6 (6th year) - Designed in 1917 for submarine use. Four-cylinder radial engine (Schwartz-Kopf Co., German type). Uses air; used to a small extent on older type submarines (RO-60, 61, etc.) during the recent war. No variations of this type.

Speed and Range	Knots	Meters	Yards
	36	7000	7660
	32	10,000	11,000
	26	15,000	16,400

Air Efficiency .... 600 hp sec/kg air
.... 13.2 lbs air/BHP hr
Explosive Charge .... 200 kg (484 lbs)

24" Type 8 (8th year) - Designed in 1919 for ship use. Four-cylinder radial engine (Schwartz-Kopf Co., German type). Uses air. There are two modifications of this type, but no attempt was made to get detailed information. This torpedo, together with Type 6, comprised the standard torpedo armament of the Japanese Navy for about 10 years.

Speed and Range	Knots	Meters	Yards
	38	10,000	11,000
	32	15,000	16,300
	28	20,000	22,000

Air Efficiency .... 600 hp sec/kg air
.... 13.2 lbs air/BHP hr
Explosive Charge .... 345 kg (759 lbs)

21" Type 89 - Developed in 1929 for submarine use. Two-cylinder, double-acting, reciprocating engine (Whitehead, English type). Uses air. This type was used in the recent war, later types not being available in sufficient numbers. Its use was discontinued at the end of 1942. No variations of this type.

Speed and Range	Knots	Meters	Yards
	45	5500	6000
	43	6000	6500
	35	10,000	11,000

Air Efficiency .... 700 hp sec/kg air
.... 11.3 lbs air/BHP hr
Explosive Charge .... 300 kg (660 lbs)

24" Type 90 - Developed in 1930 for ship use. Two-cylinder, double-acting, reciprocating engine (Whitehead, English type). Uses air. This type was used on second-class destroyers during the recent war, later types not being available in sufficient numbers. Its use was discontinued at the end of 1942. No variations of this type.

Speed and Range	Knots	Meters	Yards
	46	7000	7660
	43	10,000	11,000
	35	15,000	16,400

Air Efficiency .... 700 hp sec/kg air
.... 11.3 lbs air/BHP hr
Explosive Charge .... 375 kg (825 lbs)

Type 91 - Aircraft torpedo.

21" Type 92 - Experimental electric torpedo, designed in 1932 after many years of research.

21" Type 92 Modification 1 - Developed in 1934 for submarine use. Two lead-acid batteries each of 54 cells. Six-pole, compound, interpole motor. Due to low speed, this torpedo did not compete in performance with the Type 95. Due to its comparative ease of mass production, however, Type 92, Modification 1 came to the fore in 1942 when it was produced in quantity to supplement the supply of Type 95.

Speed and Range	Knots	Meters	Yards
	28-30	7000	7660

Explosive Charge .... 300 kg (660 lbs)

21" Type 92 Model 2 - In 1942 the Germans delivered to Japan 10 of their electric torpedoes together with drawings. The Japanese also examined German electric torpedoes at PENANG, which the Germans were using as their submarine base for operations in the Bay of BENGAL. The Type 92, Model 2 was designed in 1942 after the German type, but was never completed owing to the shortage of manpower for the project.

24" Type 93 Model 1 - Experimental torpedo. This was the first Japanese 100% oxygen torpedo and was designed in 1933. Combustion tests, horsepower measurements and running trials were made on this model. The Type 93, Model 1 was the result of oxygen research which was revived in 1928. Several new developments are incorporated in this design, and these may be considered as the chief factors in the successful development of the torpedo. They are:

1. Use of air for starting.
2. Use of sea water as a diluent.
3. Design of "buffer" chamber to smooth the delivery from the sea water pump.
4. New design of generator.
5. Improvement of gyro and gyro mounting.

24" Type 93 Model 1 Modification 1 - Following the success of the trials with the experimental 93 Model 1, the Type 93, Model 1, Modification 1 was designed in 1935 for ship use. This type was almost identical in design with the Type 93 Model 1, but with the following small changes:

1. Strength of bracing ribs in forebody and rear buoyancy chamber increased.
2. Increase of cooling water to piston rod to prevent the latter cracking.
3. Helical gearwheel for slide valve gearing made of phosphor-bronze. The wear on this gear is severe, and steel, bronze and "Silzin" had been used in the Type 93 Model 1 with only moderate success.

Speed and Range

Knots	Meters	Yards
49	20,000	22,000
40	32,000	35,000
36	40,000	44,000

Oxygen Efficiency ...... 1800 hp sec/kg oxygen
... 4.4 lbs oxygen/BHP hr
Explosive Charge .... 490 kg (1078 lbs)

24" Type 93 Model 1 Modification 2 - Same as Type 93 Model 1, Modification 1, in working principles but different in many details. Produced in quantity between 1936 and 1944. Details of differences:

1. The oxygen vessel in the Type 93 Model 1, Modification 1, consisted of a hollow forging with two dome-shaped caps bolted at each end. The oxygen vessel of the Type 93 Model 1, Modification 2 consisted of a deep pressing with one integral end and a cap on the other end. This design facilitated production, and was used for all later types of vessels.
2. Bracing ribs of rear buoyancy chamber further strengthened.
3. Gear ratio on "group valve" changed.
4. In previous models worn slide valves in the engine were replaced with new valves. In this, and all later oxygen torpedoes, the valves were repaired in order to conserve material.
5. Cooling water to the slide valves was increased with water from overflow of the buffer chamber. This required a slight modification in the latter.
6. Instead of an adjacent pipe lead for sending lubricating oil to to cross-head, a hole was drilled through the connecting rod.

Performance and explosive charge are same as Type 93 Model 1, Modification 1.

24" Type 93 Model 1 Modification 3 - This torpedo is the latest type Japanese oxygen torpedo, having been designed in 1944. Although it was never used in operations, successful running trials were completed. This type was developed to meet a Naval Staff requirement which asked for a longer range for Type 93, Model 3.

The designers of Type 93, Model 1, Modification 3 combined the propulsion system of Type 93, Model 3 with the oxygen vessel and warhead of the Type 93 Model 1, Modification 1. This design resulted in a torpedo, having the same performance and explosive charge as the Type 93 Model 1, Modification 1, combined with the improved propulsion system of the Type 93 Model 3.

24" Type 93 Model 2 - This was an experimental torpedo designed in 1935 to meet a Naval Staff requirement for a torpedo of higher speed for destroyers. Only two torpedoes of this type were built, and experiments were discontinued when research on torpedo turbines began soon afterwards. With the failure to bring the latter research to a successful conclusion, experiments on the Type 93 Model 2 were recommenced in 1941. Two designs of engine for the Type 93, Model 2 were:

1. Bore of the Whitehead type engine was increased. With this model a speed of 51 knots was realized.
2. Similar design of engine to Type 93 Model 1 but with thicker cylinder walls to withstand higher pressures.
   Stronger piston rod.
   Inlet pressure 45 kg/cm² (640 lbs/in²).
   Streamlined head (after Italian design).
   Small pitch of propellers (about 20% less than Type 93 Model 1). Higher RPM.

Three runs were made and a speed of 56 knots was realized. Range, 5000 m.

<u>24" Type 93 Model 3</u> - Designed in 1943. Improvements were made in the propulsion system, and it was fitted with smaller oxygen vessel and larger warhead. Main points were:

1. Starting air vessel ("first air vessel") was removed and replaced by "first liquid bottle", a small bottle (150 cc) of carbon tetrachloride. Thus, starting is effected with a mixture of oxygen, carbon tetrachloride and fuel.
2. Length of oxygen vessel reduced.
3. Length of warhead increased.

Speed and Range	Knots	Meters	Yards
	49	15,000	16,400
	40	25,000	27,300
	36	30,000	32,000

Oxygen Efficiency ...... 1800 hp sec/kg oxygen
... 4.4 lbs oxygen/BHP hr
Explosive Charge .... 780 kg (1716 lbs)

<u>21" Type 94 Model 1</u> - This was an experimental oxygen torpedo for use from aircraft. It was designed in 1934 but was never manufactured. Used "first air vessel" circuit. Eight-cylinder, radial engine (like Type 02) was used.

<u>18" Type 94 Model 2</u> - Circuit and engine similar to the Type 94 Model 1. The performance of these two models were approximately:

Speed and Range	Knots	Meters	Yards
	48	3000	3300

<u>21" Type 95</u> - Working on the principles employed in Type 93, efforts were made in 1935 to design a submarine oxygen torpedo. These experimental models were called Type 95, and the details of the propulsion system closely resembled the Type 93.

<u>21" Type 95 Modification 1</u> - Production commenced in 1938. As in the case of Type 93, this model ran on 100% oxygen and used "first air vessel", buffer chamber, and sea water pump for diluent.

Speed and Range

Knots	Meters	Yards
49	9000	9840
45	12,000	13,000

Oxygen Efficiency ...... 1800 hp sec/kg oxygen
... 4.4 lbs oxygen/BHP hr
Explosive Charge .... 405 kg (891 lbs)

21" Type 95 Model 2 - As in the case of the Type 93 Model 1, the "first air vessel" in Type 95, Modification 1 gave rise to trouble due to leaks, and a pressure drop serious in so small a vessel (7 liters) resulted. This problem was solved by the use of carbon tetrachloride in the case of the Type 93, but the "first air vessel" was removed from Type 95 Model 2, and starting was effected with air from the steering air vessel. It was designed in 1943. Thus main points of difference from Modification 1 are:

1. "First air vessel" removed.
2. Torpedo starts on steering air.
3. Gear mechanism to "shut-off" steering air to engine, after a predetermined number of engine revolutions.
4. Oxygen vessel reduced in length.
5. Warhead increased in length.

Speed and Range

Knots	Meters	Yards
45	7500	8200
49	5500	6000

Oxygen Efficiency ...... 1800 hp sec/kg oxygen
... 4.4 lbs oxygen/BHP hr
Explosive Charge .... 550 kg (1210 lbs)

The method of starting this torpedo on "steering air" is considered by the Japanese to be superior to the use of "first air vessel" or carbon tetrachloride.

21" Type 96 - Developed in 1942 for submarines before the successful completion of Type 95 Model 2. Due to the trouble experienced with the "first air vessel" of Type 95, Modification 1, the latter type fell out of favor with the Naval Staff. Until the trouble was overcome, about 300 torpedoes of Type 96 were made for operational use in the interim period (about a year, 1942-1943).

The Type 96 is very similar in construction to the Type 95, Modification 1 and was, in fact, constructed by modifying actual production models of Type 95, Modification 1. (Thus the identification markings may be confusing, since a Type 96 may have an oxygen vessel from Type 95 with 'Type 95' stamped on the forward end.)

The following important points show the differences between the Type 96 and its 'parent' Type 95, Modification 1.

1. 38% oxygen is used in the oxygen vessel, and as steering air.
2. No "first air vessel" is carried, since the torpedo can be safely started with 38% oxygen direct to generator.
3. The use of 38% oxygen enables the Japanese to use a thin coating of lubricating oil on the valves in the circuit between the oxygen vessel and reducer. When using 100% oxygen, these valves must be completely free from oil, and this often resulted in corrosion and irregular functioning of the valves.

Speed and Range	Knots	Meters	Yards
	48	4500	4900

Gas Efficiency ..... 1000 hp sec/kg gas charge
.... 7.9 lbs gas/BHP hr
Explosive Charge .... 405 kg (891 lbs)

There were no variations of this type.

18" Type 97 - Designed in 1937 and produced in 1938 for use in "midget" submarines. This type was used operationally at the beginning of the war (Pearl Harbor), but its use was later discontinued because of troubles with "first air vessel", as in the case of the Type 93 Model 1 and Type 95 Modification 1. The Japanese "midget" submarines (two-man crew at beginning of war, later five-man crew) are fitted with two 'built- ' tubes. The "first air vessel" of Type 97 is charged at its operat g base, and the torpedoes are muzzle-loaded into the tubes of the "midget" submarines, which are then conveyed to their target on a 'mother' submarine. Thus, the pressure of the "first air vessel" cannot be checked again before firing.

Frequently, the failure of this type of torpedo was attributed to the low pressure of the "first air vessel" resulting in the premature leak of oxygen into the latter. When the torpedo is fired, a gas very rich in oxygen is introduced into the generator, and an explosion occurs at the instant of ignition.

In working principles, this type is the same as Type 93 Model 1, Modification 1 and Type 95 Modification 1, with a two-cylinder, double-acting, reciprocating engine. There were no variations of this type.

Speed and Range	Knots	Meters	Yards
	45	5500	6000

Oxygen Efficiency ...... 1600 hp sec/kg oxygen
..... 5 lbs oxygen/BHP hr
Explosive Charge .... 350 kg (770 lbs)

18" Type 98 (or Type 97, Special) - Developed in 1942 for "midget" submarines. This type uses 38% oxygen. It was designed to meet a Naval Staff requirement for an 18 inch torpedo which would avoid the troubles experienced with Type 97. Thus, Type 98 has the same relationship to the Type 97 as the Type 96 bears to Type 95, Modification 1. The main points of difference of the Type 98 from the Type 97 are:

1. 38% oxygen is used in the oxygen vessel.
2. No "first air vessel" is carried since the torpedo can be started safely with 38% oxygen.
3. No steering air is carried, and 38% oxygen from the main vessel is used instead.
4. As in Type 96, the use of 38% oxygen enables the Japanese to use a thin coating of lubricating oil on the valves between oxygen vessel and reducer. When using 100% oxygen these valves must be completely free from oil and this often results in corrosion and irregular functioning of the valves.

Type 97 oxygen vessels frequently were used in the construction of Type 98; these vessels have 'Type 97' stamped on the forward end. Thus, a

Type 98 may be confused with a Type 97 if one relies on identification markings alone. For example, the Royal Naval Torpedo Factory, Greenock, Scotland published a report "S.T.R. No. 329" in December 1943 entitled "Japanese 18", Model 97, Torpedo No. 84"; the title of the report was taken from the actual markings on the forward end of the air vessel of the torpedo. By examination of the gas feed circuit and the composition of the gas in the oxygen vessel, it will be seen that the torpedo No. 84 was, in fact, a Type 98. There is no "first air vessel" in the model, and, on analysis, the composition of the gas in the oxygen vessel was shown to be 40% oxygen. There were no variations of this type.

18" Type 02 - Designed in 1942 for use on torpedo boats and "midget" submarines. Produced in 1944. Has an eight-cylinder radial engine (Whitehead, English type). Uses air. This is not actually a new type torpedo, but is a modified design of the aircraft torpedo, Type 91, Modification 3. Different air vessel and rear buoyancy chamber are used.

Speed and Range	Knots	Meters	Yards
	39	3000	3300

Air Efficiency .... 500 hp sec/kg air
.... 15.8 lbs air/BHP hr
Explosive Charge .... 350 kg (770 lbs)

18" Type 02 (Special) - Designed in 1944 to supplement the supply of Type 02. Very closely resembles the Type 91, having the same air vessel, fuel bottles etc. Thus has greater length and shorter range than the Type 02.

Speed and Range	Knots	Meters	Yards
	39	2000	2190

Explosive Charge .... 350 kg (770 lbs)
Air Consumption .... 16 lbs/BHP hr

11" Type 05 - Designed in 1945 for use on small torpedo boats. Two were produced. Uses air and five-cylinder, swash plate engine. It was hoped that this type could be more rapidly produced than the Type 02, but owing to its late development it never went into production.

Speed and Range	Knots	Meters	Yards
	20	1500	1650

Air Efficiency .... 300 hp sec/kg air
.... 26.4 lbs air/BHP hr
Explosive Charge .... 60 kg (132 lbs)

SUMMARY OF STANDARD JAPANESE SERVICE TORPEDOES IN CHRONOLOGICAL ORDER

Submarine (21") Torpedoes

Type 6 (called by Japanese "6th Year"): Service - 1918-1933. Air, kerosene, fresh water; used to small extent on old type submarines in recent war.

Type 89: Service - 1931-1942. Air, kerosene, fresh water.

Type 92, Model 1: Service - 1940-1945. Electric.

Type 95, Modification 1: Service - 1939-1944. 100% oxygen, kerosene, sea water.

Type 96: Service - 1942-1944. 38% oxygen, kerosene, sea water.

Type 95, Model 2: Service - 1944-1945. 100% oxygen, kerosene, sea water.

Ship (24") Torpedoes

Type 8 (called by Japanese "8th Year"): Service - 1921-1932. Air, kerosene, water. (Used in small number on second-class destroyers during the recent war.)

Type 90: Service - 1931-1942. Air, kerosene, water.

Type 93, Model 1, Modifications 1 & 2: Service - 1938-1945. 100% oxygen, kerosene, sea water.

Type 93, Model 3: Service 1944-1945. 100% oxygen, kerosene, sea water.

Type 93, Model 1, Modification 3: Produced in 1945. 100% oxygen, kerosene, sea water. (This type did not reach the naval service before end of war.)

Small Submarine (18") Torpedoes

Type 97: Service - 1939-1942. 100% oxygen, kerosene, sea water.

Type 98: Service - 1942-1944. 38% oxygen, kerosene, sea water.

Type 02: Service - 1944-1945. Air, kerosene, fresh water.

In addition Type 02, Special (18") was designed for torpedo boats, and Type 05 (11") for small torpedo boats. Only the first of these was used in service, 1944-1945.

GENERAL DESCRIPTION AND DATA

Modern surface ship torpedoes of the Japanese Navy can be divided into three main classes.

Class	Torpedo Type
Oxygen	93
	94
	95
	96
	97
	98
Air	02
	05
Electric	92

The Type 94, an experimental oxygen aircraft torpedo, was included in the investigation in order that all the information on oxygen torpedoes might be obtained.

OXYGEN TORPEDOES

The design of all oxygen torpedoes conforms to the same general plan, and since there are sections of this report dealing with heads, oxygen and fuel vessels, circuits, power units, depth gears and gyroscopes, only the general construction needs to be considered here.

Particulars of each type, model and modification are given in the following tables:

24" Type 93, Model 1, Modifications 1 and 2

Oxygen and Fuel Vessels

The Modification 1 and early numbers of Modification 2 had two detachable ends of standard Japanese design with the pressure assisting to make the joint. The fuel separator was fitted in Model 1 because this was originally fired from cruisers.

Midship Section

This is of welded steel plate 4.5mm (0.175") thick and lies between the fuel vessel and the afterbody. It consists of three sections.

Forward section. This acts as lubricating oil container and has in addition two high pressure air bottles for supplying steering air.

Center section. This is the forward buoyancy chamber and contains:

- One steering air bottle
- One "first air vessel"
- Circuit valves
- Depth gear

After section. This is the engine room and is open to the sea. It houses:

- Main reducer
- Disc reducer
- Servomotor and rudder locking gear

Buffer chamber
Generator
Main engine cylinders
Group

Afterbody

This is of steel 3mm (0.125") thick welded at the seam. It forms the rear buoyancy chamber and contains:

Relief valve
Two disc reducers
Gyroscope
Steering engine
Water flap

Tail

This is a conical steel forging housing the bearings for the shafts to which sea water has access. Woolwich type fins and rudders are used. The horizontal rudders are of equal size and are larger than the vertical rudders which also are of equal size. The propellers are keyed to bushes which in their turn are splined (three in number) to the propeller shafts. The tail is attached to the afterbody with a bayonet type joint.

General Data

Data on the Type 93, Model 1, Modifications 1 and 2, torpedoes are given in a following section on the 24" Type 93, Model 3 torpedo.

24" Type 93, Model 2

Research on the Type 93 was started in 1933 and production began in 1937. Between 1937 and 1942 attempts were made to increase the speed of the Type 93. Tests were begun which resulted in the experimental Type 93, Model 2 torpedo.

There were two designs, both modification of Type 93, Model 1, with the object of increasing engine output.

Larger bore of engine and higher RPM. No definite information about this torpedo was available but it was understood that it was not a success.

Higher inlet pressure. The engine cylinder barrels and heads were strengthened to withstand the increased pressure, and the diameters of the piston rods were increased. With this design three runs were carried out and a speed of 56 knots was obtained.

The performance compared with that of the standard torpedo was:

	Model 1	Model 2
Speed (knots)	50	56
Generator pressure (kg/cm^2)	39	45
RPM	1170	1300
Horsepower	570	850

In 1942 it was desired to develop a torpedo with a greater weight of explosive than that of Type 93, Model 1. Experiments on Model 2 were dropped and Type 93, Model 3 with 780 kg (1716 lbs) was produced. In other respects the torpedo was the same as the Model 1.

24" Type 93, Model 3

The carbon tetrachloride circuit is used in this model. The oxygen and fuel vessels and forward parts of the midship section are the same as in Model 1, Modifications 1 and 2.

Center Section

This contains the same units as Modifications 1 and 2 except that the "first air vessel" is replaced by the carbon tetrachloride unit.

Engine Room, Afterbody and Tail

The same as in Model 1, Modifications 1 and 2 except for alterations to details required by the change in the circuit.

24" Type 93		Model 1, Modifications 1 and 2	Model 3
Data			
Service		Production	Production
Used aboard		Cruiser Destroyer	Destroyer
Dates			
First design		1933	1943
Production		1936	1944
Manufacture			
Location		KURE and SASEBO	KURE and SASEBO
Number made		1150	560*
General Particulars			
Total weight	kg lb	2700 5940	2800 6160
Displacement	kg lb	2220 4884	2220 4884
Negative buoyancy	kg lb	480 1055	580 1275
Center of gravity from after end	mm in	4966 195.5	5150 202.7
Center of byoyancy from after end	mm in	5000 197.0	5000 197.0

*200 torpedoes were used for ships, the remainder were used for KAITEN Type 1.

24" Type 93		Model 1, Modifications 1 and 2			Model 3		
Trim	mm	34			-150		
Down nose -ve Up nose +ve							
Length							
Head	mm in	1400 55.2			2275 89.6		
Oxygen vessel	mm in	3448 136			2595 102.2		
Fuel vessel	mm in	496 19.5			383 15.09		
Balance chamber and engine room	mm in	1580 62.25			1671 65.8		
Buoyancy chamber	mm in	1456 57.3			1456 57.3		
Tail	mm in	620 24.43			620 24.43		
Total	mm in	9000 354.5			9000 354.5		
Passing Conditions							
Speed	knots	36 $^{+2}_{-0}$	40 $^{+2}_{-0}$	48 $^{+2}_{-0}$	36 $^{+2}_{-0}$	40 $^{+2}_{-0}$	48 $^{+2}_{-0}$
Range (not less than)	meters yards	40,000 43,800	32,000 35,000	20,000 21,900	30,000 32,800	25,000 27,300	15,000 16,400
Depth	meters feet	6 ±0.5 20 ±1.5			6 ±0.5 20 ±1.5		
Direction wander at extreme range R or L	meters yards	1500 1640	1000 1100	500 550	1000 1100	700 770	350 385
Head							
Type of pistol		Before war, Type 90 During war, Type 02			Before war, Type 90 During war, Type 02		
Total weight	kg lb	610 1340			940 2070		
Weight of explosive	kg lb	490 1080			780 1715		
Type of explosive		Type 97			Type 97		
Vessels							
Oxygen							
Volume	liters ft3	980 34.3			750 26.3		

24" Type 93		Model 1, Modifications 1 and 2	Model 3
Pressure	kg/cm2 lbs/in2	225 3200	200 2850
15°C Weight of charge 60°F	kg lb	299 657.8	204 448.8
Composition of gas		100% oxygen	100% oxygen
Thickness of wall	mm in	12 0.472	12 0.472
Air			
Volume of "first air vessel"	liters ft3	13.5 0.473	
Pressure of "first air vessel"	kg/cm2 lbs/in2	22.5 3200	
Volume of steering air vessel (3 bottles)	liters ft3	40.5 1.417	40.5 1.417
Pressure of steering air vessel	kg/cm2 lbs/in2	225 3200	200 2850
Fuel			
Composition		kerosene	kerosene
Volume	liters ft3	128 4.48	95 3.32
Displaced by		sea water	sea water
Lub. oil			
Volume	liters ft3	67 2.34	67 2.34
Power Unit			
Reducer type		2 stage	2 stage
Generator type		wet heater	wet heater
Gas outlet temperature (estimated)		660°C	660°C
Number of igniters		2	2
Composition of filling		nitroglycerine 58% mineral jelly 5% gun cotton 37%	
Engine		reciprocating	reciprocating
Type		horizontal	horizontal
Number of cylinders		2 cylinders, double-acting	

24" Type 93		Model 1, Modifications 1 and 2			Model 3		
Bore	mm	142			142		
	in	5.59			5.59		
Stroke	mm	180			180		
	in	7.09			7.09		
Expansion ratio		1.5			1.5		
Output							
Reducer pressure	kg/cm^2	20	24	38	20	24	38
	lbs/in^2	285	341	540	285	341	540
Horsepower		200	300	520	200	300	520
RPM		860	950	1200	860	950	1200
Oxygen consumption	lbs/BHP/hr	4.3			4.3		
Oxygen/fuel ratio		2.8			2.8		
Water/fuel (by vol)		8.5			8.5		
Type of diluent		sea water			sea water		
Afterbody and Propellers							
Number of fins		4			4		
Number of blades		4			4		
Forward blade dia.	mm	568			568		
	in	22.38			22.38		
After blade dia.	mm	530			530		
	in	20.88			20.88		
Wake		Scarcely visible					
Control							
Depth gear type		Pendulum type					
Depth setting	meters	2 - 16					
	feet	6.56 - 52.5					
Gyro type		Type 98					
Gyro angling		±180°					

Note: Model 1, Modification 3 is a combination of Model 1, Modification 1 with the propulsion system of Model 3.

18" Type 94

This torpedo was intended for use from aircraft. It is discussed in this report because it uses oxygen. Originally there were two models of the type; Model 1 was 21" in diameter and Model 2 was 18", otherwise they were the same. Only Model 2 was available. (See Figures 3 to 7.) The details of Model 1 were not obtained.

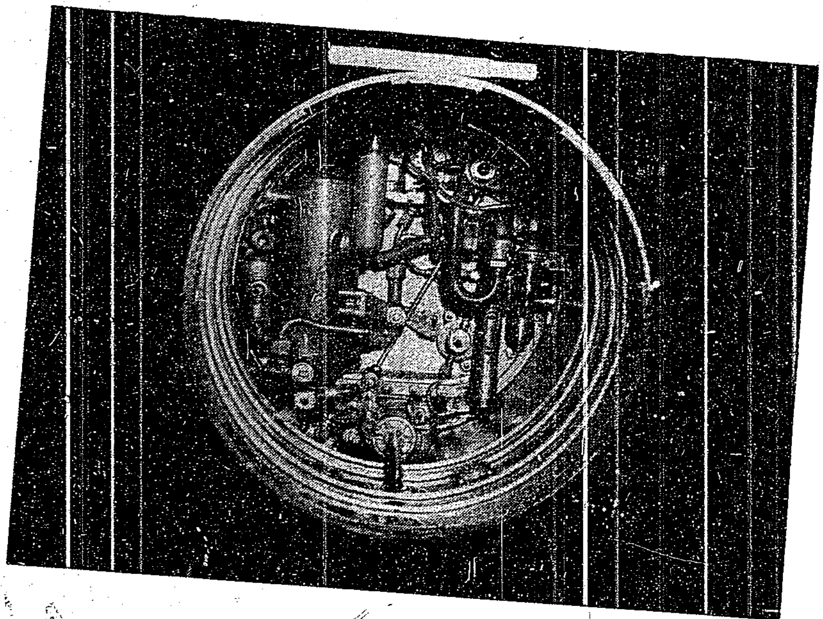


FIGURE 3
AFTER END OF BALANCE CHAMBER, 18" TYPE 94

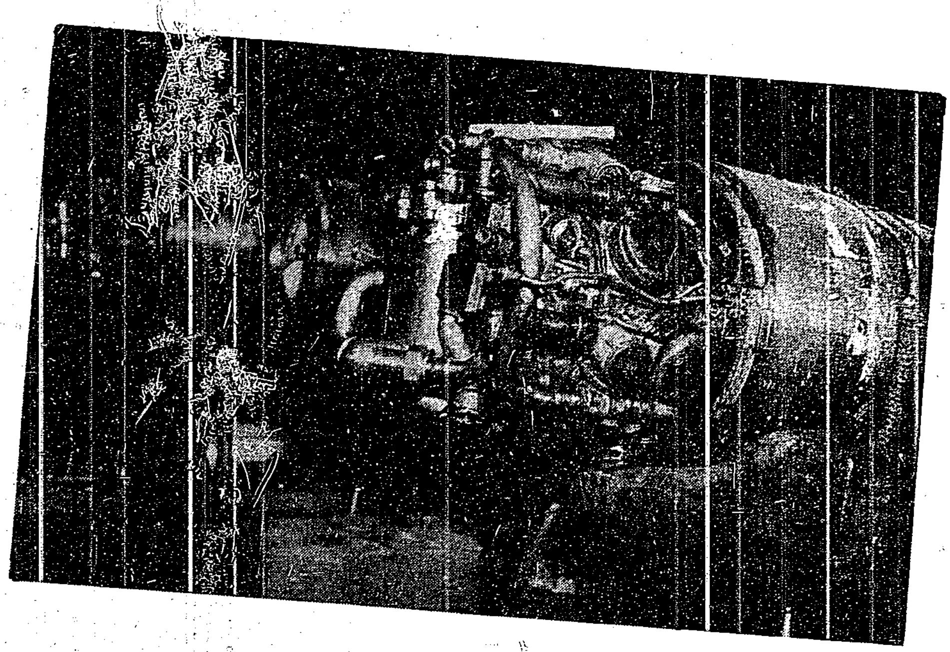


FIGURE 4
ENGINE AND GENERATOR, 18" TYPE 94

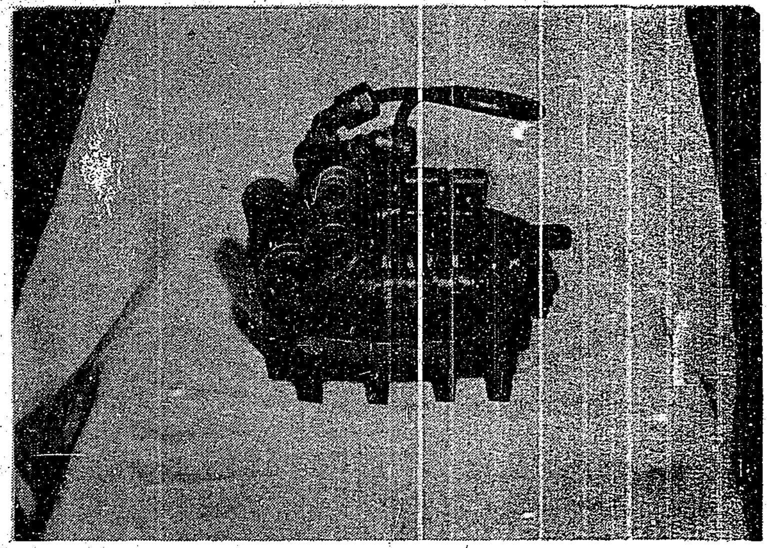


FIGURE 5
GENERATOR HEAD, 18" TYPE 94

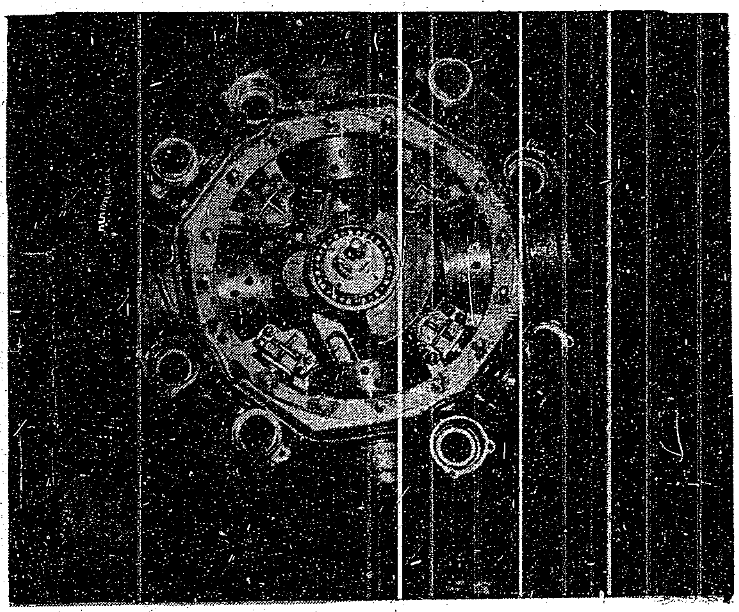


FIGURE 6
ENGINE, 18" TYPE 94

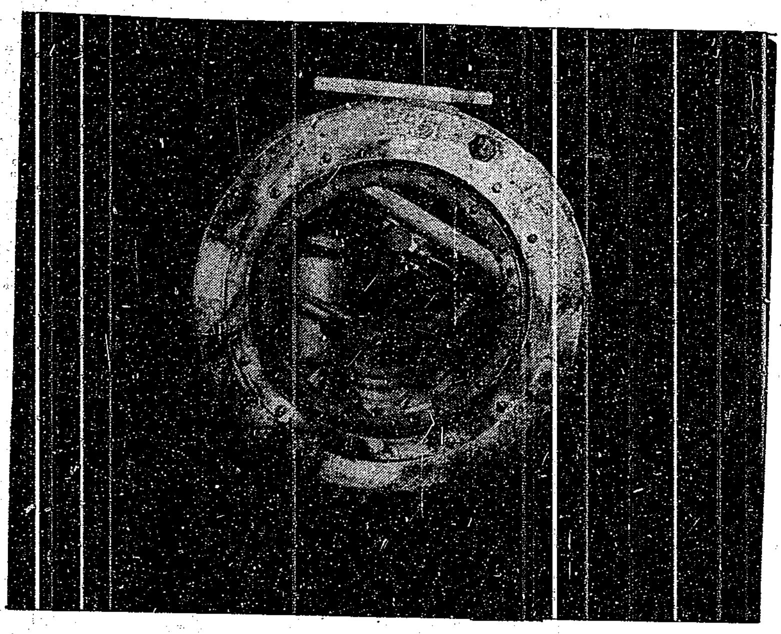


FIGURE 7
AFTER BODY, 18" TYPE 94

Model 2, designed by the Nagasaki Dockyard, uses the principles of Type 93, Model 1 and Type 95, Modification 1 torpedoes. It employs the "first air vessel" circuit and differs from them only in details, depending upon the preferences of the designers and aircraft requirements.

It is understood that the performance of the torpedo, from the technical aspect, was satisfactory but that it was not used in service because of the work involved in its preparation and upkeep.

Head

The standard heads, both exercise and war, were fitted to the 18" torpedoes, the standard bayonet type joint being used.

Oxygen Vessel

The latest design of forging having one intergral end but without strengthening band was used. The oxygen lead was screwed through the center of the boss in a way similar to that of the 24" Type 93.

To the forward (open) end was screwed and sweated, in the same way as the fuel vessel of the Type 93, a domed end having a cover of about 9" diameter bolted to it externally by 16 3/4" diameter bolts.

The joint is a spigotted one with a white metal washer. Unlike the Type 93 and 95 torpedoes the gas pressure tends to separate the joint faces. It was understood that troubles due to oxygen leaks had occurred.

Forward of the vessel and above the dome are the oxygen charging stop valve and charging connections.

The thickness of the extension shell above the domed end is 7mm (0.276"); one top guide is fitted.

Balance Chamber

The balance chamber is attached to the vessel by sweated rivets and is divided into two sections. It has ribs machined circumferentially of 3mm (0.118") thickness spaced from 6 to 8 cm apart (2.36" - 3.15") to give additional stiffness for dropping from the aircraft.

The balance chamber contains:

First air bottle	Two fuel bottles
Steering air bottle	Depth gear

Engine Room

Attached to the shell, which forms the outer casing of the engine room, are:

Group	Buffer chamber
Reducer	Servomotor

Between the two compartments is an inspection door.

Oxygen Circuit

Oxygen leaving the vessel passes first through the oxygen delivery stop valve, then through the non-return valve and into the "first air vessel". From the "first air vessel" the gas is led through the air stop valve, group, reducer, and to the generator.

Steering Air Circuit

From the steering air bottle the air passes through the charging stop valve and hence to the gyroscope and servomotor.

Water and Fuel Circuits

Brine from the reciprocating pump is supplied to the buffer chamber. It is used for diluent in the generator, to displace the fuel.

The proportions delivered to each were not forthcoming.

The two fuel bottles are connected in series. The fuel from them flows through a non-return valve to the generator.

Depth Gear

This is of the standard pendulum type with no special features.

Reducer

The small, single stage reducer has a water bottle and an oil bottle attached.

Group

In the group casting the controls for both the oxygen and steering air circuits are combined. The main group valve is in the oxygen circuit as usual but in this instance it is opened by the water flap mounted on the top of the shell. The steering air circuit valve is operated by a rack and pinion, the rack being pulled up by an attachment to the plane when the torpedo is released.

Buffer Chamber

This is of the standard design except that the oil for lubricating the regulating valve is contained in a small bottle which forms part of the main casting. The oil is displaced by water from the pump.

Generator

The generator head is of standard phosphor bronze material and is a casting. In it are housed two igniters of standard diameter, mechanically fired. There are also inlets for oxygen, fuel and water. Since the torpedo has only a single speed, there is no necessity for variable rating plugs; chokes are merely fitted into the pipe connections. A fuel sprayer of the same design as that of the larger diameter oxygen torpedoes, but smaller in size, is screwed into the top. In the same way the design of the combustion plate etc. are copies, on a smaller scale, of those of the Type 93.

The outer chamber is of 18/8 stainless steel, bolted to the head, and has two outlets welded to its bottom.

Engine

The engine is an eight-cylinder, two-row radial unit, the same as is used in the Type 91 and Type 02 except:

1. Inlet branches of rear bank cylinder heads are a bronze casting and are carried up flush with the forward bank.
2. In place of the shutter-type water pump the sea water cooling pump is a gear type, mounted on the starboard side and driven from an extension of the crankshaft. Cooling water goes to both cover plates of the crank case.
3. Diluent sea water pump. This is an addition. It is a double-acting, reciprocating pump, gear driven from the engine shaft. On its side is mounted an auxiliary water tank to give additional capacity in the circuit.

The engine has poppet valves. A workman who had been engaged on the development work stated that no trouble was experienced with the deposition of salt. This is interesting in view of other statements that the poppet valve could not be used with sea water. The explanation would appear to lie in the fact that the run was so short, 3000 meters, there was not time for the valves to stick. British experience with brine has indicated that poppet valves would operate satisfactorily for a few runs of three minutes duration. The lubricating oil circuit is governed by a small oil distributor. There are no special features in its design.

Rear Buoyancy Chamber

This contains the center tube and the gyroscope, Type 91, and steering engine. It is of welded plate.

Tail and Propellers

The tail is a conical forging with integral guide slots into which the fins fit. It is bolted onto the afterbody in the standard British manner. It contains the lubricating oil ~~bottle~~ and the mitre reversing gear. The fins and rudders are of the R.G.F. type, i.e. in front of the propellers. The propellers are the same as those of Type 91 and Type 02, although the speed is 48 knots compared with 40 and 38 respectively. They have four blades which are keyed to bushes splined to the shaft.

Since this is an aircraft torpedo no tabular statement of the data was obtained, the point of interest being only the use of oxygen.

21" Type 95, Modification 1

Oxygen and Fuel Vessels

These are the same as those of the Type 93, Modifications 1 and 2.

Balance Chamber

This contains:

- One "first air vessel"
- One steering air vessel
- Depth gear
- Circuit valves

Engine Room

In this are housed:

- Buffer chamber
- Servomotor
- Group
- Reducer
- Generator
- Engine cylinders

Afterbody and Tail

This contains:

- Engine crankcase
- Reversing gear
- Gyroscope
- Lubricating oil bottle

General Data

Data on this torpedo are given in the following section.

21" Type 95, Model 2

Oxygen and Fuel Vessels

These are the same as Type 95, Modification 1 except that there is no fuel separator, the volume being smaller.

Balance Chamber

This is the same as Modification 1 except that there is no "first air vessel". The steering air vessel is the same size.

Engine Room, Afterbody and Tail

These are the same as Modification 1 except for the design of the group.

21" Type 95	Modification 1	Model 2
Data		
Service	Production	Production
Used aboard	Submarines	Submarines

Dates			
First design		1935	1943
Production		1938	1944
Manufacture			
Location		KURE and NAGASAKI	KURE and NAGASAKI
Number made		1450	500
General Particulars			
Total weight	kg lb	1665 3660	1730 3800
Displacement	kg lb	1345 2960	1345 2960
Negative buoyancy	kg lb	320 704	385 847
Center of gravity from after end	cm in	4003 157.5	4060 160.0
Center of buoyancy from after end	cm in	3990 156.7	3990 156.7
Trim - down nose	mm in	-13 -0.512	-70 -2.75
Lengths			
Head	mm in	1530 60.3	1750 68.9
Oxygen vessel	mm in	1729 68.1	1029 40.5
Fuel vessel	mm in	271 10.67	271 10.67
Balance chamber and engine roor	mm in	1540 60.65	2020 79.5
Buoyancy chamber	mm in	1430 56.3	1430 56.3
Tail	mm in	650 25.6	650 25.6
Total	cm in	7150 281.5	7150 281.5
Passing Conditions			
Speed	knots	$45\ ^{+2}_{-0}$ $49\ ^{+2}_{-0}$	45 ± 2 $49\ ^{+2}_{-0}$
Range (not less than)	Meters yards	12000 9000 13300 9850	7500 5500 8200 6017
Depth	Meters feet	5 ±0.5 16.4 ±1.6	5 ±0.5 16 ±1.6

Direction wander at extreme range L or R	Meters yards	250 170 275 187	130 90 143 99
Head			
Type of pistol		Before war, Type 90 During war, Type 02	Before war, Type 90 During war, Type 02
Total weight	kg lb	495 1090	635 1395
Weight of explosive	kg lb	405 890	550 1210
Type of explosive		Type 97	Type 97
Vessels			
Oxygen			
Volume	liters ft^3	386 13.5	220 7.7
Pressure	kg/cm^2 lbs/in^2	215 3060	200 2840
Weight of charge	kg lb	113 248.6	60 132
Composition of gas		100% oxygen	
Thickness of wall	mm in	10 0.394	10 0.394
Air			
Volume of first air vessel	liters ft^3	7 0.245	7 0.245
Pressure of first air vessel	kg/cm^2 lbs/in^2	225 3200	- -
Volume of steering air	liters ft^3	15 0.525	15 0.525
Pressure of steering air	kg/cm^2 lbs/in^2	215 3060	215 3060
Fuel			
Composition		kerosene	
Volume	liters ft^3	50 1.75	50 1.75
Displaced by		sea water	
Lube oil			
Volume	liters ft^3	22.8 0.798	22.8 0.798

Power Unit

Reducer type		2-stage	2-stage
Generator type		wet heater	wet heater
Gas outlet temperature (estimated)		660°C	660°C
Number of igniters		2	2
Composition of filling		nitroglycerine 58% mineral jelly 5% gun cotton 37%	
Engine		reciprocating	
Type		horizontal	
Number of cylinders		2 cylinders, double acting	
Bore	mm in	130 5.62	130 5.62
Stroke	mm in	160 6.3	160 6.3
Expansion ratio		1.5	1.5

Output

Reducer pressure	kg/cm^2 lbs/in^2	22 37 312 525	22 37 312 525
Horsepower		330 430	330 430
RPM		1150 1250	1150 1250
Oxygen consumption lbs/BHP/hr		4.3	4.3
Oxygen/fuel ratio		2.8	2.8
Water/fuel (by vol)		8.5	8.5
Type of diluent		sea water	

Afterbody and Propellers

Number of fins		4 or 6	4 or 6
Number of blades		4	4
Forward blade dia	mm in	482 18.8	482 18.8
After blade dia	mm in	439 17.3	439 17.3
Wake		Scarcely visible	

Control

Depth gear type		standard pendulum	
Depth setting	meters	2 - 16	2 - 16
	feet	6.5 - 52.4	6.5 - 52.4
Gyro type		Type 98	Type 98
Gyro angling		±180°	±180°

21" Type 96

A detailed description of the construction of the Type 96 is unnecessary, since this torpedo is very similar to the Type 95, Modification 1 and is in fact a modification of the latter. The Type 96 does not have a "first air vessel"; it uses 38% oxygen.

21" Type 96

Data		
Service		Production
Used aboard		Submarines
Dates		
First design		1942
Production		1942
Manufacture		
Location		KURE
Number made		300
General Particulars		
Total weight	kg	1665
	lb	3660
Displacement	kg	1345
	lb	2960
Negative buoyancy	kg	320
	lb	704
Center of gravity (from after end)	mm	4000
	in	157.5
Center of buoyancy (from after end)	mm	3990
	in	156.7
Trim (down nose)	mm	-10
	in	-0.394
Lengths		
Head	mm	1530
	in	60.0

Oxygen vessels	mm in	1729 68.1
Fuel vessel	mm in	271 10.7
Balance chamber and engine room	mm in	1540 60.7
Buoyancy chamber	mm in	1430 56.3
Tail	mm in	650 25.6
Total	mm in	7150 281.5

Passing Conditions

Speed	knots	48 $^{+2}_{-0}$
Range	meters yards	4500 4923
Depth	meters feet	3 ±0.5 9.8 ±1.6
Direction wander at extreme range L or R	meters yards	70 76.7

Head

Type of pistol		Type 90
Total weight	kg lb	495 1090
Weight of explosive	kg lb	405 890
Type of explosive		97

Vessels

Oxygen

Volume	liters ft^3	386 13.5
Pressure	kg/cm^2 lbs/in^2	215 3060
Weight of charge	kg lb	106 233.2
Composition of gas		38% oxygen
Thickness of wall	mm in	10 0.394

Air		
Volume of steering air vessel	liters ft^3	15 0.525
Pressure of steering air vessel	kg/cm^2 lbs/in^2	215 3060
Fuel		
Composition		kerosene
Volume	liters ft^3	50 1.75
Displaced by		sea water
Lube oil		
Volume	liters ft^3	22.8 0.80
Power Unit		
Reducer type		standard two-stage
Generator type		standard wet heater
Gas outlet temperature (estimated)		660°C
Number of igniters		2
Composition of filling		nitroglycerine 58% mineral jelly 5% gun cotton 37%
Engine		reciprocating
Type		horizontal
Number of cylinders		2 cylinders, double-acting
Bore	mm in	130 5.63
Stroke	mm in	160 6.3
Expansion ratio		1.5
Output		
Reducer pressure	kg/cm^2 lbs/in^2	36 483
Horsepower		400
RPM		1220
Oxygen consumption	lbs/BHP/hr	8.0

Oxygen/fuel ratio	wt	9.0
Water/fuel ratio	vol	5.0
Type of diluent		sea water

Afterbody and Propellers

Number of fins	4
Number of blades	4
Wake	visible

Control

Depth gear type		standard pendulum
Depth setting	meters	2 - 16
	feet	o.5 - 52.5
Gyro type		98
Gyro angling		±180°

18" Types 97 and 98

Type 97 was designed at the end of 1937; development work was carried on in 1938, and production was started at the beginning of 1939. Behaviour and performance were good. On land, with the normal facilities, it could be handled satisfactorily, but at sea, in small submarines, difficulty was experienced in preparation and maintenance.

When about 100 torpedoes had been produced the percentage of oxygen was decreased from 100 to 38, no "first air vessel" being used. The torpedo was reclassified as Type 98.

Since relatively few small submarines were produced, the number of torpedoes required was not great.

Type 97 torpedoes were used in action only once, for the attack at Pearl Harbor. Subsequently, only Type 98 torpedoes were used. (See Figure 8.) These were of standard "first air vessel" design with no special features. The difference between the two types was simply that no "first air vessel" or steering air vessel was fitted in the Type 98 (Type 97 Special).

A full description of Type 98 (Type 97 Special) is given in Scientific and Technical Report No. 329 dated December 1943 of the Royal Naval Torpedo Factory, Greenock.

18" Types 97 and 98

	Type 97	Type 98 (97 Special)
Data		
Service	Production	Production
Use aboard	Small submarines	Small submarines
Dates		
First design	1937	1938
Production	1938	1939

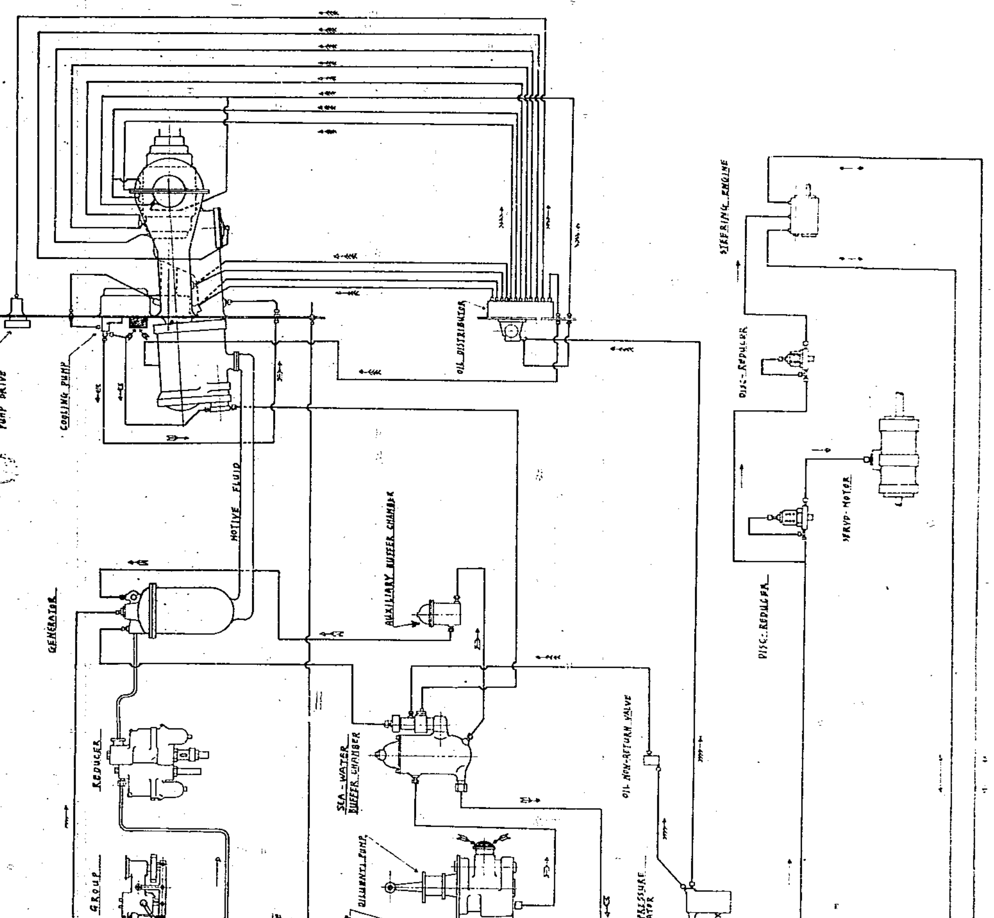


FIGURE 8
CIRCUIT DIAGRAM, 18" TYPE 98

Manufacture			
Location		KURE	KURE
Number made		100	130
General Particulars			
Total weight	kg	980	950
	lb	2156	2000
Displacement	kg	729	729
	lb	1604	1604
Negative buoyancy	kg	251	221
	lb	552	486
Center of gravity (from after end)	mm	3112	3116
	in	122.6	124.7
Center of buoyancy (from after end)	mm	3145	3145
	in	123.9	123.9
Trim negative (down nose)	mm	-33	-21
	in	-0.18	-0.083
Length			
Head	mm	1800	1800
	in	70.9	70.9
Oxygen and fuel vessels	mm	1590	1590
	in	62.6	62.6
Balance chamber	mm	423	423
	in	16.7	16.7
Engine room	mm	427	427
	in	16.8	16.8
Buoyancy chamber	mm	780	780
	in	30.8	30.8
Tail	mm	580	580
	in	22.9	22.9
Total	mm	5600	5600
	in	220.6	220.6
Passing Conditions			
Speed	knots	45 ±1	41 ±1
Range	meters	5500	3200
	yards	6017	3500
Depth	meters	5 ± 0.5	3.0 ±0.5
	feet	16.4 ±1.6	9.8 ±1.6
Direction wander at extreme range L or R	meters	80 ±15	40 ±10
	yards	87.5 ±16.4	43.8 ±11

Head			
Type of pistol		Type 90	Type 90
Total weight	kg lb	410 902	410 902
Weight of explosive	kg lb	350 770	350 770
Type of explosive		97	97
Vessels			
Oxygen			
Volume	liters ft^3	156 5.46	156 5.46
Pressure	kg/cm^2 lbs/in^2	200 2840	175 2485
Weight of charge	kg lb	41 90.2	37.8 83.2
Composition of gas		100% oxygen	38% oxygen
Thickness of wall	mm in	7.0 0.275	7.0 0.275
Air			
Volume of "first air vessel"	liters ft^3	4.0 0.14	
Pressure of "first air vessel"	kg/cm^2 lbs/in^2	220 3140	
Volume of steering air vessel	liters ft^3	7.0 0.245	
Pressure of steering air vessel	kg/cm^2 lbs/in^2	230 3266	
Fuel			
Composition		kerosene	kerosene
Volume	liters ft^3	20 0.7	20 0.7
Displaced by		sea water	sea water
Lube Oil			
Volume	liters	5.0	5.0
Power Unit			
Reducer type		2-stage	2-stage
Generator type		wet heater	wet heater

Gas outlet temperature	°C	500-600	500-600
Number of igniters		2	2
Composition of filling		nitroglycerine 58% mineral jelly 5% gun cotton 37%	
Engine		reciprocating	
Type		horizontal	
Number of cylinders		two cylinders, double-acting	
Output			
Reducer pressure	kg/cm^2 lbs/in^2	36 511	30 426
Horsepower		205	152
RPM		1200	1100
Oxygen/fuel ratio		3.0	7.5
Water/fuel ratio	vol	8.0	3.5
Type of diluent		sea water	sea water
Afterbody and Propellers			
Number of fins		4	4
Number of blades		4	4
Wake		scarcely visible	visible
Control			
Depth gear type		pendulum	pendulum
Depth setting	meters feet	5 16.4	3 9.8
Gyro type		fourth year	fourth year
Gyro angling		±180°	±180°

AIR TORPEDOES

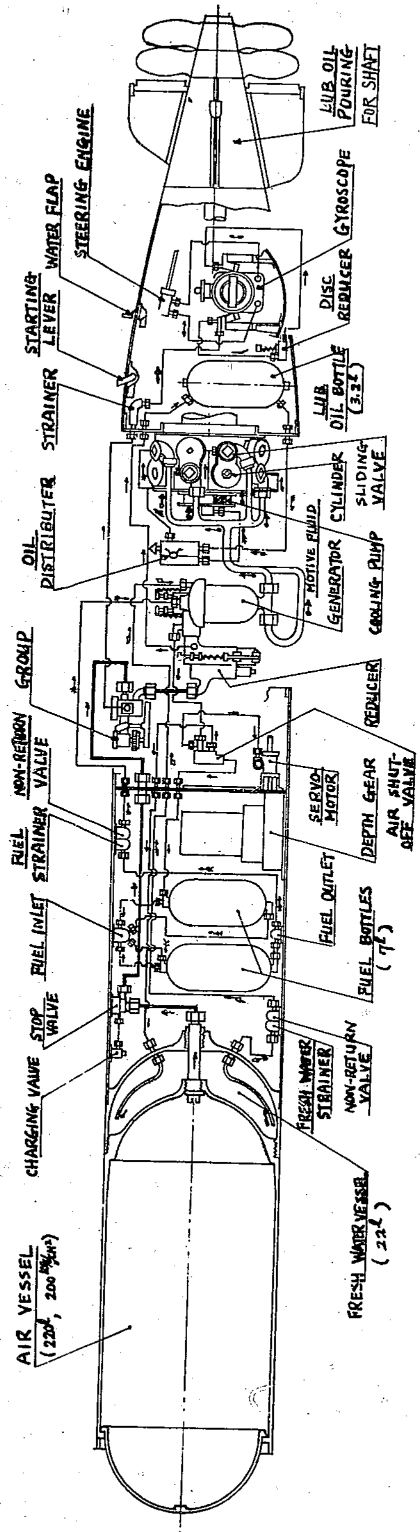
18" Type 02 and 02 Special

General

As this torpedo is very similar to the Type 91 aircraft torpedo, being an adaptation of it for use with small submarines and MTB's, it is proposed to deal only with the differences between the two torpedoes, except for the engine. (See Figure 9.)

The motive fluids are air, fresh water and kerosene.

The differences are as undernoted:



KEY	
→	AIR
(fresh water arrow)	FRESH WATER
(fuel arrow)	FUEL
(lub oil arrow)	LUB OIL

FIGURE 9
CIRCUIT DIAGRAM, 18" TYPE 02 (SMALL SUBMARINE)

Torpedo type		Type 91	Type 02
Performance			
Speed	knots	42 ±1	39 ±1
Range	meters	2000	3000
	yards	2183	3283
Air vessel			
Volume	liters	184	223
	ft^3	6.4	7.8
Pressure	kg/cm^2	180	200
	lbs/in^2	2556	2840
Balance chamber			
Number of water bottles		2 (kidney shaped)	1 (Extension of air vessel)
Capacity	liters	14.1	22.5
	ft^3	0.49	0.788
Fuel bottles			
Capacity	liters	4	7.7
	ft^3	0.14	0.27
Circuits		Similar except where modified to suit the number of bottles	
Starting mechanism		Special	Group lever and water flap
Top stop		no	yes
Stabilizer (air)		yes	no
Shape of afterbody		This is shorter in the Type 02 to accommodate longer air vessel and balance chamber for the same total length.	
Propellers		Strong to stand dropping from the air.	Standard 18" ship torpedo design.

Full details of the Type 91 torpedo are given in NavTechJap Report "Japanese Torpedoes and Tubes, Article 2 - Aircraft Types" Index No. 0-01-2.

Engine

(See Figures 10, 11, 12(a) and (b).)

Type and Leading Particulars

Eight cylinder		two-bank, radial
Bore	mm	90
	in	3.54
Stroke	mm	85
	in	3.35

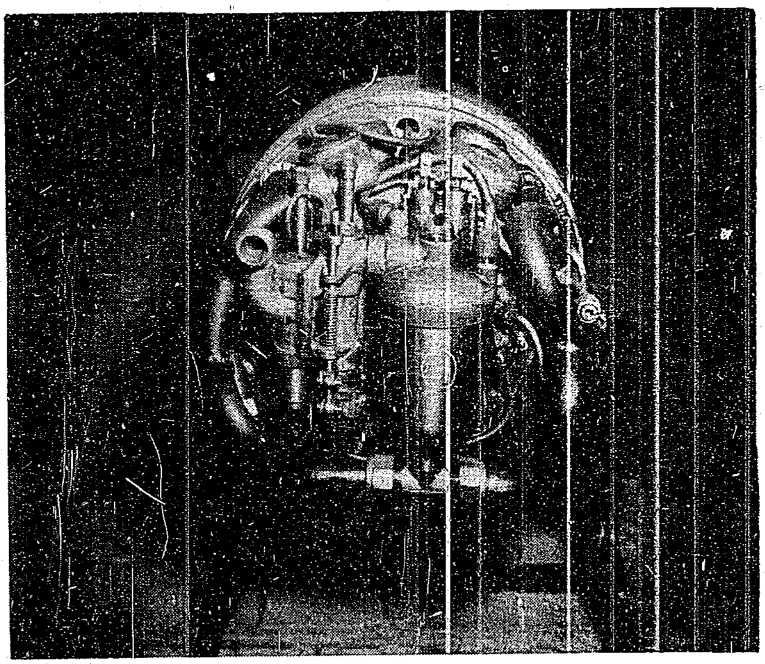


FIGURE 10
ENGINE AND GENERATOR, TYPE C2

FIGURE 11
AFTER BODY, TYPE C2

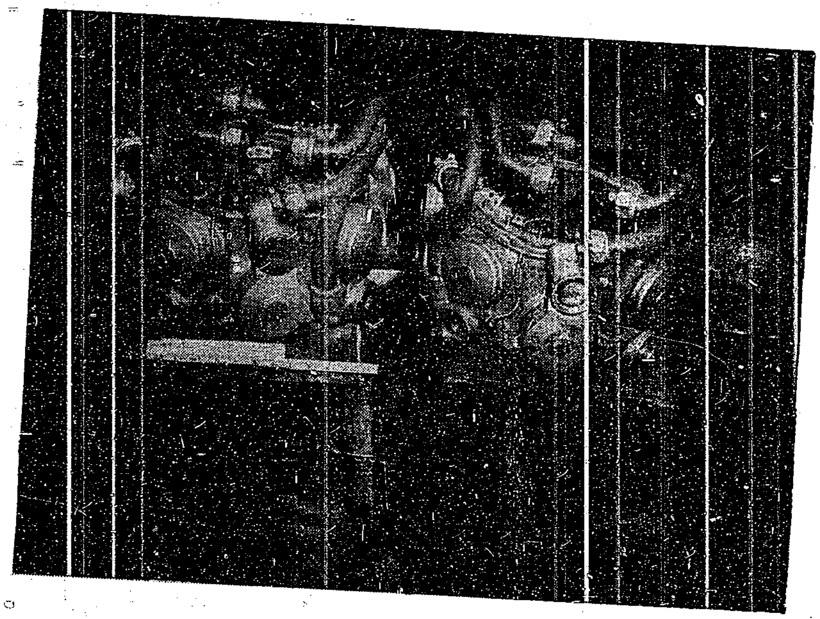


FIGURE 12(a)
ENGINE CASING, TYPE 02

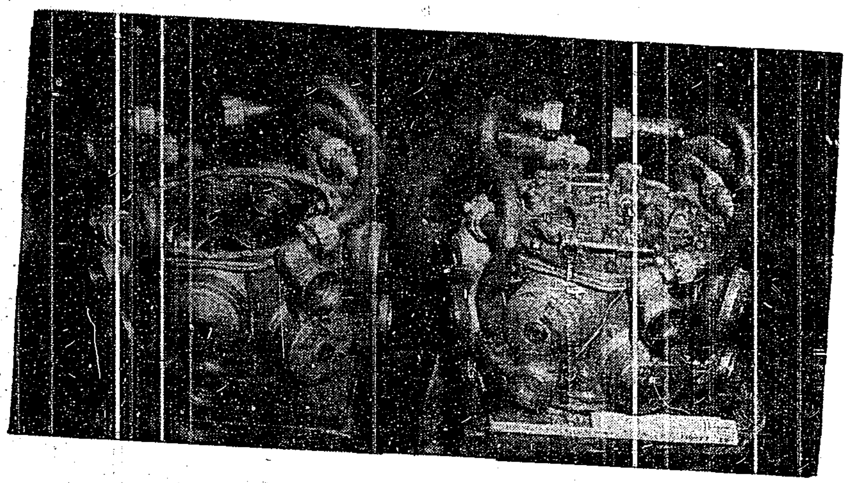


FIGURE 12(b)
ENGINE CASING. TYPE 02

Swept volume	cc in^3	4327 263.9
Max. Horsepower		150
Max. RPM		1170
Inlet Pressure	kg/cm^2 lbs/in^2	34 483
Air consumption	lbs/BHP/hr	15.8
Expansion ratio		2.7
Weight without generator	kg lb	93.2 205.0

Cycle

Wet heater

Air/fuel ratio	10 - 12.5
Water/fuel ratio	3.0 - 3.5
Gas inlet temperature (estimated)	700 - 800°C

Generator

The head is of the standard phosphor-bronze material; it is of the Whitehead type, having two igniters fired by light hammers. Kerosene and fresh water are used, and since the torpedo has only a single speed, no rating plug is required, chokes being fitted where necessary. The combustion chamber body is of heat-resisting steel without welds. It is screwed into the generator head and has a T-shaped outlet of 23mm diameter (0.906"). The generator is mounted on the front of the engine.

Air Circuit

Air enters at the side of the generator and is fed into the top of the generator head. The choke to supply the feeding head is simply a hole of 8mm (0.3125") diameter drilled in the casting. The diameter of the main inlet supply is 18mm (0.709"). An air supply to the top of the fuel and water bottles is taken from the top of the casting prior to the choke.

The main air supply is bifurcated just before the choke, 60% by-passing the choke and entering the combustion space through a steel baffle plate, 40% going through the center of the generator with the fuel.

Water Circuit

The water enters at the side of the generator head and enters the combustion space through a series of small holes outside the steel baffle plate. The baffle plate is held in place by a ring screwed into a shoulder ½" deep; this forms the outer chamber. The rating choke is screwed into a nipple in the head.

Fuel Circuit

The nozzle is similar in design to that of the Whitehead torpedo. The body is of phosphor-bronze having a steel sprayer passing down its length.

Fuel passes down the center of the sprayer and is discharged radially from seven holes approximately 0.5mm in diameter. Above the sprayer is the rated nozzle and above that is a single 100 mesh gauze strainer. At the lower end of the sprayer, between it and the fuel nozzle body is an annulus. Air enters the space between the fuel nozzle body and the fuel sprayer through inclined holes drilled about one-third of the way down.

Rating

Fuel	liters	1.8 ±0.5
Water	liters	4.6 ±0.1
W/F		3.5

The pressure used is 1 kg/cm^2 (14.2 lbs/in^2), and the duration of the test is two minutes.

Combustion Mainfold

Each outlet from the generator supplies four cylinders through pipes of 25mm (0.985") bore. The pipe bifurcates twice, supplying one pair of forward and one pair of rear cylinders. The pipes are of welded construction and are bolted to the generator and heads by eight-sided nuts. Much trouble has been experienced with joints, etc. due to expansion from heat. The excessive length of piping results in undue heat losses and explains why a water to fuel ratio so low as three can be used without damage to the engine.

Cylinder Heads

These are a phosphor-bronze casting with the thread for the union nut cut into the casting. The head is screwed onto the top of the detachable steel liner. Considerable difficulty has been experienced with the pipe connections due to the necessity of screwing the heads up to a line. A plug is screwed into the center of the head, the hole being required to obtain the engine timing.

The valve cap joint is made by a fibre washer.

The valve seats are detachable and are screwed into the valve chest. Integral with the seats are the valve guides, both being of phosphor-bronze. The joint at the bottom is knife-edged and the thread makes the joint at the top. The seat is not locked in place. There are four ports, 9mm (0.355") wide and 16mm (0.630") long.

Valves

The valve is of the standard poppet design except that a flat seat is used instead of the normal conical one. In the head of the valve is a square recess and a screwed hole for extraction purposes.

The valve stem has four oil grooves.

The valve springs are of bronze and are totally enclosed; they are retained in place by a spring cap positioned by a square on the rear end of the stem.

The leading particulars are:

Diameter of head of valve	mm in	40 1.58

Lift	mm in	6 0.236
Mean spring diameter	mm in	26.2 1.03
Wire diameter		not measured
Maximum compression	kg	7.1

Cylinder Liners

These are detachable and are of steel; they are machined with a flange two-thirds from the bottom. They are bolted into the body as well as screwed into the head. The main exhaust ports consist of two rows of holes.

The main details are:

Bore		
Thickness (minimum)	mm in	90 3.55
Exhaust ports	mm in	3 0.118
First row		
Diameter	mm in	8 0.315
Number		20
Second row		
Diameter	mm in	6 0.236
Number		20

Piston

The piston is made of bronze. The piston is of the aircraft type with no skirt but only thrust pads. The piston is fitted with a single cast iron ring. There are two gudgeon exhaust ports in the crown.

Piston measurements:

Diameter	mm in	89.5 3.526
Clearance	mm in	0.5 0.0197
Exhaust ports		
Width	mm in	4 0.158
Length	mm in	35 1.38

Distance apart	mm	35
	in	1.38

Equally spaced on each side of center line of piston.

Piston ring measurements:

Width	mm	8
	in	0.315
Thickness	mm	2.5
	in	0.10
Gap		60°
Free diameter	mm	93
	in	3.66

A bronze shell is inserted into the knuckle end to form the bearing surface. The gudgeon pins are a push fit, covered by the piston ring and are locked by grub screws.

Connecting Rod

This is of H-section steel having ports in the knuckle end to suit those in the piston. The foot of the rod is unlined and has oil grooves and holes.

Length	mm	46
	in	1.81
Width (Projected area)	mm	21
	in	0.83

Crankshaft

The two-throw crankshaft cranks at 180° have no intermediate bearing. It is of steel and is made in two parts with the crank cheek squares on the central web. These are locked in position by grub screws. The crank webs are recessed to form the retaining rings, and the cams are formed on the balance weights of the external webs. It is mounted on ball bearings at each end and has a three-splined drive for the propeller shaft.

The two crank pin bushes are of bronze.

The main dimensions are:

Forward bearing journal

Diameter	mm	45
	in	1.77
Length	mm	21.5
	in	0.85

Crank pins

Diameter	mm	35
	in	1.379

Crank pin bush

Internal diameter	mm	35.2
	in	1.386
External diameter	mm	41.5
	in	1.64

Back bearing journal

Diameter	mm	55
	in	2.17
Length	mm	25
	in	0.99

Engine Casing

This is a steel casting, eight-sided, of 3.5mm thickness. It is machined only to give joint faces. The cylinder liners slide in and are secured by nuts on the inside. Tappet lever brackets are screwed and sweated to it. Front and back covers are bolted to its flanged ends.

Front Cover

This is a bronze casting bolted to the engine casing by 16 bolts; a fiber washer is used to make the joint. It contains at its center the forward bearing race. An extension from the main shaft passes through it to drive the water pump, oil distributor and upright shaft.

Back Cover

This is of steel of 4mm (0.157") thickness and flanged to mount the engine in the afterbody. It is bolted to the engine casing in a manner similar to the front cover. It has the housing for the after crankshaft ball race which is retained by a ring nut.

Engine Cooling

The external surface of the engine is cooled by sea water circulating through the engine room. The internal cooling is carried out by a water pump of the double-shutter type. The delivery is through a non-return valve discharging via a passage around the casting through four outlets into the crankcase.

Engine Lubrication

Oil is supplied at reduced pressure to the two-point oil distributor. One connection feeds oil to the eight valve stems, and the other fee oil down through the center of the crankshaft to the big end bearing The lubrication of the ball bearings, pistons and knuckle ends is by splash.

Engine Timing

To time the engine a bronze timing cover, graduated in degrees, is fitted in place of the front cover. A dummy spindle carrying a pointer is inserted in the forward journal.

18" Types 02 and 02 Special	Type 02	Type 02 Special
Data		
Service	Production	Production

Use aboard		MTB Midget subs	MTB
Dates			
First design		1943	1944
Production		1944	1944
Manufacture			
Location		KURE, YOKOSUKA, HIKARI, and MAIZURU	HIKARI
Number made		850	100
General Particulars			
Total weight	kg	1000	975
	lb	2200	2150
Displacement	kg	735	735
	lb	1617	1617
Negative buoyancy	kg	265	240
	lb	583	528
Center of gravity (from after end)	kg	3250	
	lb	128.0	
Center of buoyancy (from after end)	kg	3170	
	lb	124.5	
Trim (down nose)	mm	-80	
	in	-3.14	
Lengths			
Head	mm	1800	1800
	in	70.09	70.09
Air vessels	mm	1330	1068
	in	52.4	42.1
Fuel vessel	mm	260	
	in	10.2	
Balance chamber and engine room	mm	850	
	in	33.48	
Buoyancy chamber	mm	780	
	in	30.75	
Tail	mm	580	
	in	22.85	
Total	mm	5600	5610
	in	220.5	221.0
Passing Conditions			
Speed	knots	$39 {+2 \atop -0}$	$38 {+2 \atop -0}$

Range	meters	3000	2000
	yards	3280	2190
Depth	meters	3 ±0.5	3 ±0.5
	feet	9.8 ±1.6	9.8 ±1.6
Direction wander at extreme range L or R	meters	45	30
	feet	147.6	98.4
Head			
Type of pistol		Type 02	Type 02
Total weight	kg	445	445
	lb	980	980
Weight of explosive	kg	350	350
	lb	770	770
Type of explosive		97	97
Vessels			
Air			
Volume	liters	220	184
	ft^3	7.7	6.45
Pressure	kg/cm^2	200	180
	lbs/in^2	2850	2560
Weight of charge	kg	54	41
	lb	119	90.2
Composition of gas		Air	Air
Thickness of wall	mm	7	7
	in	0.276	0.276
Fresh water			
Volume	liters	20	14.1
	ft^3	0.71	0.50
Weight	kg	20	14.1
	lb	44.0	31.0
Fuel			
Composition		kerosene	kerosene
Volume	liters	7.2	4.1
	ft^3	0.252	0.143
Displaced by		air	air
Lube oil			
Volume	liters	3.2	3.2
	ft^3	0.112	0.112

Power Unit			
Reducer type		2-stage	2-stage
Generator type		wet heater	wet heater
Gas outlet temperature (estimated)		750°C	750°C
Number of igniters		2	2
Composition of filling		nitroglycerine 58% gun cotton 37% mineral jelly 5%	
Engine Type		Radial	Radial
Number of cylinders		8	8
Bore	mm in	90 3.55	90 3.55
Stroke	mm in	85 3.55	85 3.55
Expansion ratio		2.7	2.7
Output			
Reducer pressure	kg/cm^2 lbs/in^2	34 483	34 483
Horsepower		150	150
RPM		1200	1170
Air comsumption lbs/BHP/hr		16	16
Air/fuel ratio		11	11
Water/fuel ratio (vol)		3.0	3.0
Type of diluent		fresh water	fresh water
Afterbody and Propellers			
Number of fins		6	8
Number of blades		4	4
Diameter fore	mm in	380 15.0	380 15.0
Diameter aft	mm in	342 18.5	342 18.5
Wake		visible	visible
Control			
Depth gear type		standard	standard

Depth setting	meters	2 - 20	2 - 20
	feet	6.5 - 65	6.5 - 65
Gyro type		2	91
Gyro angling		±90°	none

11" Type 05

This torpedo was designed by the Naval Technical Arsenal, TOKYO, in the autumn of 1944. It was a slow-speed, small range weapon of 11" diameter for use with midget torpedo motor boats. The aim of the design was ease of manufacture and handling; the standard air-paraffin, fresh water, wet heater cylce was used with a five-cylinder, swash plate engine developing seven horsepower.

The runs were carried out at YOKOSUKA, and in the initial stages no depth gear or gyroscope was fitted. The running was, however, very erratic. A simple design of gyroscope and depth gear were, therefore, fitted in the forward buoyancy chamber, and the behaviour of the torpedo because fairly satisfactory.

In the spring of 1945 manufacture was started at Sasebo-Naval Arsenal and at Nagasaki Heiki Seisakusho. The war ended before production models were available so the torpedoes were not used in service.

11" Type 05

Data

Service		Experimental
To be used aboard		small MTB

Dates

First design		1944
Development finished		1945

Manufacture

Location		SASEBO, NAGASAKI
Number made		2

General Particulars

Total weight	kg	230
	lb	507
Displacement	kg	180
	lb	396
Negative buoyancy	kg	50
	lb	110
Center of gravity (from after end)	mm	2005
	in	79.0
Center of buoyancy (from after end)	mm	1940
	in	76.5

Trim (nose down)	mm	-65
	in	-2.56
Length		
Head	mm	1000
	in	39.4
Air vessels	mm	564
	in	22.2
balance chamber	mm	1318
	in	51.9
Engine room	mm	300
	in	11.8
Buoyancy chamber and tail	mm	618
	in	24.3
Total	mm	3800
	in	149.6

Passing Conditions

Speed	knots	20 ±3
Range	meters	1500
	yards	1640
Depth	meters	3 ±1
	feet	9.8 ±3.28
Direction wander at extreme range L or R	meters	20
	yards	22

Head

Type of pistol		Experimental Type 5
Total weight	kg	75
	lb	165
Weight of explosive	kg	60
	lb	132
Type of explosive		97

Vessels

Air

Volume	liters	35
	ft^3	1.225
Pressure	kg/cm^2	160
	lbs/in^2	2270
Weight of charge	kg	6.9
	lb	15.2
Composition of gas		air

Thickness of wall	mm	7.5
	in	0.295
Fresh water		
Volume	liters	2
	ft^3	0.066
Fuel		
Composition		kerosene
Volume	liters	0.8
	ft^3	0.0262
Displaced by		air
Lube oil		
Volume	liters	0.7
	ft^3	0.023

__Power Unit__

Reducer type		single stage, diaphragm type
Generator type		wet heater
Gas outlet temperature (estimated)		650°C
Number of igniters		2
Composition of filling		nitroglycerine 58% mineral jelly 5% gun cotton 37%
Engine Type		reciprocating, swash plate
Number of cylinders		5
Bore	mm	60
	in	2.36
Stroke	mm	74
	in	2.92
Expansion ratio		2.7

__Output__

Reducer pressure	kg/cm^2	15
	lbs/in^2	213
Horsepower		10
RPM		1000
Air consumption lbs/BHP/hr		27
Air/fuel ratio		10
Water/fuel ratio (volume)		3.0

Type of diluent		fresh water
Afterbody and Propellers		
Number of fins		4
Number of blades		4
Wake		visible
Control		
Depth gear type		pendulum
Depth setting	meters feet	1 - 5 3.28 - 16.4
Gyro type		Experimental Type 5
Gyro angling		none

ELECTRIC TORPEDOES

21" Type 92

Historical

In 1921 the Japanese, on their own initiative, started to design this torpedo because of the introduction into the German Navy of an electric torpedo. The design was completed in 1925 and a torpedo, the performance of which was stated to be 30 knots to 3000 meters, was produced the same year. Development work was continued, and in 1934 Type 92 was produced. Manufacture was then stopped and the design was put to one side, ready for production in quantity when war broke out.

Head

Both the war and exercise heads are similar to those of Type 95 except for the method of securing them to the battery chamber. The method is similar to that used in Types 6 and 8 and in RN torpedoes. Flanges are riveted to the shells of the head and battery chamber, the junction of the two being effected by 23 body screws 11mm (0.433") in diameter. Thus both types of heads are the only ones which can be fitted to this type of torpedo.

Battery Chamber

The chamber is welded steel sheet 3mm thick stiffened by circular angle rings spaced along the length. In the forward end is a relief valve and an aperture for measuring the specific gravity of the acid and for ventilation. The two groups of cells are secured from the outside of the shell by four screws per group. No side lugs are fitted; only the T-headed guide similar to that of Type 95 is installed.

The end plates are of steel, dish-shaped, and are bolted on by 32 bolts. The connection between the after body and the battery chamber is the same as that for the head.

The depth gear adjusting dial is similar to Type 95 and is fitted at the top of the rear end of the battery chamber near a second aperture for ventilation.

Through the rear end plate are three connections.

1. Depth gear. As this torpedo was used in two different types of tubes, there are two external setting dials, one; already mentioned, in the battery chamber and the other in the afterbody.
2. Air duct. This duct is for the passage of forced ventilation of the battery chamber when the torpedo is in the tube. Air is supplied from the tail.
3. Power leads. These are carried through the lower part of the rear plate.

Propulsion

The torpedo is operated by a 95 hp electric motor drawing its power from two 54-cell lead-acid batteries which are pre-heated in order to obtain maximum electrical output. The circuit is as shown in Figure 13.

Battery

The battery consists of two groups of 54 cells of lead-acid type, each mounted in an aluminum alloy frame which can be run into the battery compartment on channel section bars. Connection between batteries is by means of single plugs and sockets held together by means of couplings of insulating material.

Details of cells:

Height	in	9¼
Length	in	4½
Width	in	3
Capacity		150 ampere-hours.
Plates		11-VE, 10 + VE Pasted grid construction
Cases		Hard rubber (vulcanized)

Two types of cell are used. They have terminals specially designed to facilitate inter-cell connection.

A lighter battery was kept for trial purposes so that the blowing head would have sufficient buoyancy to float the torpedo at the end of the run. When no special battery was available for trials the running batteries were used with four cells removed from the end of one rack. All batteries used on trials were fitted with unspillable vents.

The battery racks were fitted with six metal-enclosed heaters along the underside so that the battery could be warmed up from an external electric supply before the torpedo was fired. The heating supply was connected by means of a socket in the tail section of the torpedo. Each heater was rated at 250 watts, and the external supply voltage was 220 volts.

Charging

A polarized socket was provided in the tail section for charging the battery, and an air line was connected to an opening on the right hand side of the after body to ventilate the battery. The air, after entering the battery compartment, was discharged through a non-return valve at the forward end of the battery compartment. When a torpedo was assembled

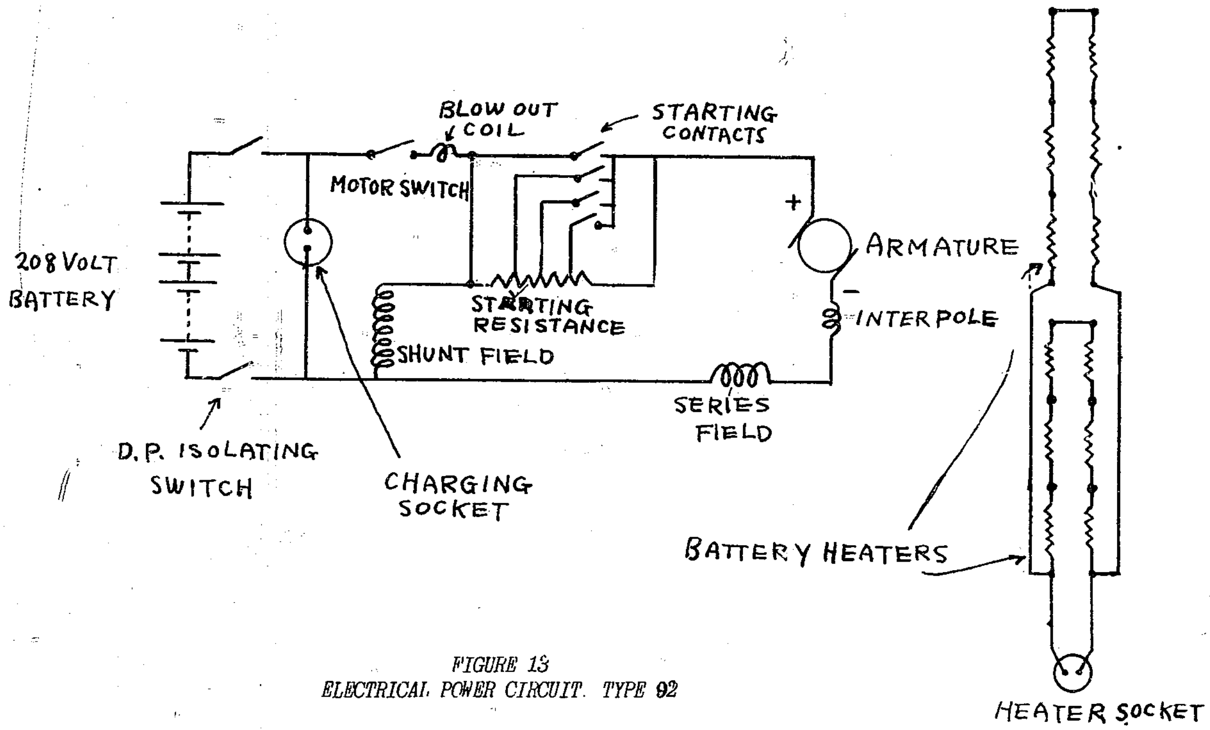


FIGURE 13
ELECTRICAL POWER CIRCUIT. TYPE 92

with battery ready for use but not actually about to be fired, the access hole at the forward end of the battery compartment and the vent hole just behind the power switch were left open to keep the compartment fresh. The large access hole was also used to check the specific gravity of the cells in its vicinity.

Maintenance

For the purpose of battery maintenance the racks were placed in shallow concrete troughs and connected to charge-discharge switchboards. The meters on these boards were center-zero, 30-0-30 ampere instruments, and the discharge resistances were water cells constructed of stone with iron plates for electrodes.

Main Switch

A double-pole main switch is mounted in the battery compartment above the after battery and operated by a key externally, before the torpedo is loaded into the tube.

Motor

The motor is a six-pole, compound interpole machine connected in long shunt operating at 200 volts, 450 amps. The armature is built on an extension of the main shaft and has bearing at the commutator end. The rated horsepower is 95 at 1250 RPM, and it is arranged for resistance starting under full shunt field.

Starting Resistance

The motor starting resistance is constructed of iron strip material clamped in a frame insulated with asbestos. Copper connections between the resistance and the starting switch are brazed to iron tags on the resistance.

Operation

When the starting lever is operated, the motor switch closes and the motor starts with all the resistance in series with the armature circuit. An extension shaft on the commutator end of the motor drives a cam shaft which cuts out the resistance after a predetermined number of motor revolutions as follows:

Resistance Stage	Motor Revs. From Starting
5 (all in)	0
4	75
3	105
2	123
1 (all out)	130.5

The cam shaft would complete one revolution after 850 revolutions of the motor and is marked 0.600, but at about 300 revolutions a pawl lifts and the cam shaft is disengaged, leaving the motor connected directly to the battery through the motor switch.

An extension of the cam shaft is brought through the shell of the torpedo so that it can be turned by hand, and also that its position can be checked before a run.

Cut-Out Switch

The motor switch is fitted with a magnetic blow-out coil, and another cam driven by the extension on the motor shaft, and can be arranged to trip this switch at any number of revolutions from about 1000 to 14,000. This valve can be set externally by means of a key next to the starting cam extension. The purpose of the arrangement is to disconnect the battery from the motor during trials, thus avoiding complete discharge of the battery. When used operationally the maximum setting is put on the dial.

Afterbody

The afterbody is of welded steel and contains the second depth setting dial and the range setting wheel.

The tube starting lever is fitted in the normal position; when this goes aft, air is turned on to the servomotor and gyroscope and the main switch is closed, the propellers rotating slowly. The discharge is effected by air pressure in the tube.

The tail fins are of R.G.F. pattern i.e., forward of the propellers and are attached to the shell by screws.

Tail

The tail is a forged steel cone having guide channels integral with the forging into which the fins are fitted and then rivetted; on the ends of the fins are guide strips, those on the horizontal fins have lignum-vitae insets to reduce the friction on discharge.

Between the fins on the starboard side is the charging connection for the steering air bottle. On the port side is the steering air stop valve and connections for charging the batteries when the torpedo is in the tube.

The rudder rod adjustment apertures are on both sides of the top vertical fin.

On the port side in the rear at the bottome is the depth gear and servo-motor. These are of standard design but smaller in size and are located together in one pocket. Aft of this is the gyroscope, Type 98, with the setting gear at the top.

The steering air bottle also is in the rear buoyancy chamber.

At the bottom on the starboard side is the connection for heating the batteries.

The rudder control gear is of the standard type.

The main drive from motor to propellers is transmitted through a mitre gear system which functions as a reversing and a reducing gear.

The bevel gear wheel from the motor shaft is geared to the two larger side wheels of the mitre gear. The reduction ratio here is 24/38. On the inside of the two side wheels of the mitre gear are two bevelled wheels which are locked to the larger side wheels of the gear system, and are equal in size to the bevel gear on the motor shaft. These two inner wheels are directly geared to the sleeve shaft and to the propeller shaft, without further change in gear ratio. The overall reduction ratio of the mitre gear system is 24/38. Thus, for the full motor speed of 1250 RPM, the propellers rotate at a speed of about 800 RPM. By this means the load on the motor is reduced.

The propellers are of the standard type; four blades are keyed to the shafts and held in place by nuts locked by great screws.

General

The main defect was a leak between the battery chamber and the after body.

A number of details in this report differ from the information given in U.S. Navy Mobile Explosive Investigating Unit Number 4, Intelligence Report Number 79 dated 25 June 1945, but all changes have been verified by interrogation of Commander HORI and by examination of complete specimens of the Type 92 torpedo.

21" Type 92 - Data

Service	Production
Used aboard	Submarines
Dates	
First design	1932
Production	1942
Manufacture	
Location	YOKOSUKA, KURE & MAIZURU
Number made	650

General Particulars

Total weight	kg	1720
	lb	5940
Displacement	kg	1420
	lb	4840
Negative buoyancy	kg	300
	lb	1055
Center of gravity	mm	3900
(from after end)	in	195.5
Center of bouyancy	mm	3820
(from after end)	in	150.8
Trim (down nose)	mm	-80
	in	-3.15
Length		
Head	mm	1125
	in	44.3
Battery chamber	mm	3539
	in	139.4
Balance chamber & engine room & buoyancy chamber	mm	1976
	in	77.8
Tail	mm	510
	in	200.9
Total	mm	7150
	in	354.5

Passing Conditions

Speed	knots	28^{+2}_{-0}
Range	meters	7000
	yards	7650
Depth	meters	3 ±.05
	feet	9.8 ±1.6
Direction wander at extreme range, L or R	meters	120
	yards	131.5

Head

Type of pistol		90
Total weight	kg	375
	lb	825
Weight of explosive	kg	300
	lb	660
Type of explosive		97

Vessels

Air

Volume of steering air vessel	liters ft^3	12 420
Pressure of steering air vessel	kg/cm^2 lb/in^2	205 2920

Lube oil

Volume (in tail)	liters ft^3	3 0.984

Power Unit

Engine type		Electric motor
Volts		200
Amperes		350
Number of batteries		108

Output

Horsepower		95
RPM		1250

Afterbody and Propellers

Number of fins		4
Number of blades		4
Wake		None

Control

Depth gear type		Standard
Depth setting	meters feet	2 - 12 6.5 - 39.4
Gyro type		92
Gyro angling		$\pm 180^{\circ}$

METACENTRIC HEIGHTS OF JAPANESE TORPEDOES

The "pull round" forces for a number of Japanese torpedoes were available and are shown below with the calculated metacentric heights:-

TYPE	DIAMETER cm	WEIGHT kg	PULL ROUND FORCE kg	METACENTRIC HEIGHT mm	in
89	53	1668	45	7.2	0.28
90	61	2605	41	4.8	0.19
93					
Modif. 2 95	61	2765	64	7.1	0.28
Modif. 1	53	1650	46	7.4	0.29
97	45	980	25	5.7	0.23

These figures for M.C.H. are low on British standards, which aim at about 0.4 inches, but the Japanese claim freedom from serious rolling.

DEVELOPMENT OF THE USE OF OXYGEN FOR TORPEDOES

HISTORICAL

Japanese experimental work on the use of oxygen in torpedoes commenced in 1916 but, owing to explosions occurring in the generator at the instant of ignition, the work was discontinued shortly afterwards. Efforts were then directed to the development of Type 6 and Type 8 (1917 and 1919 respectively), and in 1924 the new Whitehead torpedo with a maximum speed of 46 knots and a range of 3,000 meters was adopted for use by the Japanese Navy.

In 1927 OYAGI, later promoted to the rank of Admiral, was in England studying torpedo design at the Whitehead Works, Weymouth (not Messrs. Vickers Armstrongs) when he heard that HMS NELSON and HMS RODNEY were equipped with 24½" oxygen torpedoes. OYAGI stated that he had never been able to ascertain the truth of the rumor even to the present day. Japanese interest in oxygen torpedoes was stimulated and, as a result, the Government sanctioned the reopening of research on oxygen torpedoes in 1928. In 1930 an experimental model using about 50% oxygen was successfully constructed, and in 1933 attempts were made to produce a pure oxygen torpedo. The main difficulties which had to be contended with were as follows:

1. Prevention of explosion at instant of ignition.
2. Control of temperature in generator.
3. Use of sea water as diluent.
4. Increase in the structural strength of the engine to increase its life at the greater speeds and ranges involved.
5. With increased range, greater accuracy in direction keeping was required and therefore improvements in the gyroscopic control were sought.

Prevention of Explosion at Instant of Ignition

This difficulty was overcome by the use of a "first air vessel" which was charged with air at a pressure slightly in excess (5-10 kgs/cm^2 71-142 lbs/in^2) of the pressure of the main oxygen charge in the oxygen vessel. The torpedo was started therefore on natural air and the oxygen concentration was gradually raised to 100%.

The Type 93, Model 1, Modifications 1 and 2; Type 95, Modification 1 and Type 97 were all fitted with "first air vessels". OYAGI stated that in about 10 years experience there had been no accidents resulting from the use of pure oxygen. The design, however, was not without defects.

Research on the improvement of the types using pure oxygen followed two lines. In the case of the Type 93 the "first air vessel" was removed and a vessel (first liquid bottle) containing 150cc of carbon tetrachloride (CCl_4) was placed in the oxygen line so that, initially, a mixture of CCl_4 and oxygen was fed into the generator. Carbon tetrachloride is a negative oxidation catalyst, or oxidation retardation agent, and therefore prevents an explosive oxidation of the fuel at the instant of ignition. This system was successfully adopted in Type 93, Model 3. There were no accidents with the Type 93, Model 3 torpedo. A disadvantage in the use of CCl_4 is the fact that it causes pitting and corrosion of the "group" and reducer.

In the case of the Type 95, Model 2 torpedo the "first air vessel" was removed and some of the air charge in the steering air vessel was used for starting. As the engine revolves it operates a mechanism which slowly opens the oxygen delivery stop valve, admitting oxygen from the oxygen vessel, and shuts off air from the steering air vessel until finally the engine is running on pure oxygen.

Control of Temperature in Generator

This was accomplished by using sea water injection as diluent to control the temperature of the generator.

The design of a generator to give complete combustion of the oxygen, rapid and complete evaporation of the diluent with minimum heat loss was the most difficult problem in the development of the torpedo. A year was devoted to it, and many designs of breech ends, fuel sprayers, and perforated plates were tested before the final design was completed.

Use of Sea Water as Diluent

To save weight and space, sea water was chosen in preference to fresh water. It was pumped by a reciprocating pump, driven from the engine, to a pressure regulator and was used as well to displace the fuel. The quantity was governed in the normal way by a rated nozzle in the generator. This system has been adhered to for all types of oxygen torpedoes.

The use of brine raised special problems due to the deposition of salt in the engine inlet valves and in the cylinders.

Slide valves were used at the cylinder inlets and these were subject to severe wear. They had to be replaced about every three runs. The valves were made of siliconchrome steel and are water-cooled.

Structural Strength of Engine

No structural alterations were necessary in the cylinders due to the use of sea water, but due to the deposition of salt (melting point of salt 792°C) it was found that the clearance at top dead center was reduced to zero. This resulted in hammering of the copper cylinder head by the piston, causing deformation of the head. The clearance was, therefore, increased and the loss in efficiency accepted.

Control

The friction and resultant sluggish operation of the link mechanism between the gyroscope wheel and the slide valve was eliminated by using a diaphragm balanced on each side by equal air pressure. Rotation of the gyroscope spindle reduced the pressure on the appropriate side of the diaphragm, unbalancing the pressure and causing a lateral movement of the spindle carrying the disc. This movement operated the slide valve. In addition, the gyroscope was mounted on rubber.

Development Work

This was carried out in three stages:

1. Bench experiments with a combustion chamber and a blower for introducing fuel, oxygen and water.
2. Dynamometer tests.
3. Ranging.

Fuels

Kerosene is always used. Alcohol was investigated, following French practice at Schnieder works of using 100% alcohol as fuel and diluent, but was never adopted.

"FIRST AIR VESSEL" CIRCUIT

This method is used in the Type 93, Model 1, Modifications 1 and 2; Type 95

Modification 1 and Type 97. (See Figures 14 and 15.) A vessel of volume up to 13 liters, containing air at a pressure slightly above the pressure in the oxygen vessel (10 kg/cm² greater) is added to the oxygen circuit. The circuit is shown diagrammatically in Figure 14. Working from the nose to the tail there is first an oxygen charging stop valve and charging connection at the forward end of the vessel for charging the oxygen vessel with 100% oxygen. From the after end of the oxygen vessel there is a lead through the delivery stop valve and non-return valve to the "first air vessel". From the "first air vessel" the connection goes to the air stop valve and charging connection and from there to the group. The group is connected to the main reducer which in turn is connected to the generator.

When the circuit functioned correctly, no oxygen was discharged from its vessel until the pressure in the "first air vessel" had fallen below that in the oxygen vessel. The torpedo, therefore, started on natural air and the oxygen concentration was gradually raised to 100%.

Type 93, Model 1 Modifications 1 and 2.
Sequence of operation is:

1. Open "first air vessel" stop valve by hand when torpedo is in the tube.
2. Open oxygen delivery stop valve, also by hand, when torpedo is in tube. Special geared spanners to give slow opening are used, and the valves are opened just before firing.
3. Tube operated starting lever is pulled aft to operate safety mechanism on group. Air is supplied to gyroscope, servo-motor and steering engine by opening a second valve in the circuit.
4. Torpedo is then fired and flap goes aft and opens small valve on group.

Type 95 Modification 1.
The sequence is the same as that of Type 93.

Defects

This design was not without its defects, and a great deal of trouble resulted from leakage occurring in the "first air vessel". Since the volume of this vessel is small, the pressure soon fell below that of the oxygen vessel, and as soon as the oxygen delivery stop valve was opened, oxygen passed into the "first air vessel" and enriched its charge. These leakages usually appeared at the joint of the pipe leading to the oxygen vessel. The joint was of standard design using copper, and was subject to hardening and shrinking.

In the Type 93, Model 1 torpedo this defect did not have any serious consequences since it was possible to check the pressure in the vessel whilst the torpedo was in the tube and "top up" if necessary. In submarines using the Type 95 torpedo this was difficult to do and in the midget submarines using Type 97 (18"), where the torpedo was muzzle loaded into the tube, it was impossible. Since a leak resulted in an explosion at the start of the run, not only was the target missed but the effect on the ship was serious, and an alternative method of starting had to be found.

STEERING AIR VESSEL CIRCUIT

This circuit, as used in the Type 95 Model 2 torpedo, is shown diagrammatically in Figure 16. The oxygen vessel has an oxygen charging stop valve and charging stop valve and charging connection at the forward end of the vessel for charging with 100% oxygen. Oxygen from the vessel passes through the mechanically operated oxygen delivery stop valve through the group to the reducer and thence to the generator.

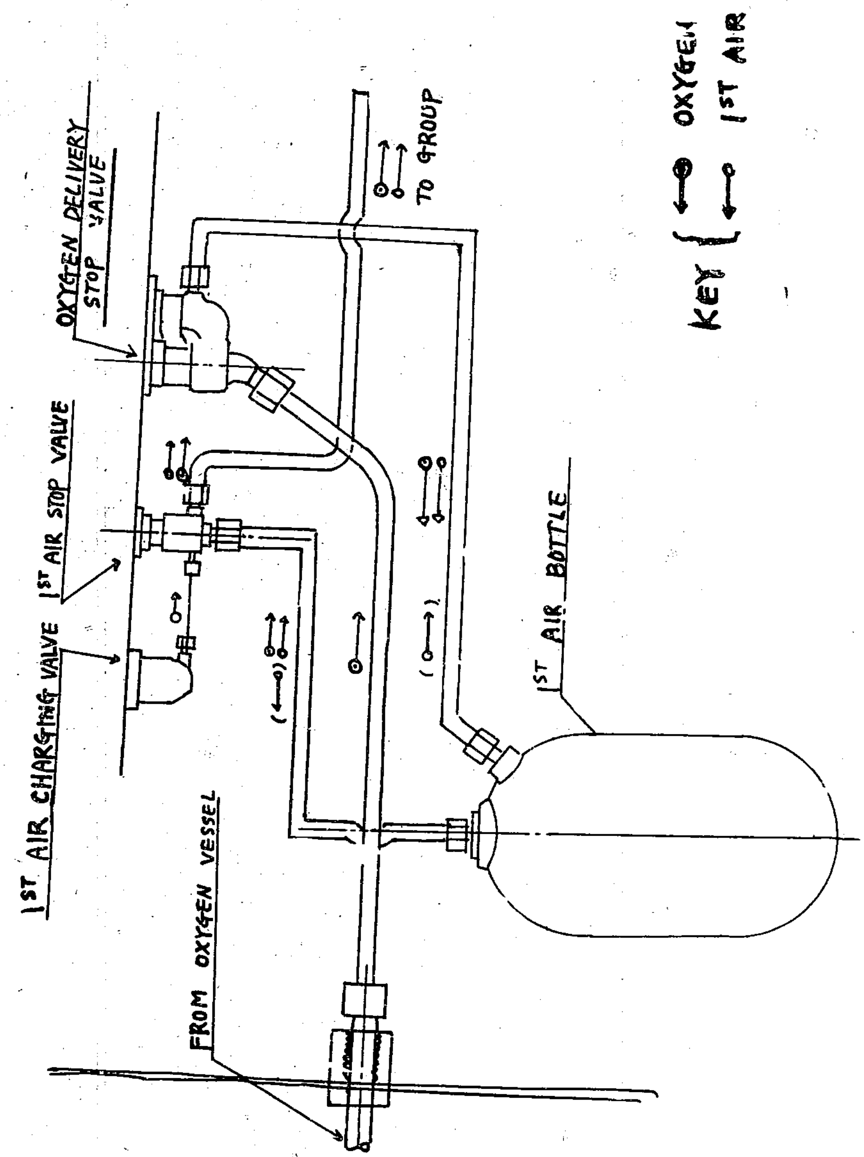


FIGURE 14
CIRCUIT DIAGRAM. TYPE 93 MODEL 1 MODIFICATION 2

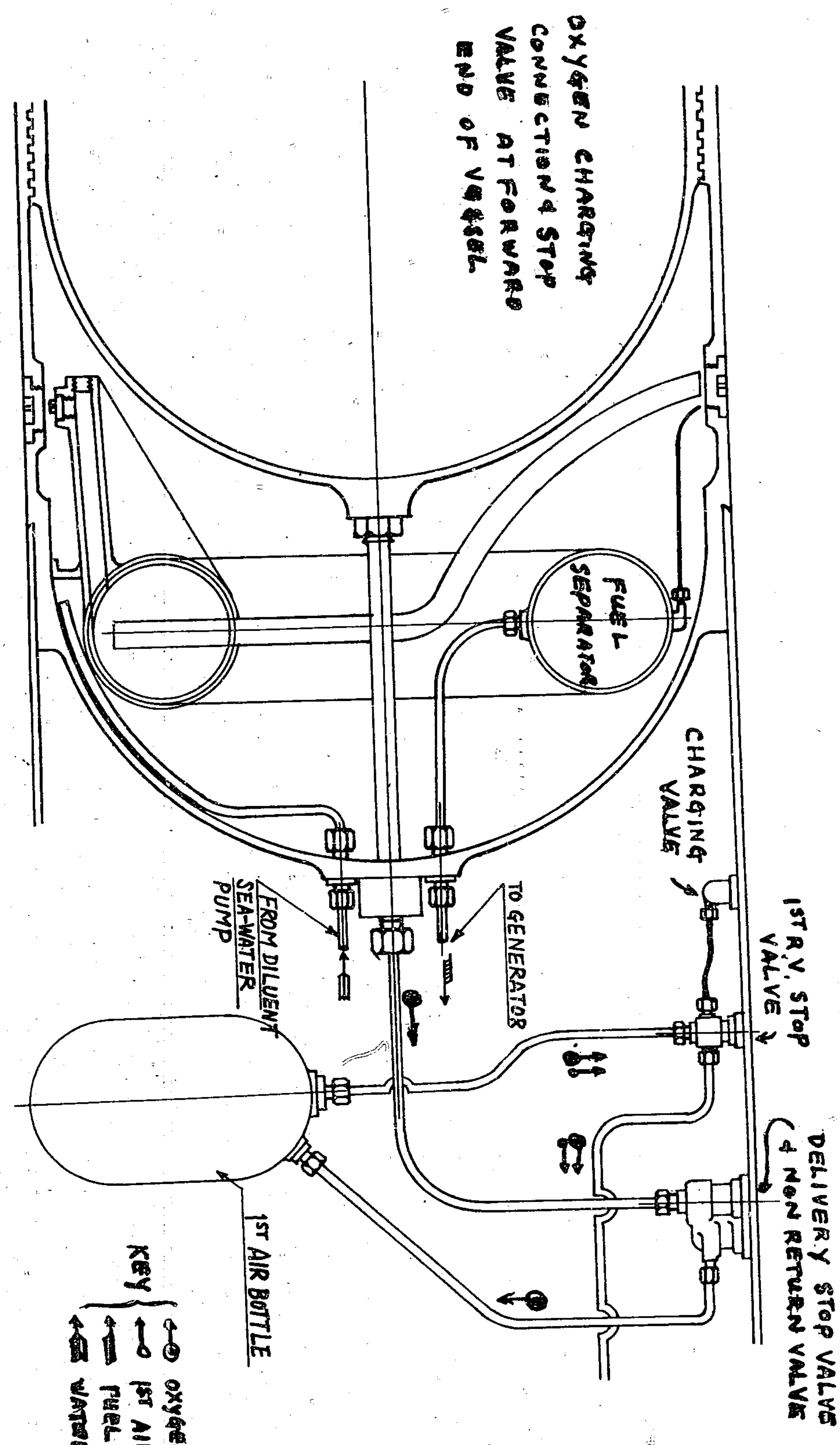


FIGURE 15
CIRCUIT DIAGRAM, TYPE 95 MODIFICATION 1

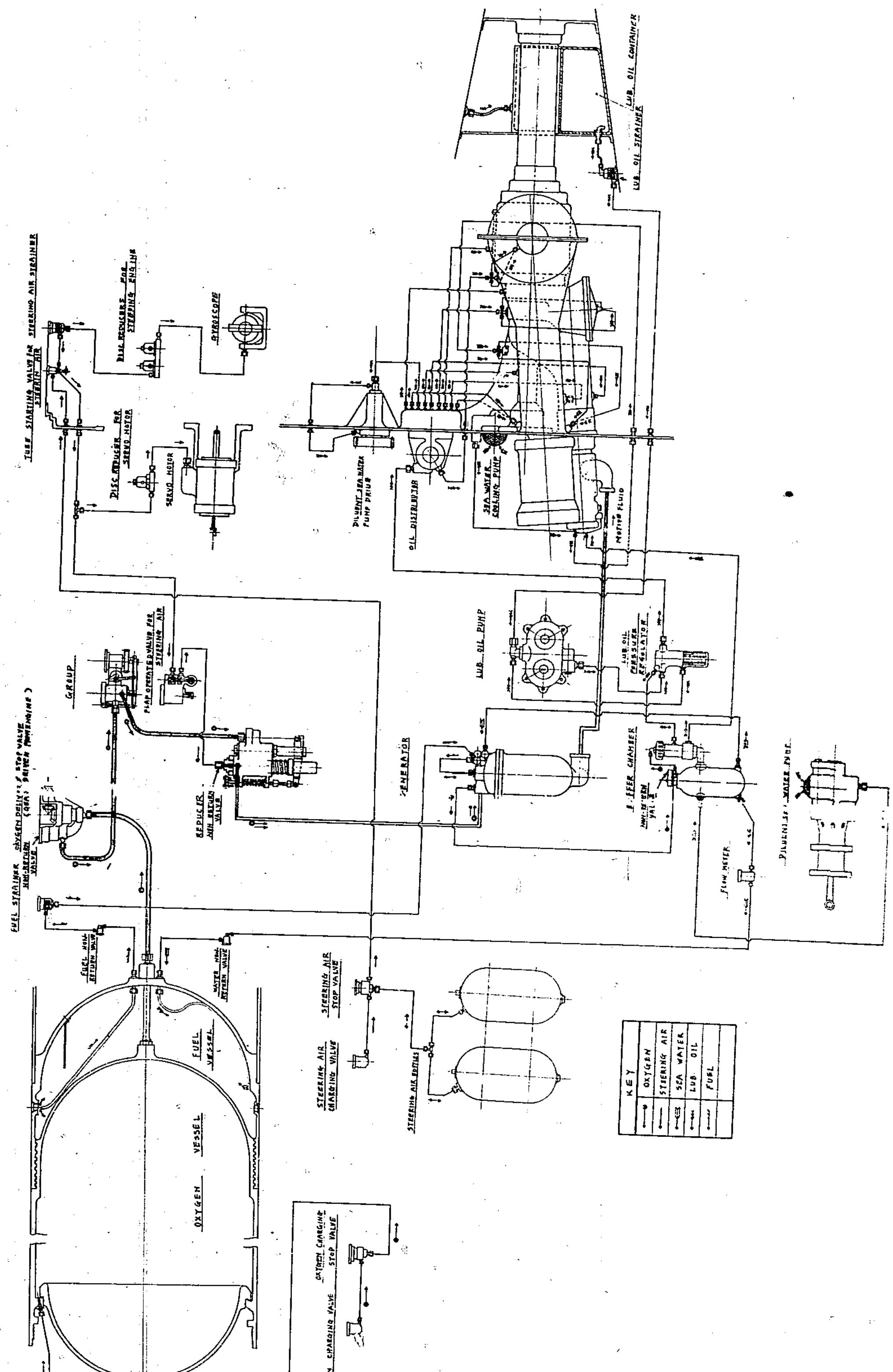


FIGURE 16
CIRCUIT DIAGRAM. TYPE 95 MODEL 2

Air from the steering air bottles flows through the steering air stop valve to the tube-operated starting valve. From this valve, one lead goes to the water flap-operated valve attached to the group, another goes to the disc reducer and then to the servomotor; a third lead goes to an air strainer and then to the disc reducers and to the gyroscope.

The Sequence of Operations

1. Tube starting valve is opened and air is admitted to servomotor, gyro and pilot valve in group.
2. Torpedo is fired and water flap goes aft admitting air to reducer and generator.
3. Engine revolves and opens main oxygen delivery stop valve fully in 60 revolutions and closes steering air valve suddenly after 40 revolutions.
4. Range is set on group in the normal way; the valve closes when the range is run off.

This system does not suffer from the disadvantages of its predecessor on the mechanical side, nor on the other hand is it liable to the corrosion caused by the chemicals used in the third circuit.

Method of Operation

The standard group has a special attachment for controlling the starting by steering air. (See Figures 17 and 18.) This consists of a spring-loaded operating valve lifted by a cam. The valve is placed in the circuit between the steering air stop valve and the top of the second reducer. In the cap of the second reducer is a non-return valve to prevent the flow of oxygen back into the steering air circuit and a restriction to control the quantity of steering air for starting the engine.

The water flap is connected to the cam of the operating valve. A lever mechanism is included so that additional force to turn the cam to open the valve against the steering air pressure can be applied by a spring. With the flap in the forward position the lever mechanism is just over dead center. The flap moving aft merely pushes the lever over dead center and allows the spring to turn the cam.

A bevel drive from the engine, off the extension of the drive for opening the oxygen delivery valve, closes the valve by rotating, in the reverse direction, the cam through a dog clutch on the end of the spindle. A stop pin is used to prevent overrotation during the opening period. The valve is open for 40 engine revolutions only. A spring-loaded ratchet on the cam enables 40 revolutions to be set regardless of the engine position. To open the oxygen delivery valve an extension from the engine cooling pump is connected to a worm drive with a 12:1 reduction. After the worm drive there is a train of gears giving a further reduction to the bevel drive to the top of the delivery valve. Here a bevel wheel having 18 teeth gears with another having 26 teeth. The total reduction is 102.7 engine revolutions to one revolution of the valve spindle which is keyed to the second bevel wheel. The latter has three teeth missing so that after 100 revolutions of the engine the valve is wide open and the gear disengages.

It was stated that great difficulty had been experienced in obtaining satisfactory functioning of this gear, since there were frequent tooth breakages. To obtain satisfactory operation in service the teeth had to be strengthened and better material used.

CARBON TETRACHLORIDE CIRCUIT

The use of carbon tetrachloride was first proposed by Lieutenant Commander

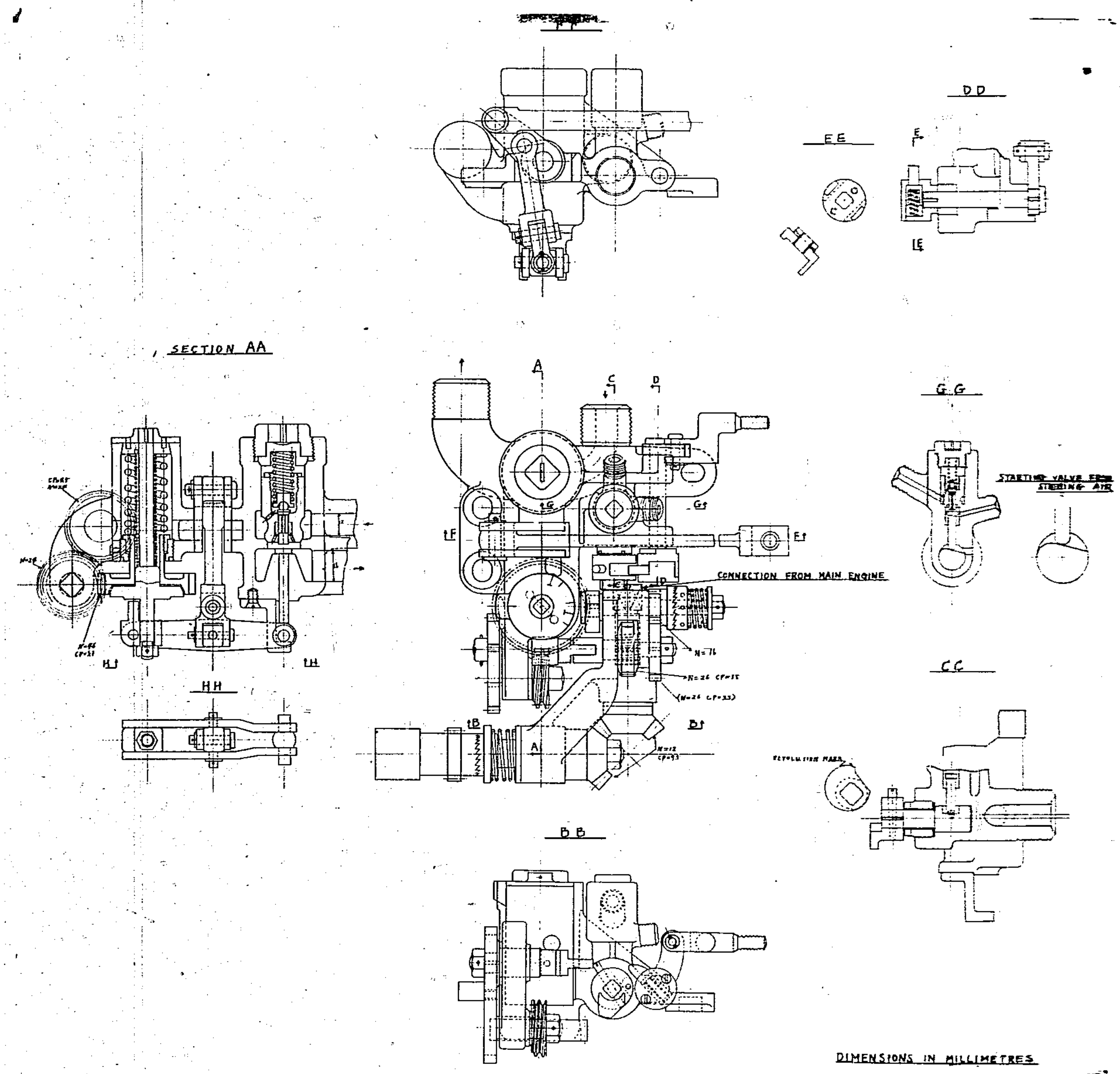


FIGURE 17
GROUP MECHANISM, TYPE 95 MODEL 2

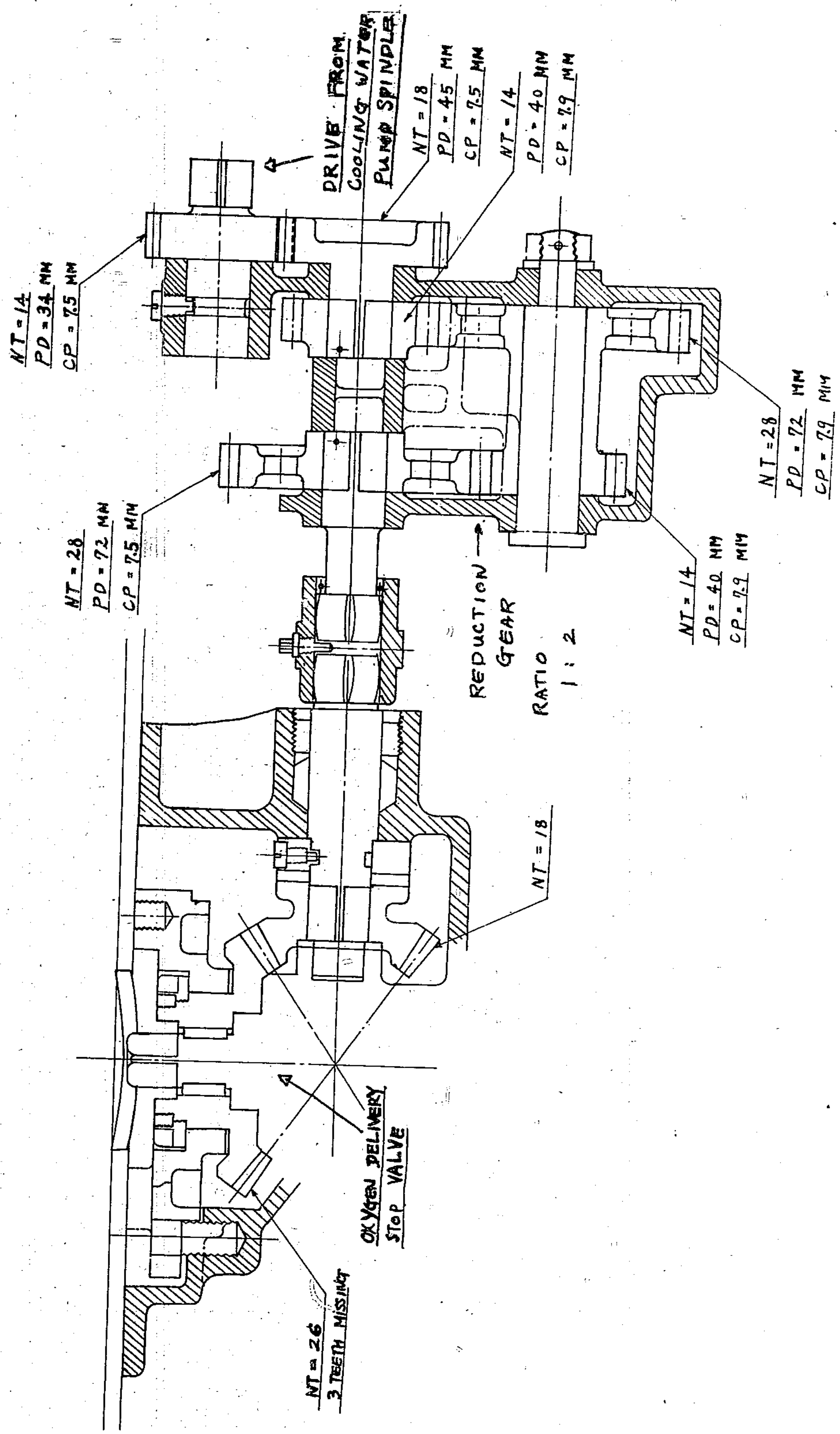


FIGURE 18
GEAR DRIVE OF OXYGEN DELIVERY
STOP VALVE TYPE 91 MODEL 2

KAWASE, Torpedo Department, KURE, in 1943. The basis of the proposal lies in the oxidation retardation property of carbon tetrachloride. It was hoped that the oxidation of kerosene in the presence of high pressure oxygen would be inhibited by carbon tetrachloride to such a degree that an explosion at the instant of ignition would not result. This anticipated result was confirmed by experiment.

Experiments

Experiments were carried out with a Type 93 generator head clamped in a horizontal position (flame horizontal), without the generator body. The oxygen and kerosene were fed to the generator nozzle in the usual way and ignited with a small flame. The ratio of oxygen to fuel was the same as that used in the Type 93 torpedo. No water was used. Two distinct methods were tried for the introduction of carbon tetrachloride into the flame. In one case, the tetrachloride was mixed with the fuel in the fuel bottle; in the other case, it was fed into the oxygen stream before the latter entered the generator head.

A series of experiments was conducted with varying percentages (5 to 95%) of carbon tetrachloride in the fuel. The results below show the percentage of CCl_4 used in the fuel and the estimated percentage of CCl_4 on the basis of oxygen, assuming an oxygen fuel-CCl_4 mixture ratio of 2.8/1.

CCl_4 in fuel (%)	CCl_4 in oxygen (%)	Remarks
0-20	0-8	Combustion good; short, intense, bluish flame.
70-80	25-29	Combustion poor; long, weak, reddish flame.
80 and above	29	Combustion completely inhibited; no flame.

(More detailed data was not obtainable from the Japanese.)

To use this method in a torpedo, a carbon tetrachloride bottle (first liquid bottle) of 50cc capacity was incorporated in series with the fuel vessel. (See Figure 19). When the torpedo is fired, the sea-water pressure forces the fuel into the first liquid bottle, displacing CCl_4 and mixing with the remaining CCl_4 in the bottle. Thus, 100% CCl_4 is first introduced into the generator and this percentage falls with increase of fuel percentage, until finally the CCl_4 is exhausted and fuel alone is introduced.

Practical Difficulties

The expansion and contraction of the fuel, due to atmospheric changes of temperature, seriously affect the efficacy of this method. Expansion and contraction of the fuel result in considerable mixing of the latter with the carbon tetrachloride before firing. In this way, a mixture of fuel with only a low concentration of tetrachloride may be present in the generator at the instant of ignition; the dangers of explosion will therefore not be removed. Futher, excessive expansion may push out CCl_4 from the first liquid bottle into the generator, where it will be lost to exhaust in the first few revolutions of the engine, before the igniters are fired.

To overcome this disadvantage, a two-way valve was designed (see Figure 20) so that when the fuel expanded, it passed into a special overflow reservoir and not into the carbon tetrachloride bottle. Then, when the torpedo was fired, the full pressure of the fuel automatically closed the

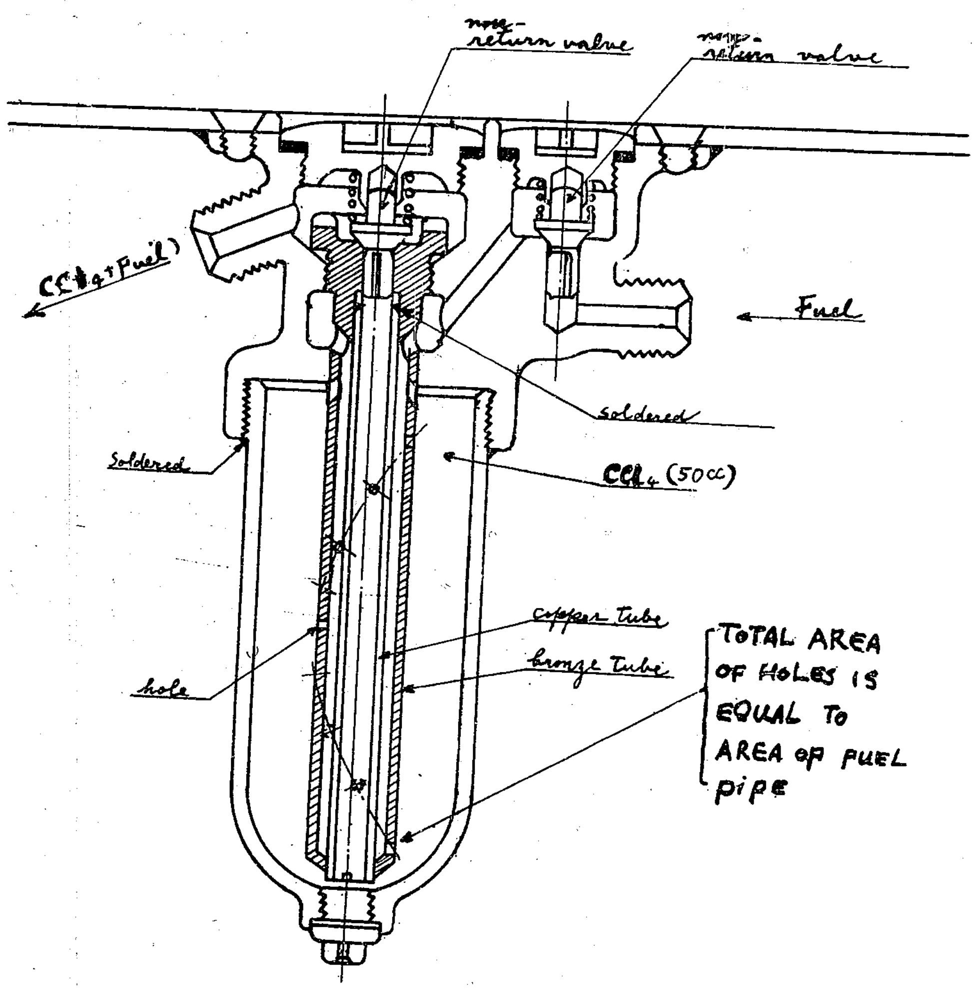


FIGURE 19
DETAILS OF CCl_4 BOTTLE IN FUEL CIRCUIT

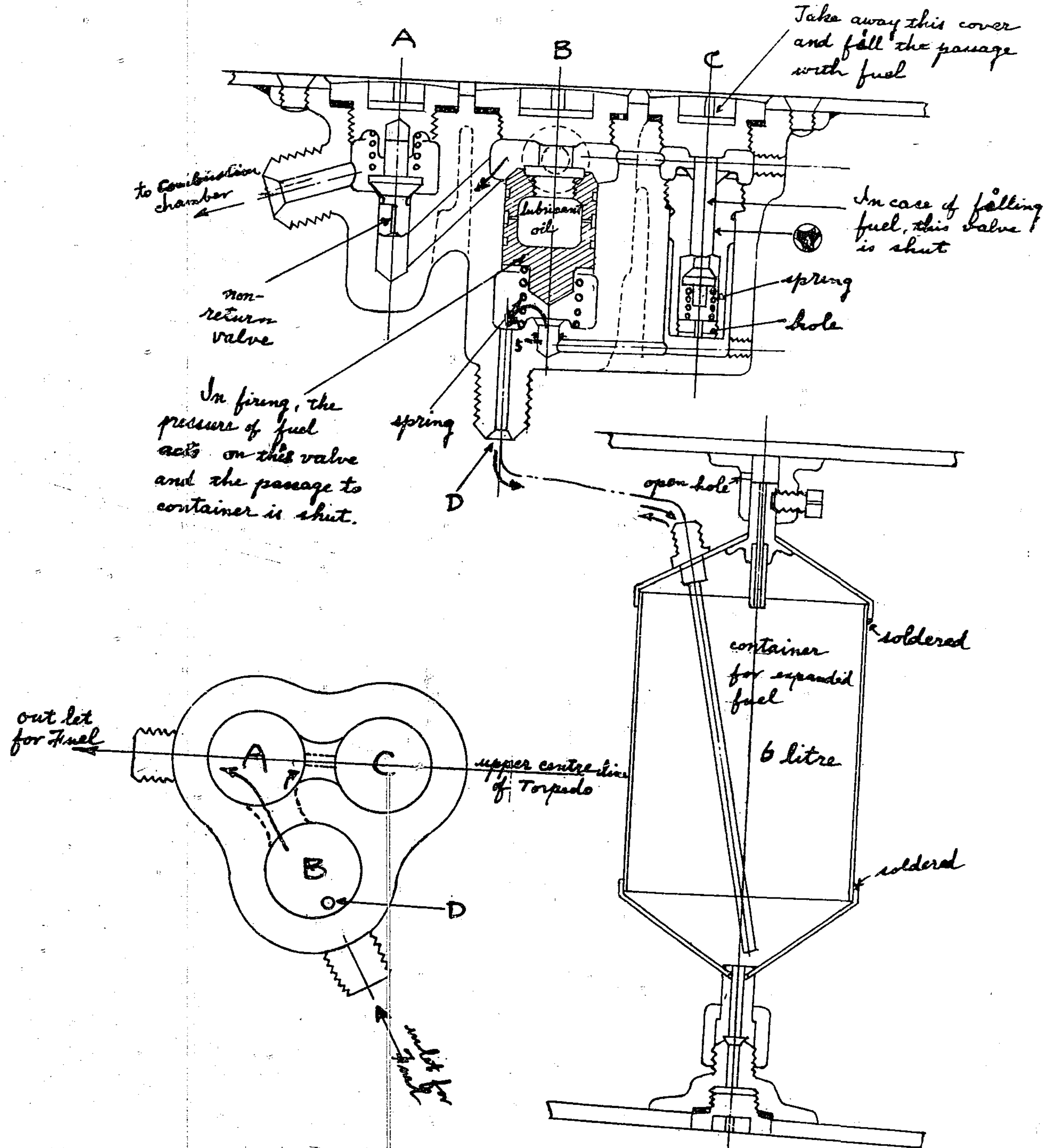


FIGURE 20
REGULATING VALVE FOR FUEL EXPANSION

by-pass to the overflow reservoir, and the fuel flowed into the first liquid bottle. The overflow reservoir had a capacity of six liters, which seems to be unnecessarily large.

This method of starting was never used in practice, because experiments with CCl_4 in the oxygen feed pipe (which were undertaken in parallel with the above experiments) were more quickly brought to a successful conclusion.

The use of a first liquid bottle in the fuel pipe, nevertheless, is favored by many Japanese. The great advantage of the method is the introduction of the tetrachloride in to the generator without passing through the group valve and reducer. In these two important units tetrachloride causes corrosion, as occurs in the Type 93, Model 3 where the first liquid bottle is included in the oxygen supply line. If the first liquid bottle in fuel circuit is adopted, corrosion troubles may arise in the two-way valve, but corrosion in this unit is less serious than in the "group" and reducer.

Function in Torpedo

The first liquid bottle is described in detail later. Shortly before firing, the first liquid bottle is filled with CCl_4. About 300cc are used, and when the bottle is filled (150cc) the remaining liquid fills up the pipe between the first liquid bottle and the gorup valve. When the torpedo is fired, the oxygen pressure pushes out the CCl_4 in the pipe into the generator, and the drop of pressure across the bottle introduces the liquid in the bottle into the oxygen stream. Therefore, the mixture in the generator contains a high percentage of CCl_4 at the start, and this falls off until finally pure oxygen flows into the generator. No precise information is available on the time taken to exhaust the first liquid bottle, but it is estimated that that time is about four seconds.

Ignition

Each of the igniters burns for 40 seconds at atmospheric pressure and probably for about seven seconds at the pressure of the generator. Thus the two igniters together (fired at five revolutions apart) will burn at least eight seconds. Therefore, when the concentration of CCl_4 in the generator is high, the igniters are fired and they continue to burn until the concentration of CCl_4 has fallen to zero. At the start, the rate of oxidation of the fuel will be very slow; then with the fall of the concentration of CCl_4 it will increase in a controlled manner until finally normal combustion is established.

The use of tetrachloride has the secondary advantage of cleaning the feed pipe, "group" and reducer of contamination (which may have been introduced after cleaning) before pure oxygen begins to flow.

Disadvantages

Corrosion is the main trouble arising from the use of tetrachloride. This may seriously prejudice the proper functioning of the group valve and the main reducer. Carbon tetrachloride decomposes slowly in the presence of moisture and forms hydrochloric acid. The decomposition is accelerated by sunlight. As a result, CCl_4 always contains traces of hydrochloric acid, and this is the corrosive agent which is harmful in torpedoes when CCl_4 is used.

Inhibitors

Attempts have been made by the Japanese to inhibit the carbon tetrachloride so that the development of acidity might be prevented. The following inhibitors have been tested: pyridine, miscellaneous amines, traces of caustic potash and traces of caustic soda. Definite evidence confirming the value of any of these materials as inhibitors was not obtained. The tetrachloride is used therefore in its uninhibited state, but great care is taken to insure the purity of its condition.

Only chemically pure tetrachloride should be used; it should be stored in dark bottles and kept in a cool place. Although not so convenient in handling, petrol tins have been successfully used as tetrachloride containers during the war.

Chlorine Content

Not more than a trace of chlorine ions is acceptable, when tested with silver nitrate.

Acidity

The tetrachloride should be neutral to phenolpthalein.

Moisture

No special precautions are taken to exclude moisture, although it is probable that the latter plays a part in the decomposition.

Trichlorethylene (C_2HCl_3)

Trichlorethylene was tried in the first liquid bottle as an alternative to CCl_4. This material is more stable under ordinary conditions (and can more effectively be inhibited) than CCl_4 and therefore is less likely to corrode metals. When used in the experiments, however, it was found that C_2HCl_3, which is non-inflammable under normal circumstances, caused serious explosions. This explosive property of trichorethylene was further confirmed in later experiments in connection with KAITEN 2.

General

Carbon tetrachloride is used for starting in Type 93, Model 3 (1944) and Type 93, Model 1, Modification 3 (1945) torpedoes.

As an added precaution, about 30cc CCl_4 is poured into the oxygen delivery non-return valve of the Type 95, Model 2 before firing.

The use of carbon tetrachloride in Japanese torpedoes is an interesting application of chemical retardation. It suggests a fruitful field of research into the many other compounds which act as oxidation inhibitors in various circumstances; some of these may well be superior to CCl_4 in the special conditions pertaining to torpedo propulsion.

Torpedo Design

As in the other two circuits, the charging of the vessel is carried out at the forward end through stop and charging valves (Figure 21). From the vessel the gas passes to the carbon tetrachloride unit. In this unit is incorporated the oxygen delivery stop valve, the CCl_4 bottle and a non-return valve, (see Figures 22-25). The body is a high pressure casting of "SILZIN" silicon bronze (50 kg/cm^2, 71,000 lbs/in^2 tensile). Into the base of the casting a stainless steel (18/8) bottle is screwed and sweated. The outlet pipe, having two baffle plates sweated to it, is also screwed to the body and passes down to center of the bottle almost to the bottom.

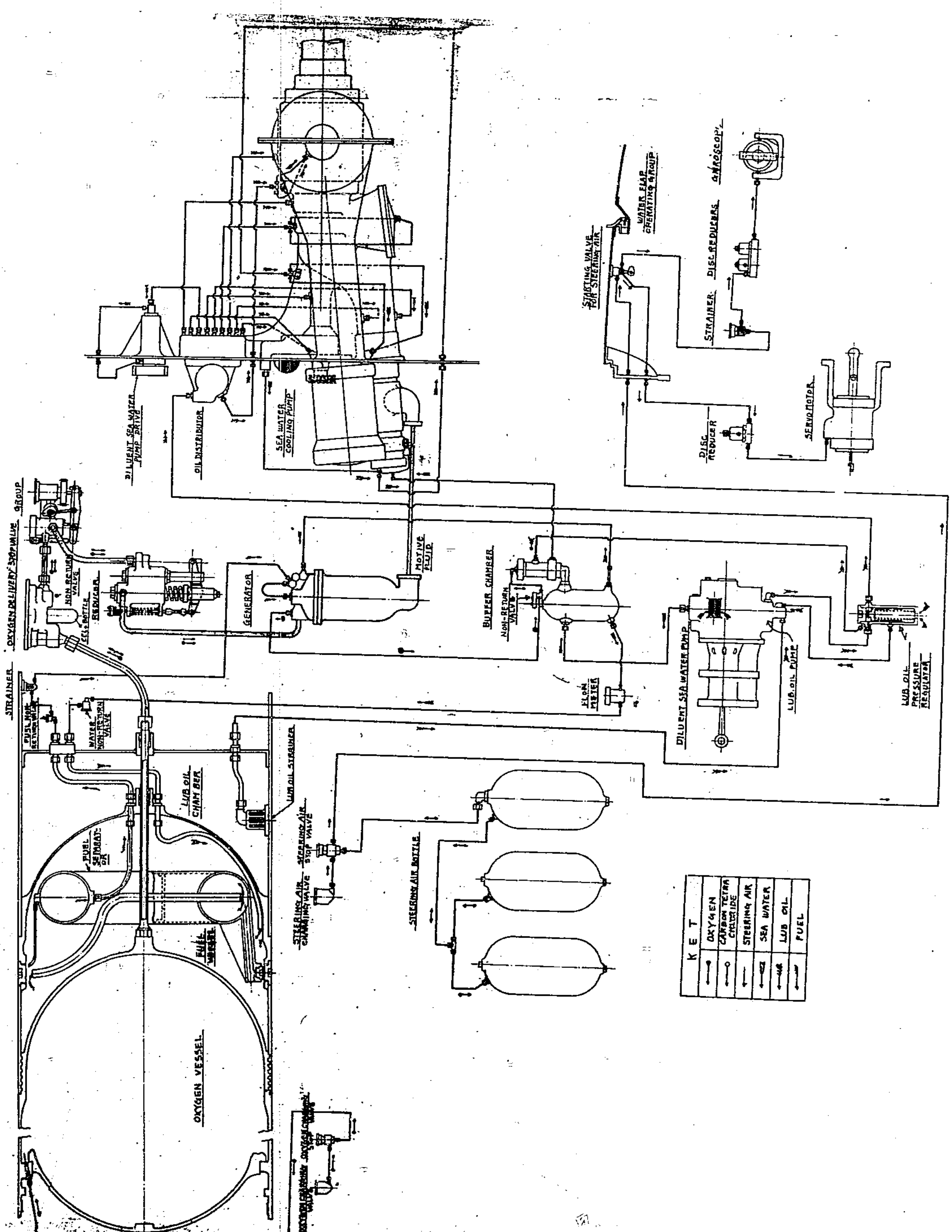


FIGURE 21
CIRCUIT DIAGRAM, TYPE 93 MODEL 13

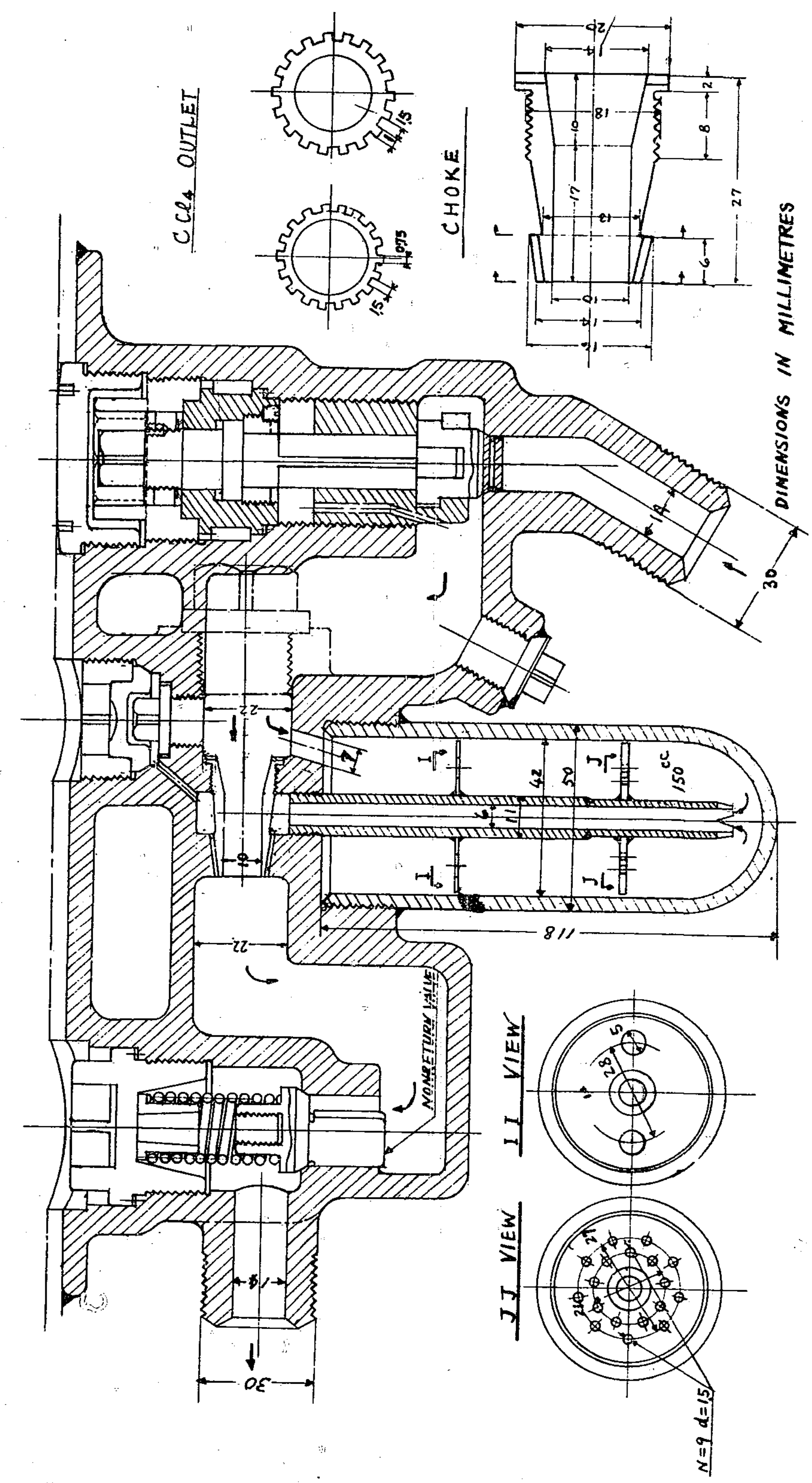


FIGURE 22
CARBON TETRACHLORIDE UNIT, TYPE 93 MODEL 3, SECTIONAL ELEVATION

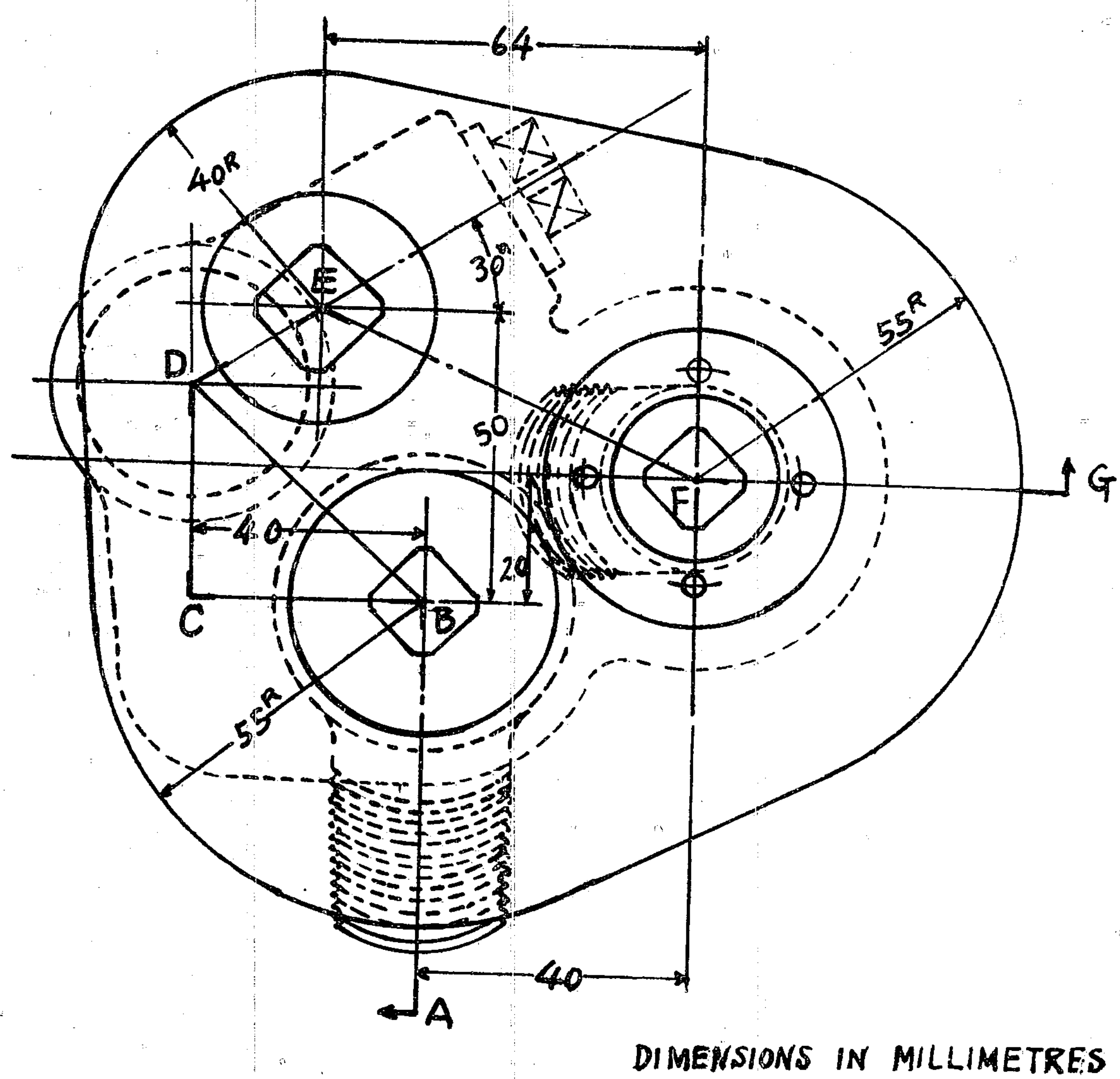


FIGURE 23
CARBON TETRACHLORIDE UNIT, TYPE 93 MODEL 3, PLAN

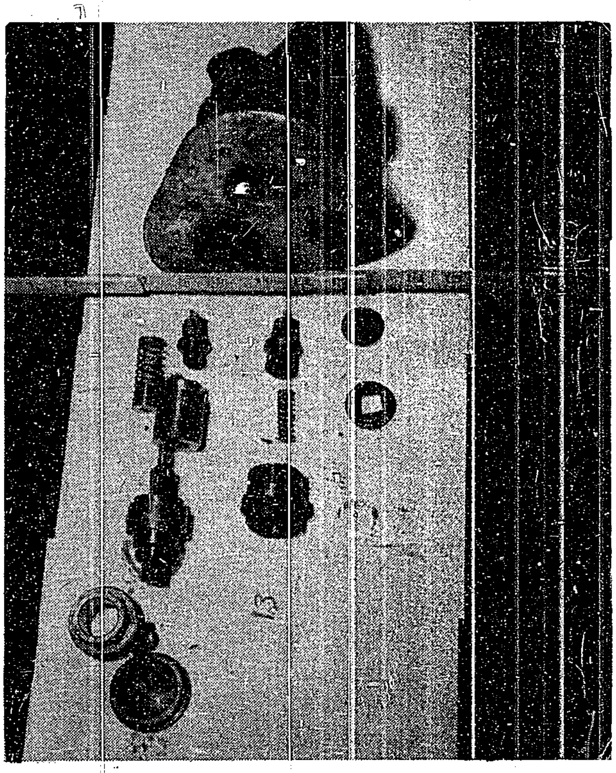


FIGURE 24
CARBON TETRACHLORIDE UNIT DETAILS

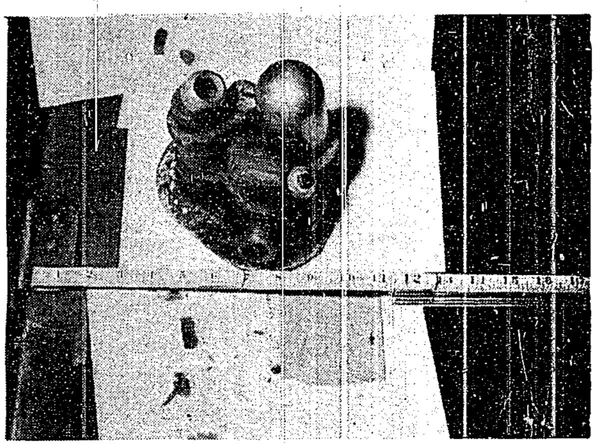


FIGURE 25
CARBON TETRACHLORIDE UNIT BODY

The choke is screwed into the body and is serrated on the external surface to break up the CCl_4 stream.

The stop valve is of the normal three-winged type with a 60° cone seat. To reduce the leakage of oxygen a special type of valve cap has been designed and is used throughout the torpedo. Below the normal screw-down cap is a conical seated valve held on its face by the pressure of the cap.

The oxygen passes through the stop valve, into the center of the unit, where it is bifurcated at the choke, the main supply passing through the center and the remainder passing into the top of the CCl_4 bottle, displacing the liquid by the pressure difference set up by the choke. The delivery rate is controlled by the pressure difference, the area of the choke having been determined by trial and error.

Finally, the oxygen and CCl_4 pass out of the unit through the non-return valve.

Since the bottle is not filled until just before the run, no attempt is made to retain the liquid. The actual filling takes place after that of the fuel bottle.

From the tetrachloride unit the oxygen passes through the group valve to the reducer and the generator. The group valve is opened by the water flap in this case.

Sequence of operations:

1. Open oxygen delivery stop valve by hand when the torpedo is in the tube.
2. Tube-operated starting lever is pulled aft, to operate group safety device. A cam on the same shaft opens the steering air starting valve.
3. Torpedo is now fired and water flap goes aft and opens pilot valve in group.

Summary

The use of the various circuits is as undernoted:

"First air vessel"
Type 93, Model 1, Modifications 1 and 2
Type 94
Type 95, Modification 1
Type 97

Steering air
Type 95, Model 2

Carbon tetrachloride
Type 93, Model 1, Modification 3
Type 93, Model 3

UNITS:

The components in the circuit such as the group, reducer, etc., are of standard design, modified to suit particular torpedoes, and are used, unless otherwise stated, in all types of torpedoes.

Group Valve

The design is similar to that used by the Whitehead Torpedo Company before the war. (See Figures 26 to 28.) It is the same as that in the

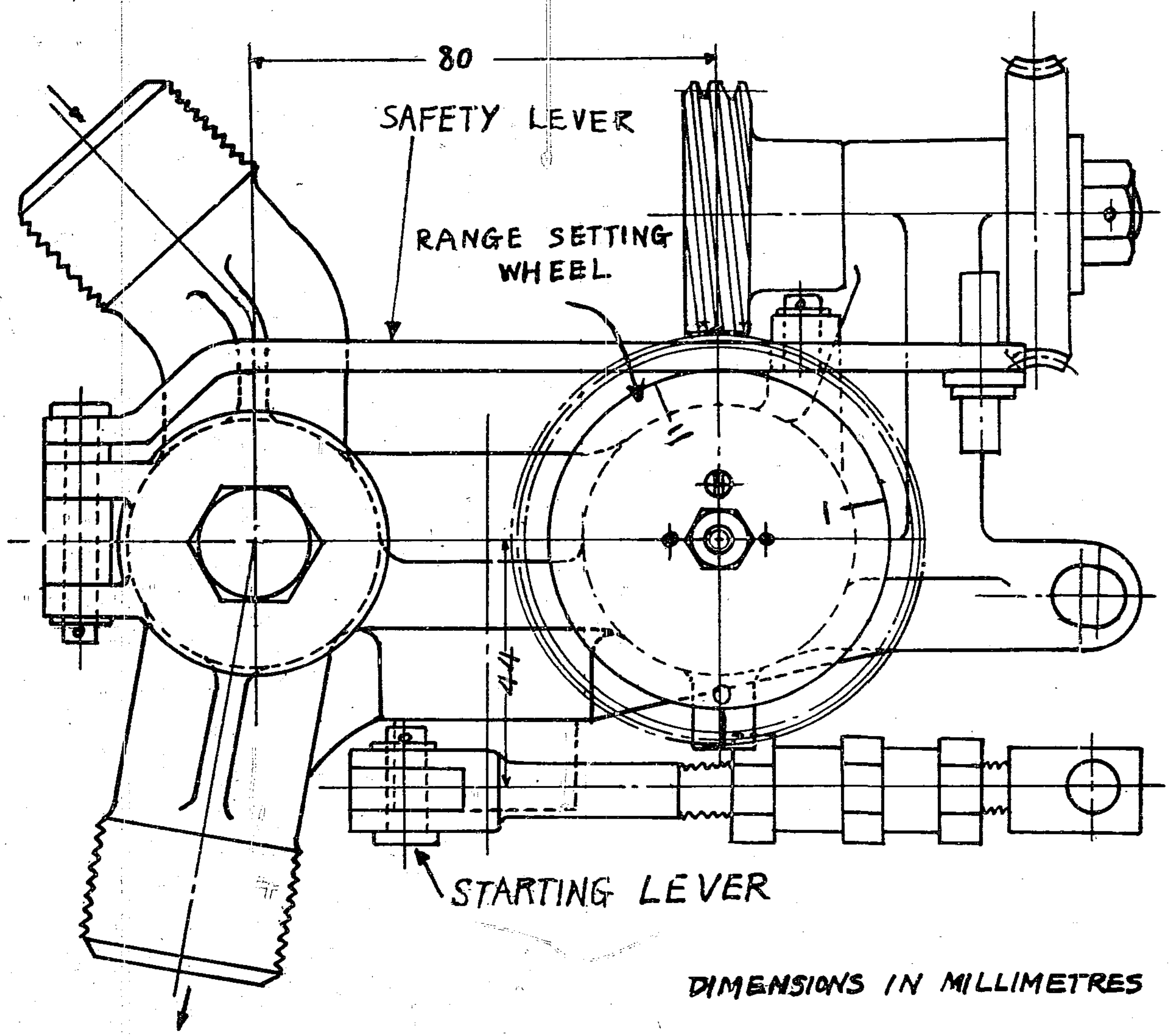


FIGURE 26
GROUP VALVE TYPE 93 (PLAN)

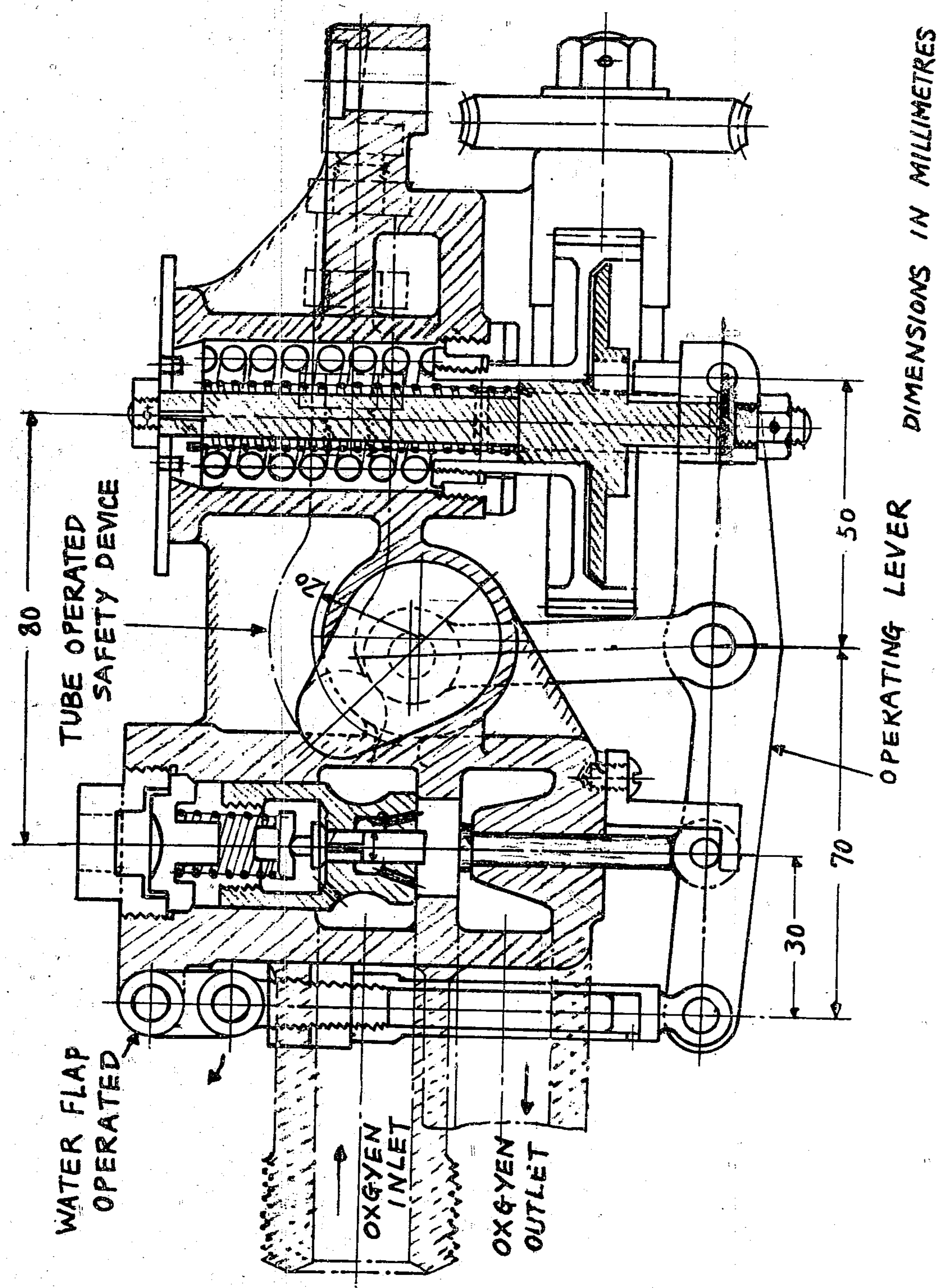


FIGURE 27
GROUP VALVE, TYPE 53 (SECTION)

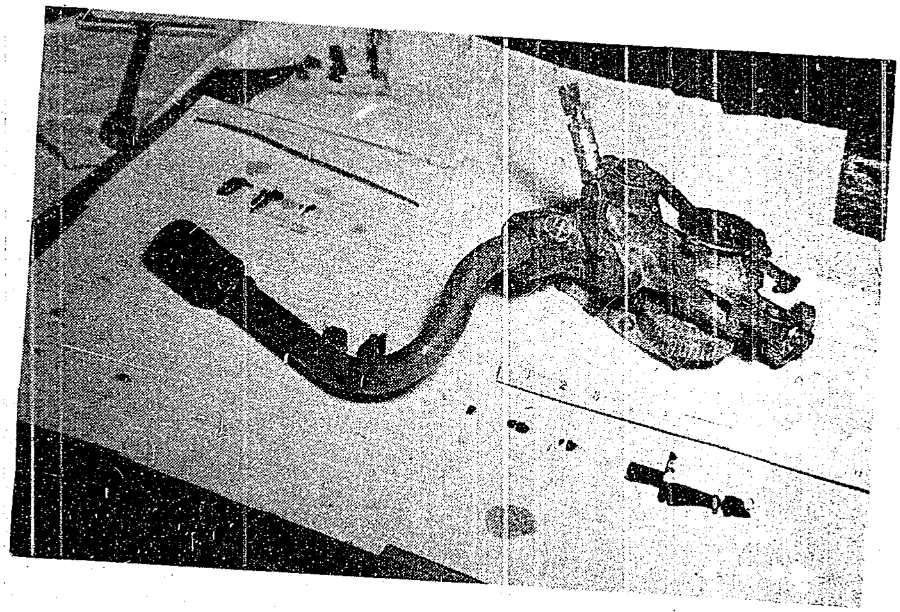


FIGURE 28
VIEW OF GROUP VALVE, TYPE 93

Type 90 and has been used for all torpedoes since 1933. Improved material (stainless steel) for the plunger has been introduced in later models. Since pure oxygen passes through the valve no oil can be used for lubrication and the valve, being left dry, sticks occasionally.

The range wheel has three settings: (1) 15,000 meters, (2) 25,000 meters, (3) 30,000 meters (for the Type 93, Model 3).

The body is a phosphor-bronze casting and contains two valves, the smaller being inside the larger. Both valves are of special aluminum bronze, the smaller being the harder. The spindle of the smaller valve is usually chromium plated but in some cases it is made of stainless steel.

The special design using the conical seat is employed for the valve cap.

Oxygen enters the group in the valve chamber; it passes up through the small orifice into the space above the valve, the pressure being utilized to keep the valve shut. When the small valve is lifted, oxygen passes through the body of the valve into the lower chamber. Since the outlet passage is much larger than the inlet, the pressure above both valves falls and the pressure around the body of the valve opens it.

The group is fitted with a tube-operated safety device. The operating lever is pivoted on a cam, the rotation of which adjusts the clearance between the push rod and the valve. When in the "safe" position the clearance is large, so that, should the water flap be knocked aft accidentally, the torpedo will not run. Just before firing (when the torpedo is in the tube) the cam is rotated so that the clearance is reduced to a minimum.

Upon firing, the water flap goes aft and opens the small valve. A friction drive is used to set the range. During the run, the plate revolves until at the required range a pin drops into a recess in the plate, allowing a spring to operate a lever which closes first the small valve and then the larger valve by the difference of pressure set up.

The main pipe diameters are 18mm (0.709") and 25mm (0.985").

Reducing Valve

A standard design has been adopted for all oxygen torpedoes. It is the same as that fitted to the Type 90 torpedo with the addition of a water bottle. (See Figures 29-32.)

The casting is of phosphor-bronze (60/40); this material is used for all details subjected to high pressure, i.e. "group", reducer, upper part of generator and engine cylinder block.

Oxygen from the group valve passes through the first reducer, through the second reducer and on to the generator. Each reducer plunger unit has an oil ~~bottle~~ and a water bottle incorporated in it. The bottles (150cc capacity) are of stainless steel and are screwed and brazed into the casting. Oxygen at vessel pressure is first admitted through drillings 0.3mm in diameter to the top of the water ~~bottles~~, displacing the water which in its turn displaces the oil, thus lubricating the plunger. The quantity delivered is controlled solely by the tightness of the lap of the plunger. The diameters of the drillings are 1mm through the plunger housing and 3mm elsewhere. The oil used consists of a mixture of two mineral oils, the proportions being altered to suit summer and winter conditions. The actual delivery is 20-30cc/min.

An extremely tight lap is used. It is difficult to insert the plunger, which is of the same general design as in British torpedoes, into the barrel. A long lap is also employed to reduce leakage.

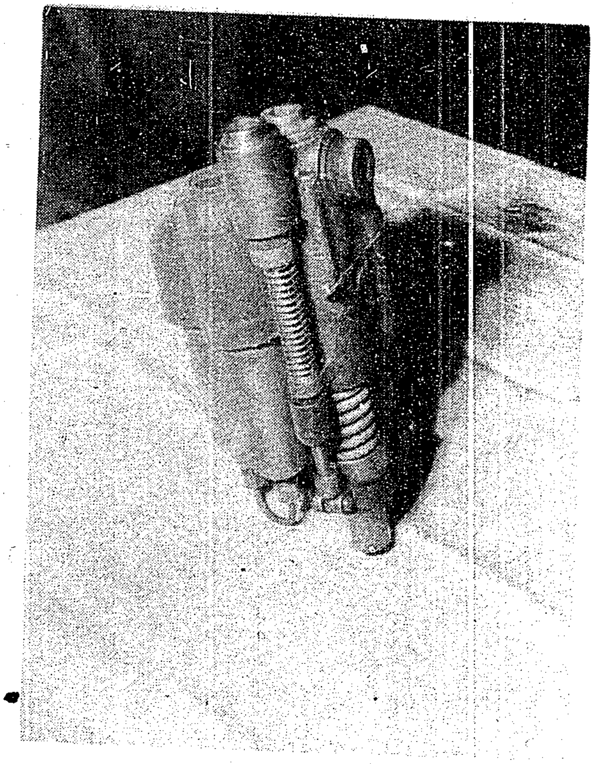


FIGURE 29
REDUCING VALVE, TYPE 93

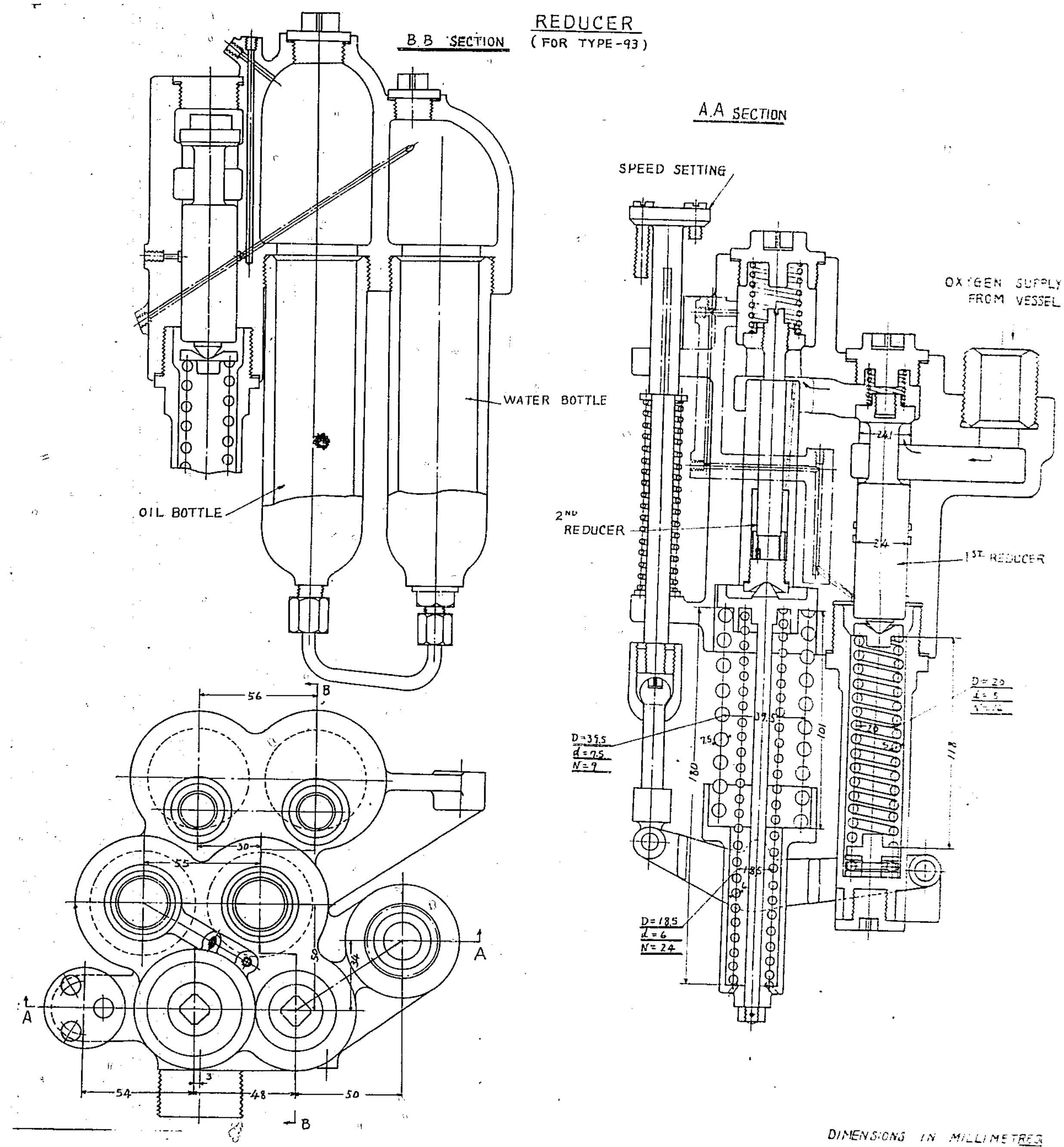


FIGURE 30
SECTION OF REDUCING VALVE. TYPE 93

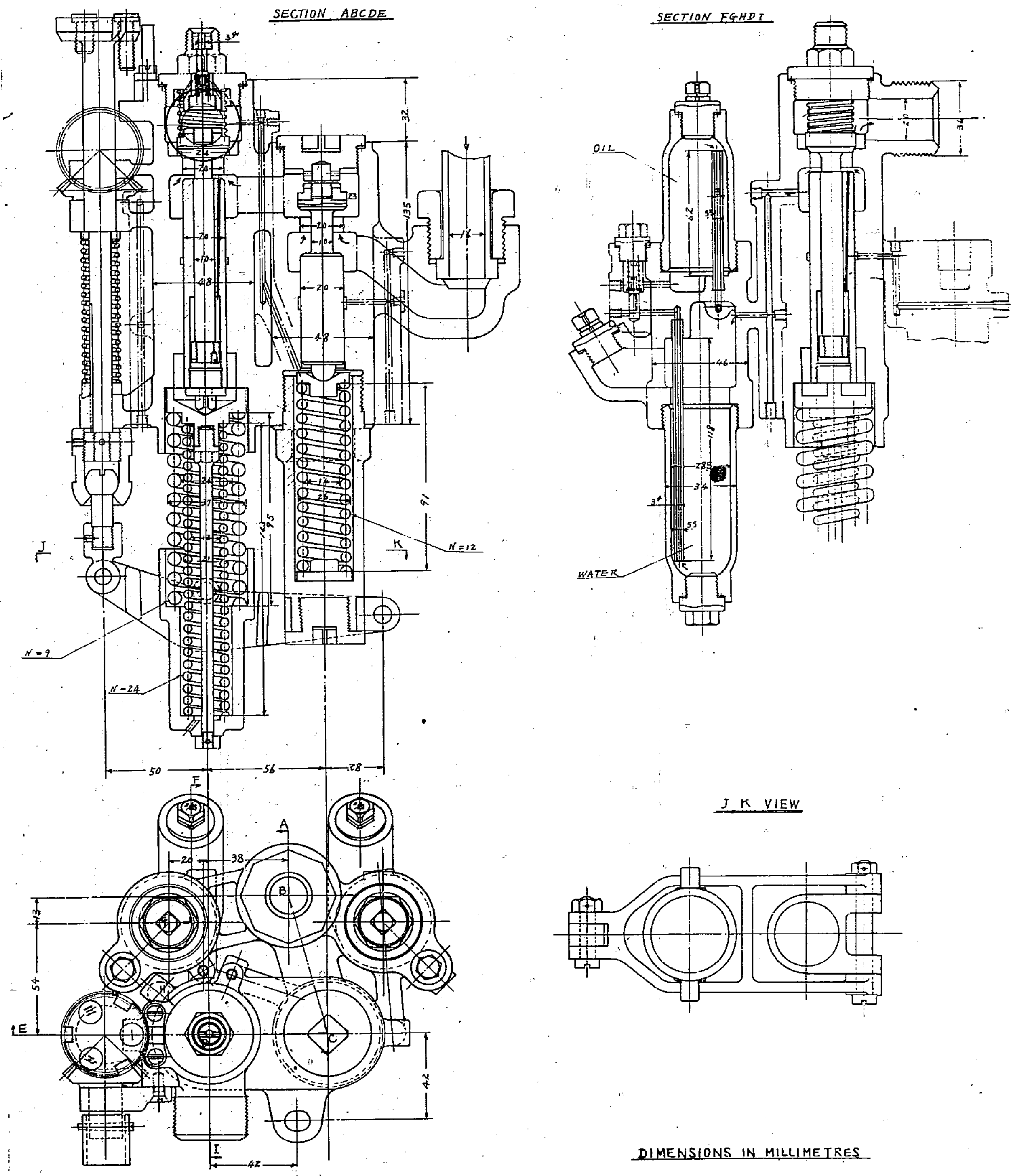


FIGURE 31
SECTION OF REDUCING VALVE. TYPE 95

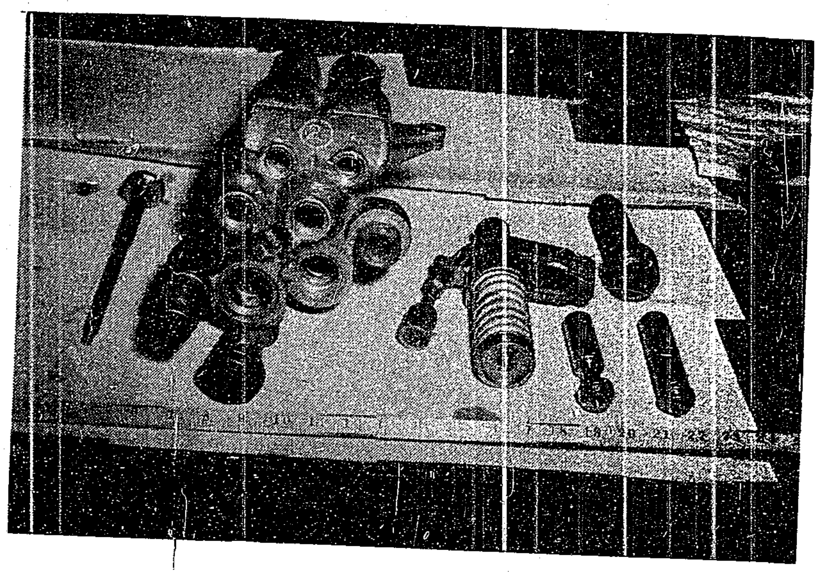


FIGURE 32
VIEW OF REDUCER DETAILS. TYPE 93

Cadmium-plated steel springs are used. In the case of the first reducer no adjustment of the spring tension is possible. The speed setting is controlled by means of a lever pivoted on the casing of the first reducer.

To ensure a slow opening of the valve of the second reducer, it is fitted with a loose sleeve having a hole drilled throughout its length to equalize to pressure.

The spring of the first reducer has a mean diameter of 20mm (0.788") and has 16 coils of 5mm (0.197") wire. The design stress is stated to be 35 kg/mm^2 (9,700 lbs/in^2).

The length of the spring under compression is 118mm (4.65"). Its free length is such that the cap thread can be started and then screwed up. A ball race is fitted beneath the cap to enable the cap to be screwed down.

The second reducer has two springs of dimensions:

	Outer	Inner
Free length	101mm 3.98 in	180mm 7.08 in
Mean diameter	39.5mm 1.55 in	18.5mm 0.73 in
Diameter of wire	7.3mm	6mm
Number of coils	9	24

The initial compression in the working condition is equal to the travel of the sleeve (20mm; 0.788").

Water Pump

The sea water is pumped to the buffer chamber by a double-acting, reciprocating pump (Figure 33) driven by the engine. Details are given in the discussion of the engine.

Buffer Chamber

This, with the generator is the most important element of the oxygen torpedo. (See Figures 34 and 35.) Its function is to maintain a steady pressure to the generator and fuel bottle by damping out the pump pressure fluctuation.

The unit consists of two parts: the water chamber, the capacity of which should be as large as possible, and the regulating valve chamber. Water from the pump is discharged into the vessel near the top and is delivered to the generator and fuel chamber from near the bottom. Oxygen at reduced pressure is supplied through a non-return valve to the top of the chamber and the regulating valve chamber. Pressure inside the vessel is therefore maintained constant, the regulating valve opening and discharging water to the engine for cooling when the pressure exceeds the reduced pressure, the non-return valve on the oxygen supply closing at the same time.

At the start of the run with the vessel full of water, water is supplied to the generator by the oxygen pressure. The capacity of the vessel is designed so that the vessel will not empty before the pump begins to deliver water. A small nozzle is fitted to the oxygen inlet supply to prevent the gas flowing back into the pump. The two parts form part of one bronze casting, the regulating valve being cylindrical in shape and spring loaded. It is lubricated by oil from the distributor.

The distribution of the water is:

	Generator and Fuel Vessel (%)	Engine Cooling (%)
High speed	60	40
Medium speed	40	60
Low speed	30	70

The capacity of the pump is stated to be 13 liters per 100 engine revolutions.

The main water supply passes from the buffer chamber to the generator when it acts as the diluent, part of it is piped to the fuel vessel when it enters at the bottom, displacing the fuel. The surplus water is fed into the engine crank case for cooling purposes.

Fuel Separator

A separator (Figure 36) is fitted only to Type 93 torpedoes to prevent water from being delivered with the fuel. (See also Figure 37.) It consists of a closed ring pipe of circular cross-section with a capacity of seven liters (fuel chamber capacity: 95 liters). Water is pumped into the bottom of the chamber. Fuel is drawn off from the top and is fed by a pipe into the bottom of the separator where it flows up the two sides of the ring, past a baffle half way up, and is delivered to the generator from the top. At the bottom of the separator is a drain pipe to the bottom of the fuel chamber, for draining at the end of the run.

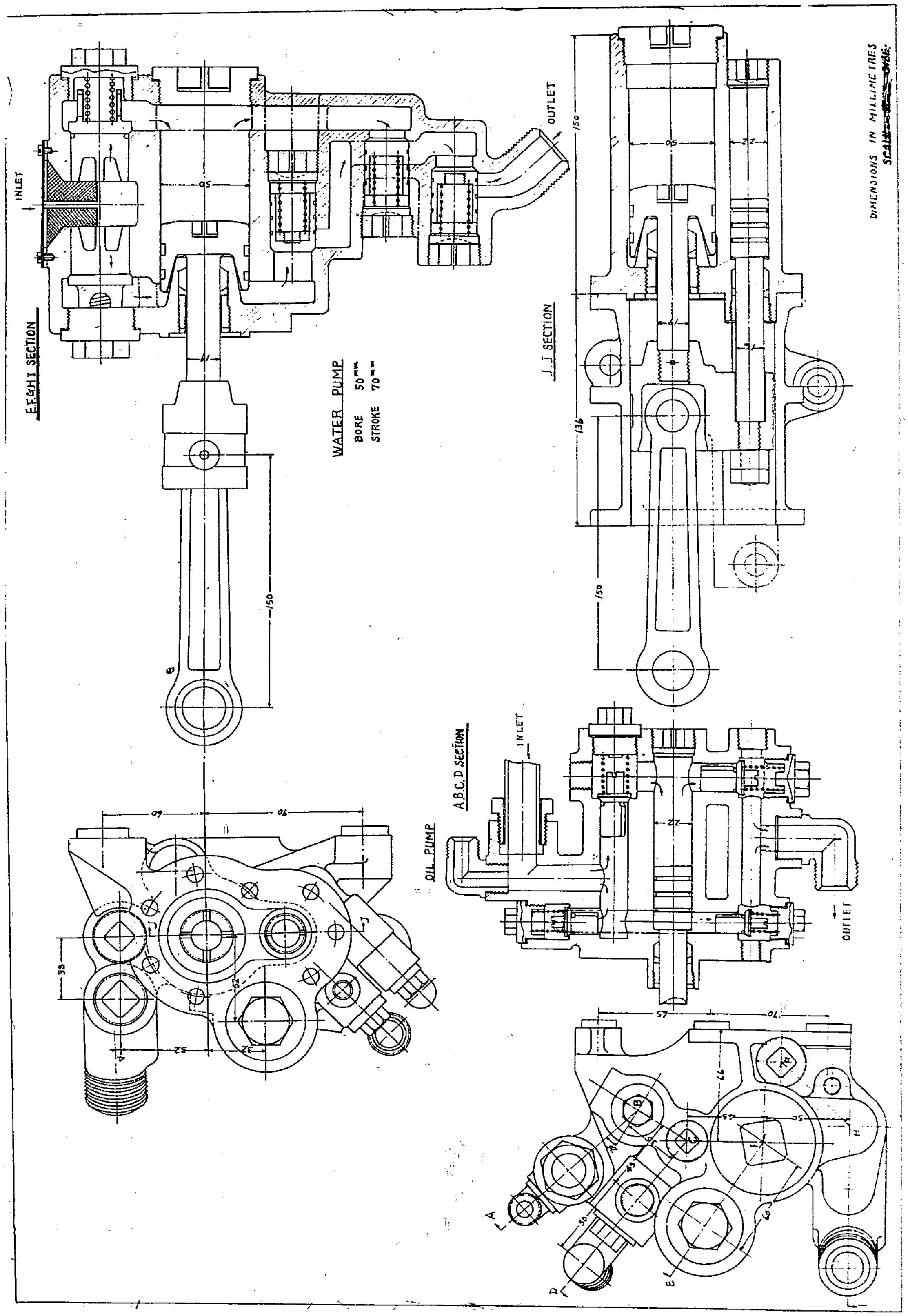


FIGURE 33
SEA WATER AND OIL PUMP SECTION, TYPE 93

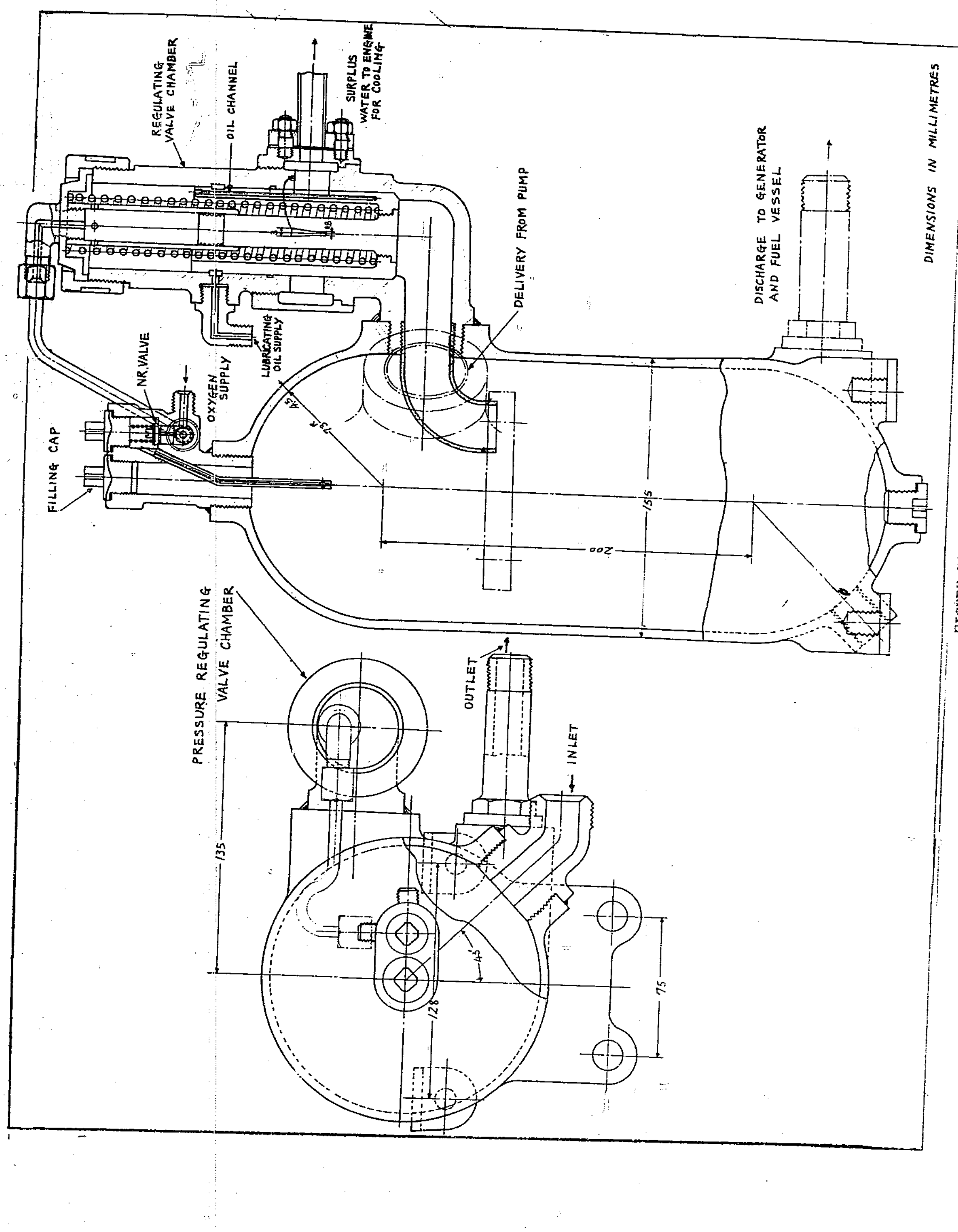


FIGURE 34
BUFFER CHAMBER PLAN AND SECTION, TYPE 93

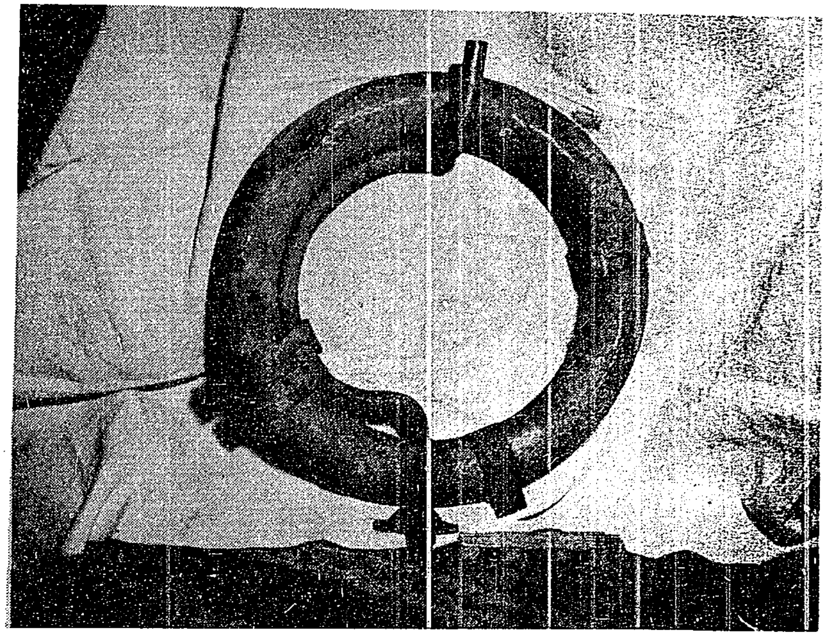


FIGURE 35
BUFFER CHAMBER DETAILS, TYPE 93

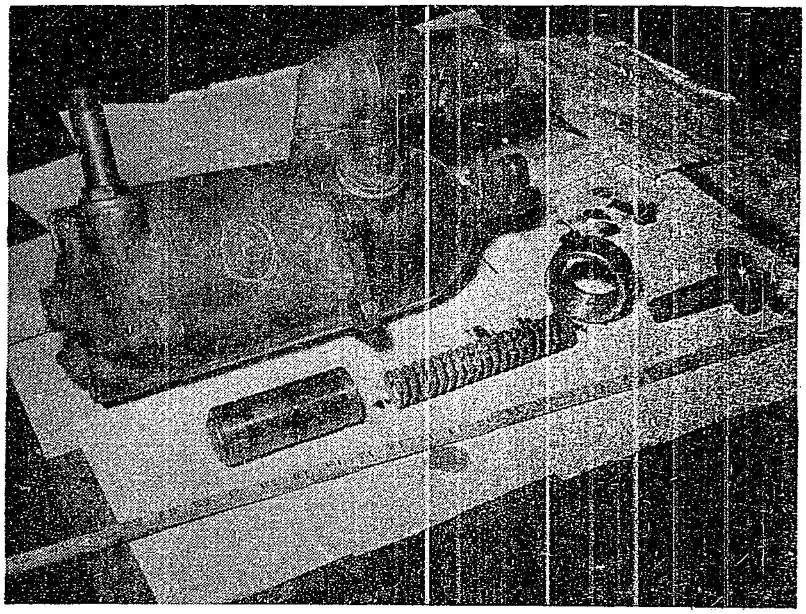


FIGURE 36
VIEW FUEL SEPARATOR, TYPE 93

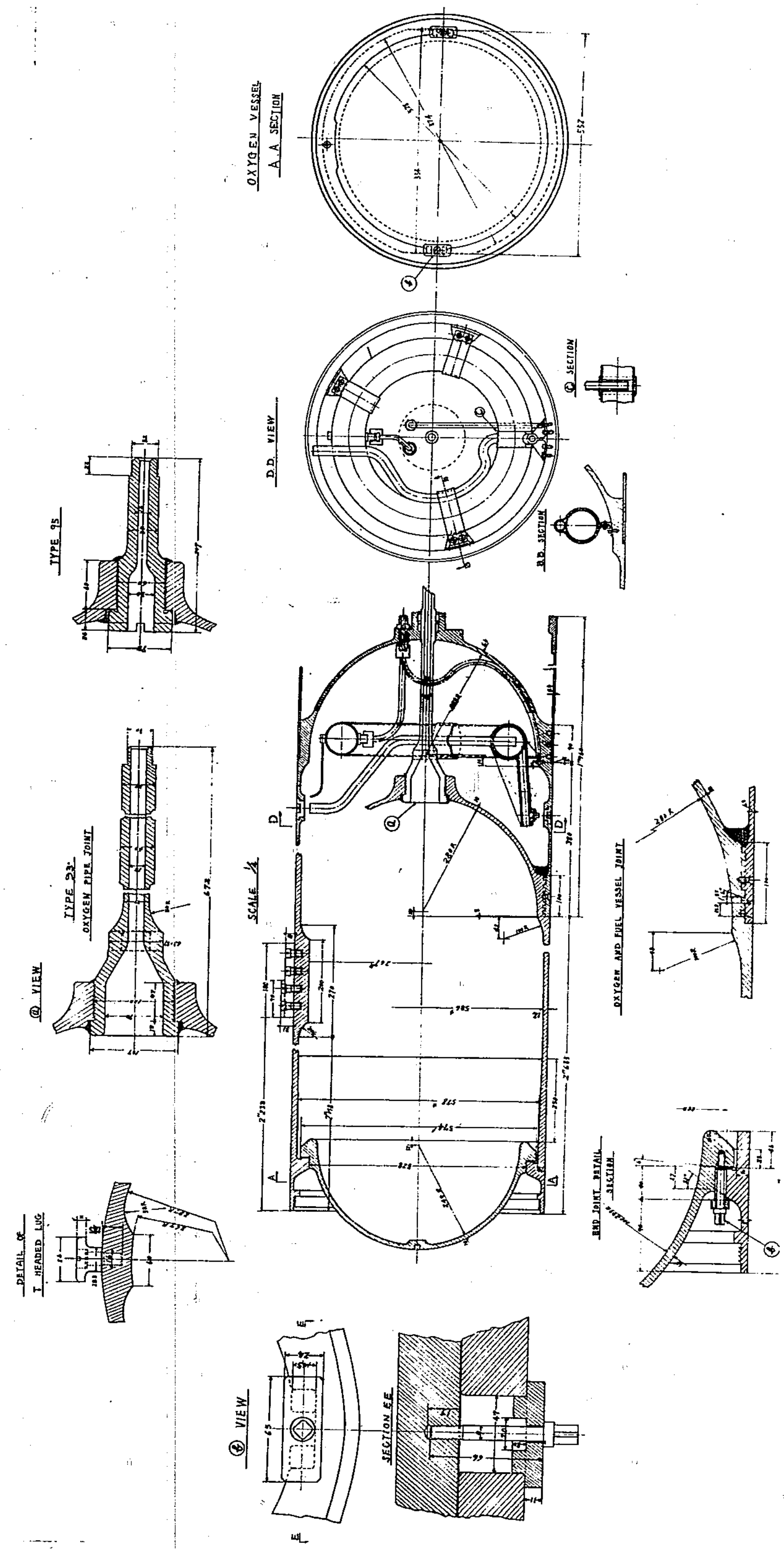


FIGURE 37
OXYGEN AND FUEL VESSEL DESIGN, TYPE 93

It was stated that the separator prevented water from being carried over with fuel at the beginning and end of the run. At the start there was a tendency for the water to be thrown to the top of the chamber due to the initial dive. It enables less fuel to be carried since the layer of fuel remaining at the end of the run can be reduced.

In earlier models a simpler from of separator was used.

From the separator the fuel passes through a non-return valve, fitted to the shell of the torpedo, and hence to the generator.

Generator

In the generator head there are three separate circuits delivering the three fluids into the combustion space. (See Figures 38-41.)

Oxygen circuit - The main oxygen supply, after leaving the choke enters the generator head at one side near the igniters, passes through a baffle plate, then through the combustion head into the combustion chamber. It was finally decided, as a result of experiments, to bifurcate the oxygen supply, 30% entering the top of the chamber and mixing with the fuel and 70% passing into the side of the generator head. The bifurcation is effected by a conical-shaped restriction in the pipe, 30% passing through the center and 70% through the outer annulus.

The pilot supply of oxygen passes from the restriction down and around the outside of the sprayer, then through holes angled towards the center, and is discharged vertically downwards into the recess at the end of the sprayer at right angles to the fuel delivery.

Fuel circuit - Fuel from the ~~bottle~~ passes through a rating device which consists of a lap fit rotary plug into which rated nozzles are screwed (one for each speed setting; three in the case of Type 93, Model 3). The rotation of the plug is effected by a lever and is interlocked with a similar plug for the water supply so that the correct W/F ratio is obtained for each speed setting.

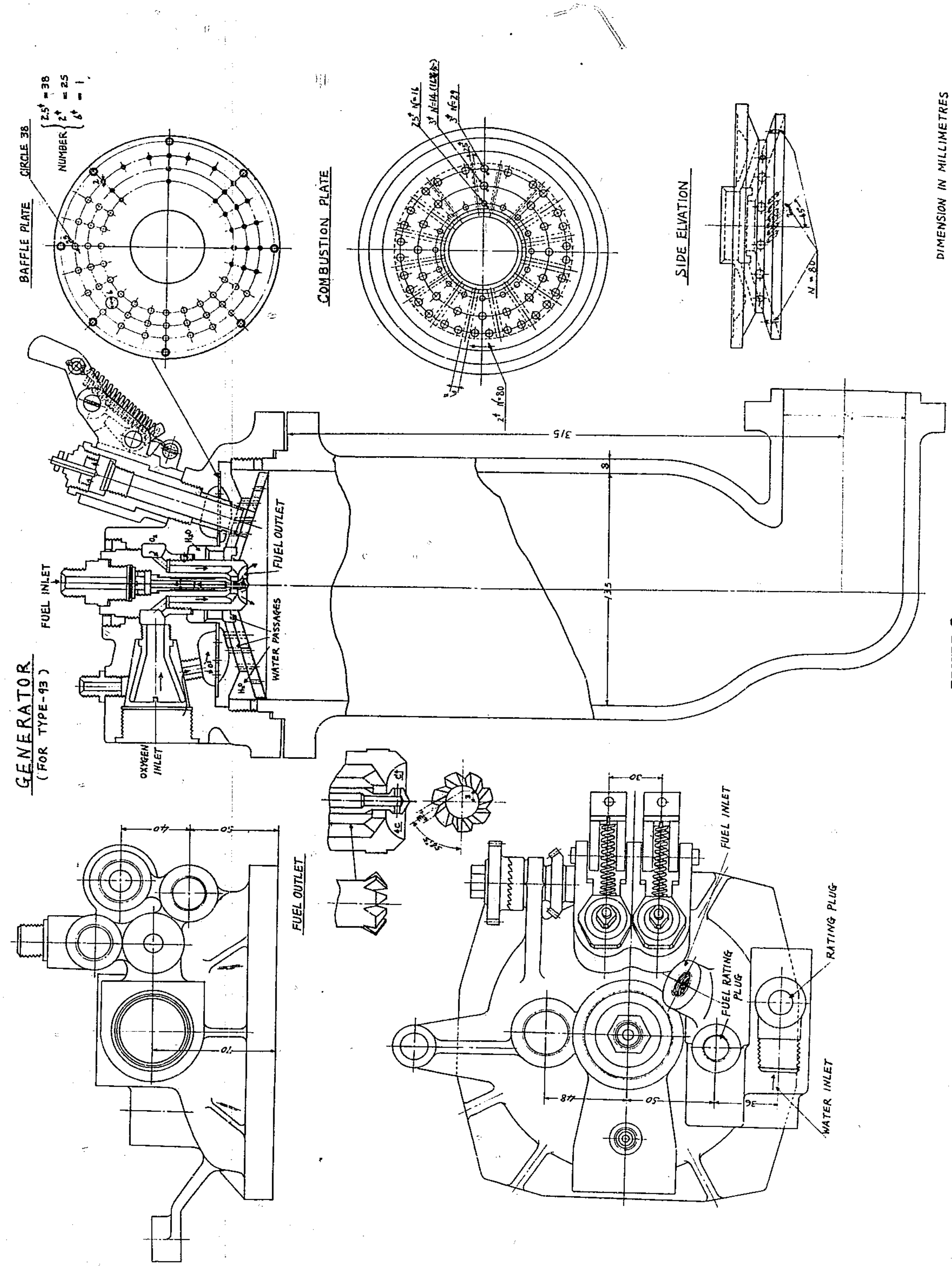
From the rotary plug the fuel is piped to the fuel sprayer which is screwed into the center of the generator head.

Since the rating device is in the rotary plug there will be no pressure head to spray the fuel. It will therefore only dribble in and depends upon the velocity of the oxygen to obtain the required turbulence.

The nozzle is made up of three parts: bronze body, steel head, and steel fuel sprayer. The bronze body screws into the generator head. Below the thread is an annulus into which the oxygen is supplied. Ten holes are drilled, angled as shown in Figure 38, to admit the oxygen around the outside of the central spindle which is bell-bottomed to form a swirler. Over the spindle the steel head is screwed down, the outside forming an annulus between it and the generator head through which flows the diluent water for cooling purposes. The bottom of the recess of the head is cup-shaped.

The fuel sprayer is screwed down the center of the body, the joint being made by a copper washer. Above the sprayer is a strainer secured by a plug with a hole through the center for the passage of the fuel. The fuel flows down the center of the sprayer and discharges at right angles to the oxygen stream through seven holes, 1mm (0.0394") in diameter, drilled radially in the head of the sprayer.

The thickness of the copper washer is adjusted to get the correct position of the discharge holes in relation to the cup.



PICTURE 38
GENERATOR (SECTION), TYPE 93

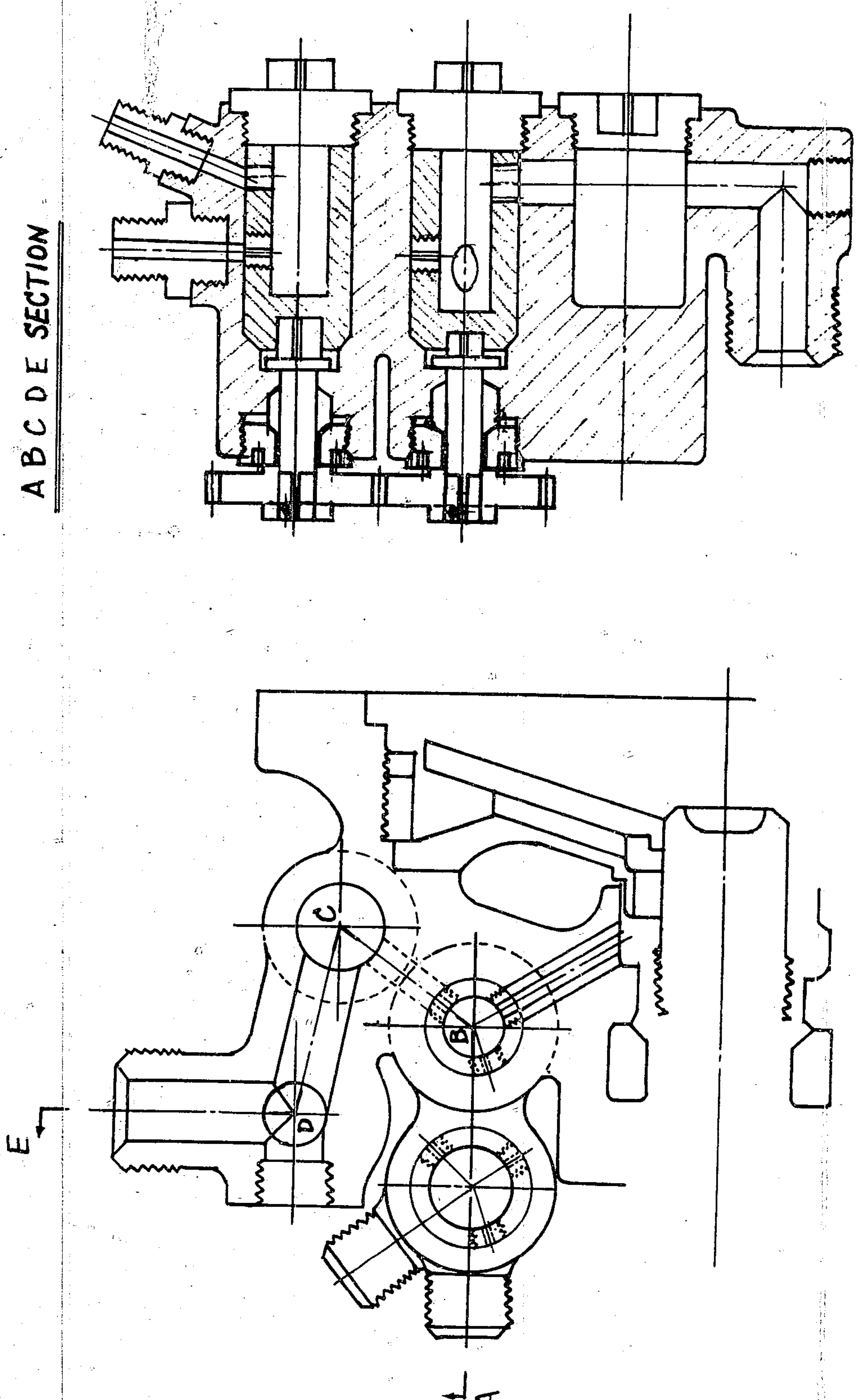


FIGURE 39
GENERATOR HEATING NOZZLES, TYPE 93

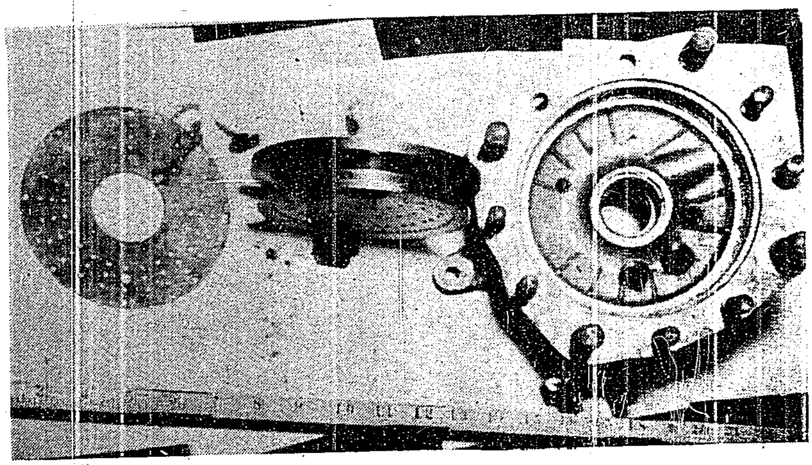


FIGURE 40(a)
GENERATOR DETAILS, TYPE 93

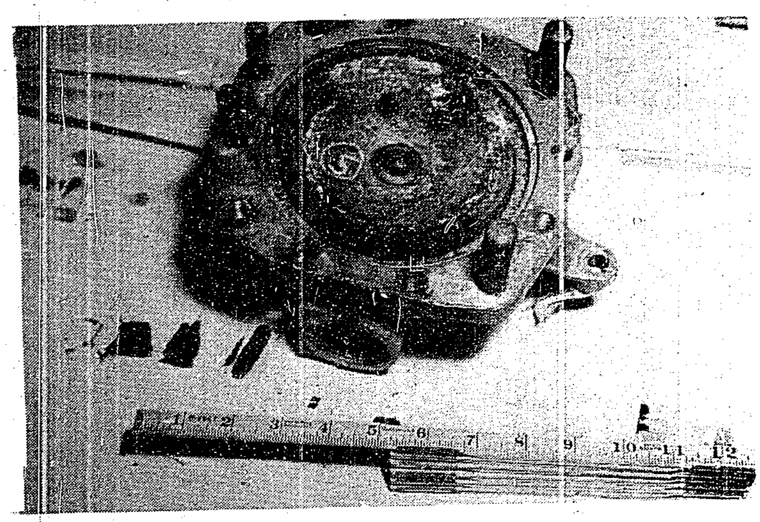


FIGURE 40(b)
GENERATOR DETAILS, TYPE 93

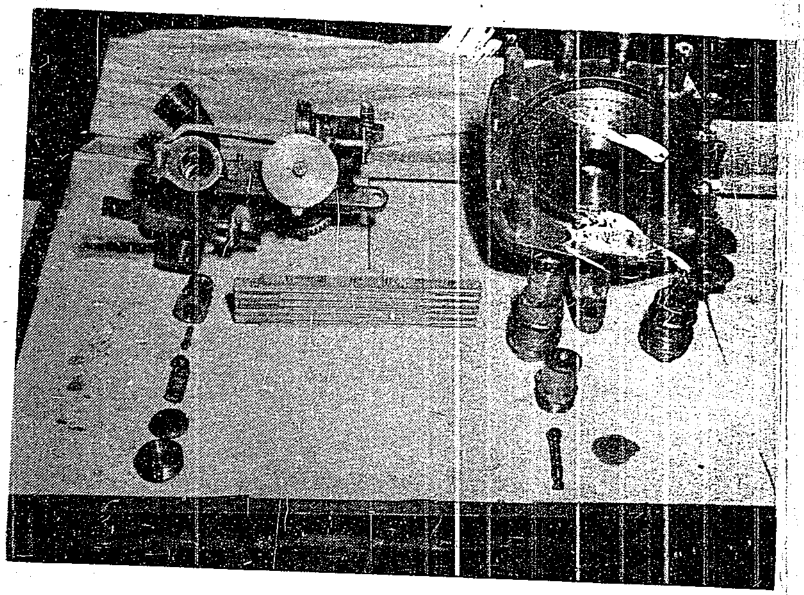


FIGURE 41
GENERATOR AND GROUP VALVE DETAILS TYPE 93

The position of the end of the nozzle and of the lip of the nozzle cup is extremely critical, and the distance should be between 1.1mm and 1.5mm (0.043" and 0.059"). If the nozzle projects too far, the combustion head will become overheated and melt; conversely, if the projection is too small, the flame will be too long and the outer casing and engine will be overheated. The number, position, and area of the holes in the combustion plates also are critical.

Water circuit - Sea water is supplied by the reciprocating pump at a constant pressure controlled by the buffer chamber. After passing through a rating plug, similar to that for the fuel (where the quantity is metered to give the correct W/F ratio), it passes through the combustion head casting to the outside of the sprayer which it cools. It then flows to a recess in the combustion plate through holes at the outer perimeter and into the combustion chamber.

Design details - The materials used for the generator unit are:

Generator head	60/40 phosphor-bronze
Outer casing, Combustion head, Fuel sprayer	Heat resisting steel, 18% chromium, 8% nickel

The generator head is a casting and is only machined where required; air, fuel, and water leads are drilled in the casting. The baffle plate is positioned by pegs on the upper side of the combustion plate, the latter being secured to the casting by a ring nut. The outer casing is bolted to the casting by studs. The two joints are made with copper washers. The unit as a whole is bolted to the engine by lugs integral with the casting.

The outlet pipe from the generator is welded to the outer casting. There is no generator-engine pipe, the flange of the outlet from the generator being bolted to the engine valve chest.

Fuel strainers are fitted (1) at the outlet from the bottle, (2) in the body of the non-return valve, and (3) at the top of the sprayer. 100-mesh gauge is used, 200-mesh having been found to be too fine.

A connection to the underside of the combustion head enabled the pressure in the space behind the combustion plate to be measured. The difference in pressure between the underside of the plate and the reduced pressure was found to be 5 kg/cm^2 at the high speed setting and was used for rating the nozzles; ultimately the pressure was dropped to 1 kg/cm^2 (14.2 lbs/in^2).

Two small igniters are fitted. The heat output was not known. The Whitehead type hammer gear, having small hammers of small weight operated by light springs, is used. No details were obtained of the energy of the blow. The firing spindle is fitted with teeth staggered so that the igniters are fired at five revolution intervals, arrangements are made to enable ignition delay to be set.

Nozzle Rating - A special bench apparatus is used. The generator is mounted in a vertical position on the bench. A water bottle is connected in turn to the water and fuel inlet unions in the generator head.

Using a pressure of 1 kg/cm^2 (14.2 lbs/in^2) water is fed to the nozzle for a period of two minutes. During this time the nozzle setting for each speed is used, and the delivery is measured by volume.

Torpedo	Nozzle	Delivery (Rate)	W/F Volume Ratios
Type 93, Model 3			
High speed	Water	54 liters	9.4
	Fuel	5.7 liters	
Medium speed	Water	30 liters	10.0
	Fuel	3 liters	
Low speed	Water	21 liters	9.5
	Fuel	2.2 liters	
Type 95, Model 2			
High and Low speeds	Water	35 ±0.1	8.7
	Fuel	4 ±0.05	

It appeared that the rating apparatus was used in connection with the experimental torpedo. Bench rating figures were obtained; the torpedo was then run and the consumption measured.

Adjustments were made on the bench and the torpedo was again run until the correct quantities were obtained. From the results, the diameters of the nozzles were measured. Production torpedoes initially were fitted with nozzles of these diameters and then ranged, adjustments being made as required from the range records. It was stated that, as a result of experience, the spread was found to be:

Diameter of Nozzle	% of Torpedoes
2.7 mm (0.0106")	80
2.8 mm (0.0110")	11
2.6 mm (0.0102")	9

When questioned as to the accuracy of the measurement, Captain WATANABE stated that no appreciable leak occurred during the run and that one non-return valve was sufficient to retain the fuel in the bottle, the quantity of fuel remaining being measured by volume.

An exact description of the method of measuring the fuel consumption is given in the section of this report on ranging of torpedoes.

Flame Test

For this test only the fuel nozzle is required. The purpose of the test is to determine the optimum shape and dimensions of the flame.

To measure the position of the nozzle in the body, a piece of wire is pushed through the outlet holes and the distance from the lip of the cup is measured with a depth gauge. At the same time the thickness of the washer is measured. Subsequent adjustment of the position is made by adjusting the thickness of the washer.

As previously mentioned, the distance between the holes in the fuel sprayer and the lip of the cup of the nozzle is extremely critical. On the correct adjustment of this distance, depends the successful running of the torpedo. If the distance is altered, the angle of entry of the oxygen stream into the generator is changed, and this greatly affects the shape of the flame. If the flame is too long, the engine will be damaged; if the flame is too broad, the perforated plate in the generator head and the sides of the generator will be burnt.

The fuel nozzle cannot be made with sufficient accuracy to keep the critical distance constant at the desired figure, about 1.3mm (0.051"). The Japanese, therefore, devised a simple test to be applied to every combustion nozzle before being fitted in a torpedo. In this test, no attempt is made to reproduce the conditions occurring in the generator during a run, but after a large number of experiments, a certain shape of flame occurring in the test is known to be the one which is produced by a nozzle that will give maximum efficiency when fitted in a torpedo.

Details of test - A specially constructed steel hut is used. The hut is roughly 8' long, 6' wide and 8' high. It is well ventilated by square apertures in the roof and walls. The flame can be observed through the apertures in the wall. The combustion nozzle is fitted in about the center of one of the end walls. A number of 1" holes are drilled concentrically around the nozzle holder to increase cooling.

Air and fuel supply - No rating plug is used, and the fuel is fed to the fuel sprayer at a constant pressure of 1 kg/cm^2 (14.2 lbs/in^2). Compressed air is supplied to the oxygen supply inlet. The pressure of this air is gradually increased from zero up to the point where the flame is finally extinguished.

Observations during test - The mixture of fuel and air is ignited, and the pressure of the air is slowly increased. The shape, dimensions and color of the flame are observed throughout the test. Considerable experience is required for the satisfactory interpretation of these observations. One measurement, however, which gives a good indication of the satisfactory adjustment of the nozzle is the pressure of compressed air required to extinguish the flame. The adjustment of the nozzle gives optimum results if this pressure is 12-14 kg/cm2 (170-200 lbs/in2). The limits of the critical distance are generally from 1.1 mm (0.043 in) to 1.5 mm (0.0591 in).

Below are shown a number of experimental results for various positions of fuel sprayer:

Distance between fuel holes and the lip of the nozzle cup		Air pressure to extinguish flame.		Remarks on flame
mm	in	kg/cm^2	lbs/in^2	
0.3	0.0118	20	284	Flame very broad. Length of only about 6".
0.9	0.0354	50	710	Above air pressure of 22, flame became very short, intense, noisy and blue at base.
1.0	0.0394	22	312	Shorter and broader flame than that considered satisfactory.
1.1	0.0433	20	284	At this figure, begins to approach the shape of the best flame. About 2' wide and 7' long.
1.3	0.0512	14	198	Satisfactory flame. About 9' long and 2' wide.
1.5	0.0591	13	185	Satisfactory flame. As for setting of 1.3.
2.3	0.0906	12	170	Fairly satisfactory flame, but slightly narrower and longer than for 1.3 and 1.5.
3.0	0.118	10	142	A long flame tending to remain alight at the end.
3.5	0.138	11.0	156	Very long narrow jet alight at end only.
4.0	0.158	13.0	185	Extremely long jet alight at end only.

The observations of the flame were made, unless otherwise stated, just before the extinguishing pressure was reached.

It will be noticed that advancing the sprayer in the cup has a much greater affect on the flame shape than when the sprayer is withdrawn into the steel head. In the latter case, the "cupped" sides of the steel head are the determining factor in the shape of the flame. In the former case, however, when the sprayer is near the "lip" of the "cup", end-effects appear, and small movements of the sprayer greatly affect the shape of flame. From this, it would appear that a combustion head could be designed with the fuel sprayer fixed so deeply in the "cup" that small movements relative to the "lip" would not affect the shape of the flame. By this means, perhaps, the nozzle test would not be necessary.

Oxygen and Fuel Vessels

Design of Oxygen Vessel

Oxygen Vessel Body

The oxygen vessel bodies of earlier types of torpedoes consisted of a forged steel body with hemispherical ends. In the Type 93, Model 1, Modification 2 and subsequent torpedoes, the body and after end were forged in one piece.

The leading particulars of the vessel of the Type 93, Model 3 torpedo which was designed in 1943 are:

Diameter	mm	610	in	24
Length	mm	2688	in	105.9
Weight	kg	700	lb	1540
Volume	liters	750	ft^3	26.25
Wall thickness	mm	12	in	0.473
Working pressure	kg/cm^2	200	lb/in^2	2844
Weight of charge	kg	200	lb	440
Ratio of steel/oxygen (wt.)	kg	3.5		

The design is shown in Figure 37. The body has a shoulder at the forward end, for making the forward joint, with a shell thickness of 16mm (0.63"), tapering off to 12mm (0.473") in a length of 70mm (2.76"). There is a strengthening band at the point where the T-headed lug is screwed to the external surface. In above-water tubes, the last three lengths of the guide strip, into which the lug fits, are detachable so that the release of the torpedo can be controlled. The fuel container which is of the same general form, having an integral after end, is screwed to the after end of the main vessel just before the start of the reduction in diameter; a square-shaped thread undercut on one side is used.

At the center of the after end the oxygen lead is taken from a machined boss.

On the forward end a bayonet type joint ring is screwed on for securing the warhead to the vessel.

After End

In the Type 93, 95 and 02 torpedoes the boss in the after end has an internal thread in the bore through the center of which the discharge pipe is screwed from inside the vessel.

In the Type 93 torpedo a hexagon is machined on the pipe so that the pipe can be tightened from outside the vessel (see Figure 42). A flat face is turned on both the pipe collar and the oxygen vessel boss, the joint being made by the lead fillet. An alternative design, not introduced into service, was to make the pipe a push fit in the bore and tighten up the joint by a nut outside the oxygen vessel. It was stated that this new method was superior because it was possible to apply much greater force in tightening the nut.

In the Type 95 and 02 torpedoes the pipe is tightened by a peg spanner fitted into slots in the pipe collar. In addition, a knife-edge is turned on the collar to make the joint. A final sealing against small gas leaks is made by running a lead fillet between the collar of the pipe and the oxygen vessel shell.

Forward End

The forward end of the vessel is turned with a plain joint face. (See Figure 43.) The end, with two flats on the flange, is inserted into the body sideways through two diametrically opposed slots cut in the shoulder of the vessel body. The actual joint is made by a plain copper washer, the end being bolted to the flange by a number of screws around the circumference in the case of Model 1 and only two screws in the Model 3. Water glass is used in making the joint, the washer being coated with it. The general design is shown in Figure 37.

The object of fitting the end inside the vessel is to utilize the gas

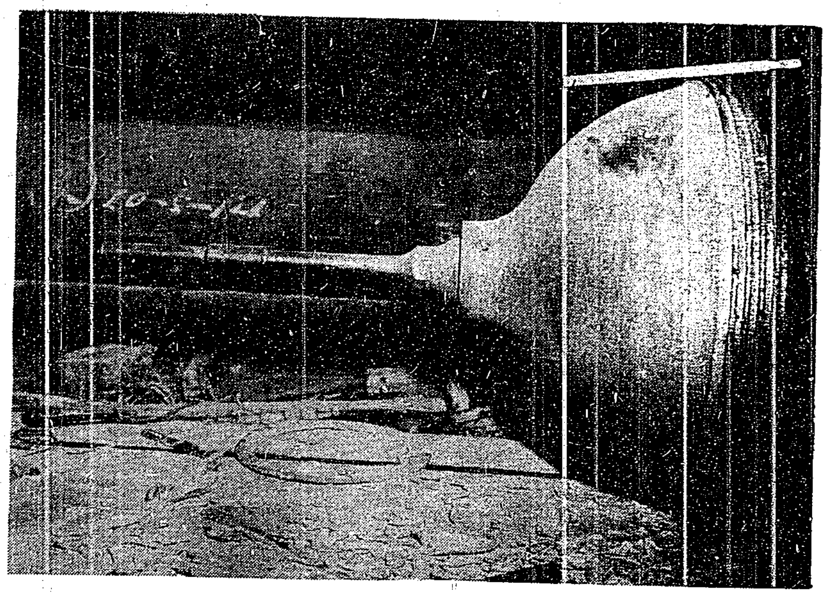


FIGURE 42
AFTER END OF OXYGEN VESSEL, TYPE 93

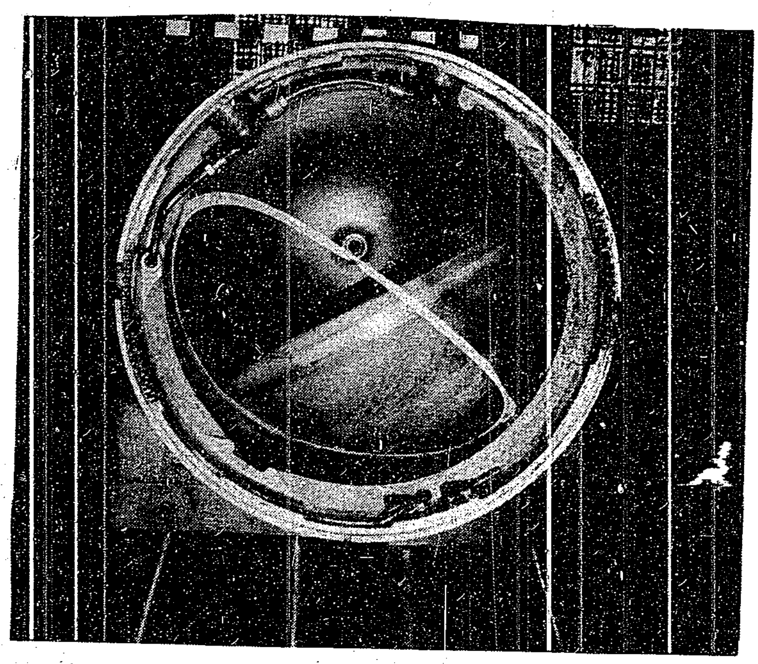


FIGURE 43
FORWARD END OF OXYGEN VESSEL, TYPE 93

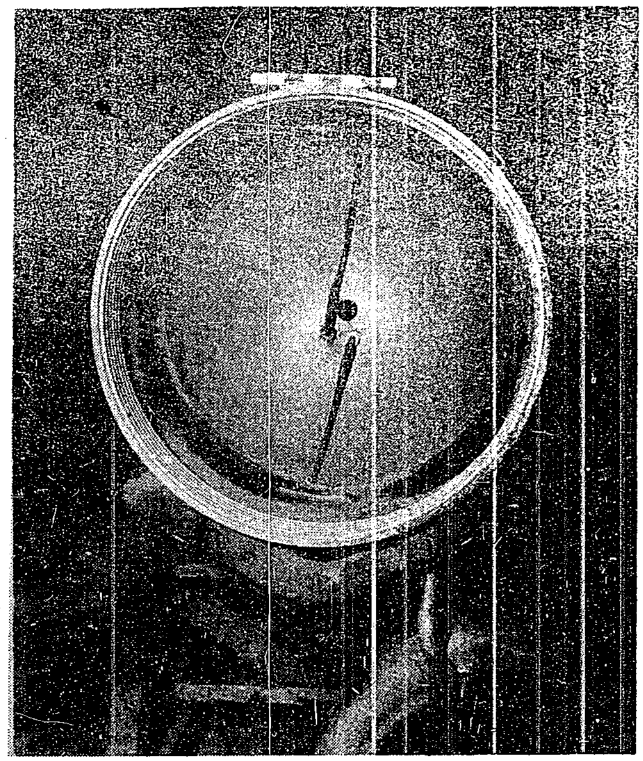


FIGURE 44
FUEL VESSEL. TYPE 93

pressure in making the joint, the leaks decreasing with increase in pressure. For the Type 93 with a gas pressure of 225 kg/cm^2, the pressure on the joint face is 20,700 lbs/in^2 (9.25 tons/in^2). At low pressure (30-40 kg/cm^2; 430-570 lbs/in^2) a joint of this type is liable to leak, but it is claimed that at high pressures no leakage occurs and that the pressure will be maintained for at least six months after charging. Experience in the ranging indicates that this is probably correct. A similar design of end is used by the U.S. Navy. It has the advantage of ease of manufacture and ease of remaking the joint.

<u>Safety Factor</u>

It was stated that a general safety factor of 1.5 was used for both the body and the ends.

From the formula used in British design:

$$p = \frac{2t \times B}{D}$$

Where

p = bursting pressure (lbs/in^2)

t = thickness of the wall (inches)

B = tensile strength (lbs/in^2)

D = mean diameter of shell (inches)

The safety factor for this vessel is 2.19.

The vessel was designed originally for the Type 93, Model 1 torpedo in which the pressure was 225 kg/cm2 (3200 lbs/in^2). Using this figure and the yield point in place of the ultimate the factor becomes 1.77.

The actual safety factor can be derived from:

$$\frac{\text{Bursting pressure}}{\text{Working pressure}} = \frac{6550}{2844} = 2.3$$

In view of recent information on the failure of vessels due to repeated charging and discharging, it is considered that the safety factor based on the repeated test pressure, i.e. 3550/2844 = 1.25 (see subsequent data on test pressures), be taken into account in estimating the strength of a vessel. A number of experiments to determine the relation between bursting pressure and pressure cycles would be required. From the information obtained by the Japanese (see subsequent data on test pressures) tests on the effect of size would be needed in addition.

From the equation, a second term to take into account the effect of "topping up" could be added to the present formula which will have the form:

$$p = \frac{2t \times B}{D} - KX^n$$

Where

X = number of cycles

K = constant

K and n being determined from the repeated test pressure curve for the vessel and will be dependent on the volume.

Design of Fuel Vessel

The design of the fu·l vessel is similar to the design of the oxygen vessel except that there is neither a strengthening band nor a shoulder for making the end joint(see Figure 44). It is screwed on by a square thread undercut on one side to .e oxygen vessel, the joint being finally sealed by lead fillet.

The balance chamber is secured to the fuel vessel by screwed and sweated rivets.

The thickness of the vessel is reduced from 12mm (0.473") to 6.5mm (0.256") since the vessel is only subjected to the pressure in the circuit after the reducer.

The oxygen supply pipe passes through the vessel at the boss at the center, together with the water inlet and fuel outlet pipes. The joint for the oxygen pipe is a gland packed with a leather washer in the Type 93, Model 3, and with a white metal washer in the Type 95. The pipe is straight, no allowance being made for expansion. It was stated that no leaks into the balance chamber had occurred.

Materials

Details of both the specification and sample analysis for the oxygen vessel steel of the 24" Type 93 torpedo were obtained from the metallurgical section of the Kure Dockyard. This section carried out research in, and manufactured steel forgings for gun barrels as well as torpedo vessels.

Chemical Composition

Body Forging

The undernoted three specifications for chemical analysis were used; No. 1 was in use before and at the beginning of the war, No. 2 in the later stages, and finally No. 3 was used. The changes were necessary due to a shortage of nickel.

	No. 1	No. 2	No. 3
Carbon	.3%	.3%	.3%
Silicon	<.3%	.3%	.3%
Manganese	.5%	.7%	1.0%
Phosphorus	<.035%	< .035%	<.035%
Sulphur	<.035%	< .035%	<.035%
Nickel	2.7%	1.7%	1.0%
Chromium	.8%	1.2%	1.0%
Copper	<.2%	1.0%	<.4%
Molybdenum	.5%	.4%	.4%

It will be noticed that there is a steady decrease in the percentage of nickel and an increase in the percentage of chromium. Apparently no change was made in the acceptance tests for mechanical properties, the required figures being obtained by additional heat treatments. Composition No. 1 was stated to be that of "VIBRAC", proprietary steel.

Fuel Vessel

The chemical composition differs slightly from that of the oxygen vessel:

Carbon	.4%
Silicon	<.3%
Manganese	1.0%
Phosphorus	<.035%
Sulphur	<.035%
Nickel	.5%
Chromium	1.0%
Copper	<.4%
Molybdenum	.2%

As the war progressed the average percentage of nickel was decreased.

Mechanical Tests

Two tensile and Izod sets of test pieces were machined from a ring parted off the forward end of the forging and a third set was machined from the after end.

Body Forging

The specification and sample analysis were as follows:

	Specification		Sample Test	
	Top	Bottom	Top	Bottom
Yield point kg/mm2	>100	>100	105	105
tons/in2	> 63.4	> 63.4	66.7	66.7
Ultimate strength kg/mm2	>110	>110	115	115
tons/in2	> 69.8	> 69.8	73.0	73.0
Reduction in area %	30	-	40	-
Elongation %	>15	> 7.5	16	10
Gauge length mm	50			
Izod ft/lbs	>22	>11	25	15
Hardness Brinell	320-385	320-385	325	325

During one interrogation Engineer OHATA stated that the mechanical test results usually were low on ultimate strength and rarely came within the specification. Retreatment of 20% of the oxygen vessel forgings was required. If the results of the first test were outside the limits, the second specimen was tested, and if the results were within the limits, the forging was accepted.

Forward End

The specification and sample analysis were as undernoted:

	Specification	Sample Test
Yield point kg/mm2	>85	90
tons/in2	>54.0	57.1
Ultimate strength kg/mm2	>95	105
tons/in2	>60.3	66.7
Elongation % Gauge length 50mm	17	20
Reduction in area %	>35	40
Izod ft/lbs	>30	35
Hardness Brinell	280-360	320

Fuel Vessel

One tensile and one Izod test piece were machined from a ring parted off the open end of the forging.

The specification and sample results were quoted as follows:

	Specification	Sample Test
Ultimate strength		
kg/mm^2	95	100
tons/in2	60.3	63.5
Elongation % Guage length 50mm	12	15
Hardness Brinell	280-385	310

Working Tolerances

The staff of the metallurgical department gave vague replies when questioned on the subject of tolerances. Ultimately it became clear that a forging was accepted on the results of the mechanical tests and that the chemical analysis was disregarded if the former were within limits.

Manufacture

Oxygen Vessel Body

Melt

Either an acid open hearth furnace (capacity about 50 tons) or a "Heroult" type basic electric furnace of 30 tons capacity is used.

The particulars of the ingot are :

Weight	8.5 tons
Length	2228mm (7.31 ft)
Maximum diameter	1730mm (5.7 ft)
Minimum diameter	630mm (2.1 ft)
Shape	Octagonal

Forging

The first heat treatment takes place in a car-type producer gas furnace for a period of 10 hours for the last four of which the temperature is maintained at 1250ºC. The ingot is next forged by a 2000 ton press into an approximate circle, 20% being cut off the top end and 5% off the bottom.

The second heat treatment is carried out in the same type of furnace but lasts only for six hours, the last two being at a temperature of 1250ºC.

The 4000 ton press is used next to form a hollow cylinder weighing six tons and having dimensions:

Length	4495mm (14.76 ft)
External diameter	660mm (2.17 ft)
Internal diameter	475mm (1.56 ft)

Annealing

Annealing takes place in a car-type furnace and lasts 38 hours; 8 hours to heat up to a temperature of 700ºC, 10 hours at the maximum temperature and about 20 hours cooling down to 300ºC. The forging is then removed and allowed to cool in open air.

Rough Machining

Rough machining is done in a lathe and boring machine. The external diameter is reduced to 621mm (24.5") and the bore increased to 500mm (19.7").

Heat Treatment

Harden	2.5 hours at 830°C Quench in rape seed oil
Temper	4 hours at 580°C Quench in oil

Forward End

Melt

The "Heroult"-type basic electric furnace of six tons capacity was used.

The ingot produced had particulars:

Weight	55 tons
Length	750mm (28.8")
Maximum diameter	350mm (13.8")
Minimum diameter	308mm (12.1")

After annealing at 800°C, the top end is cut off.

Forging

The reheat requires six hours, two at 1250 C in a car-type furnace. The forging is carried out in a die with a punch in a 2000 ton vertical press.

Maximum diameter	600mm (23.6")
Minimum diameter	470mm (18.5")
Depth	336mm (13.2")
Shape	Hemispherical, flanged at top

Annealing

This is the same as for the oxygen vessel body.

Rough Machining

The forging is now turned in the lathe to the following dimensions:

External diameter	590mm (23.2")
Minimum diameter	480mm (18.9")
Depth	289mm (11.4")

Heat Treatment

The heat treatment after machining is:

Harden	2 hours at 830°C Quench in oil
Temper	4 hours at 600°C Quench in oil

Fuel Vessel

Melt

"Heroult"-type furnace is again used (capacity six tons). An ingot weighing 1.6 tons is produced having dimensions:

Length	1030mm (40.7")
Maximum diameter	530mm (20.9")
Minimum diameter	500mm (19.7")
Shape	16-sided

The top end is cut off in the same way as that of the air vessel end.

Forging

The reheat takes place in the car-type furnace; it requires six hours of which two hours are at 1250°C.

Deep pressing is done in the 4000 ton press. The dimensions of the forging are:

Length	1070mm (42.2")
Outside diameter	650mm (25.6")
Inside diameter	520mm (20.5")

Annealing

The same as for the air vessel body and end.

Rough Machining

The forging is turned to the undernoted sizes:

Length	855mm (33.7")
Outside diameter	621mm (24.5")
Inside diameter	558mm (22.0")

Heat Treatment

After machining the heat treatment is:

Harden	2 hours at 830°C Quench in oil
Temper	4 hours at 600°C Quench in oil

Workshop Equipment - 4000 Ton Press

The outstanding feature of the manufacture of the vessel was the use of a 4000 ton horizontal press (see Figure 45-48). This press is of Japanese design and manufacture and is copied from a "Hadfield" design. It was first used in 1935 to speed up manufacture by enabling the forging to be produced in one operation; with smaller presses five operations had been necessary. In practice it was found that frequently two operations were required.

A general view is given in Figure 45.

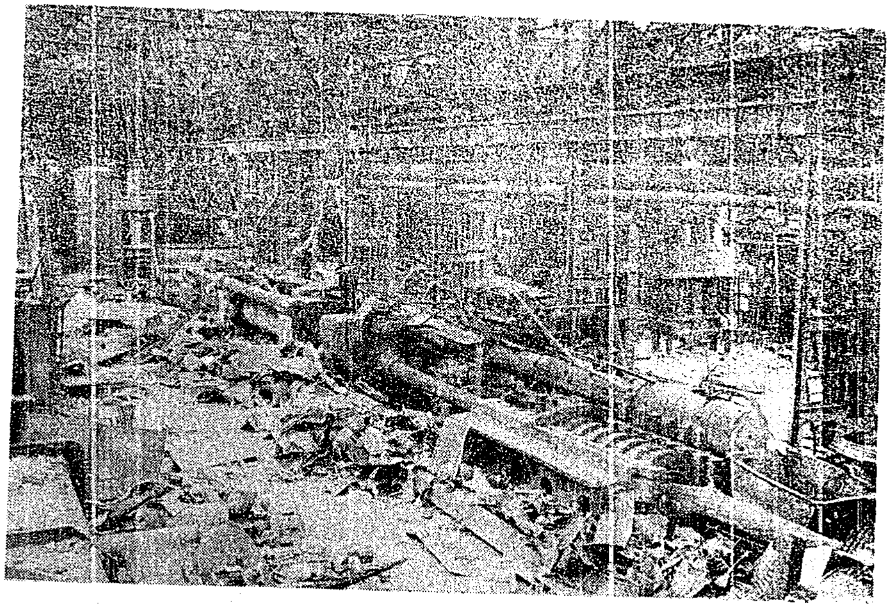


FIGURE 45
FOUR THOUSAND TON PRESS

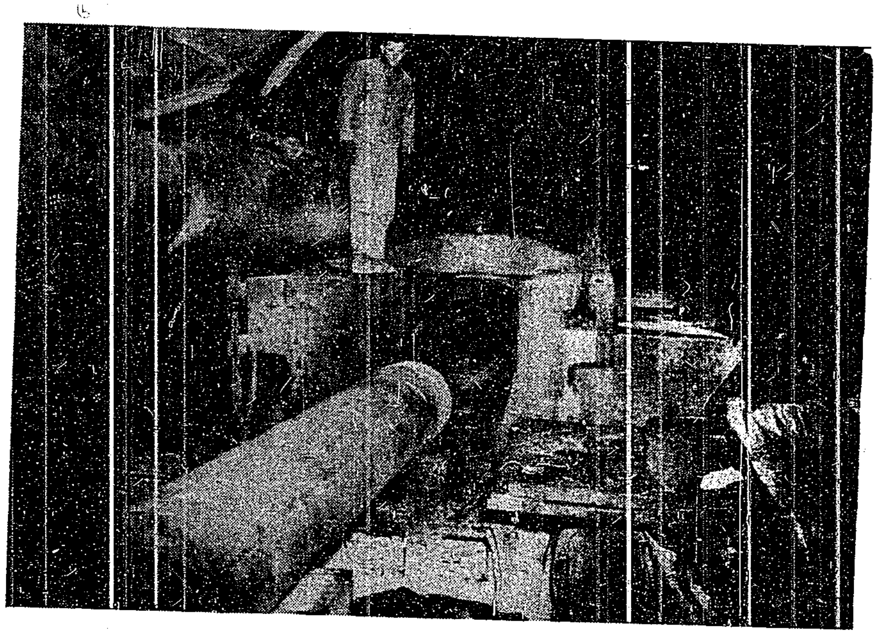


FIGURE 46
RAM OF PRESS

The ram (Figure 46) is connected to a crosshead (Figure 47) and moves on three supporting guides. It passes into a container (Figure 48). The nose piece is detachable. It was stated that up to 100 forgings could be made before renewal of the nose. The container, which can be changed but was stated to have a life of over 1000 forgings, has a bore slightly tapered to facilitate the ejection of the forgings.

The crosshead is connected at the center to the main power cylinder piston and at the upper corners to the two return cylinder pistons. At the back end of the container is the ejection cylinder (Figure 48). The ram of this was used to eject the forging.

The leading particulars are as follows:

	Weight (excluding hydraulic pump)	600 tons
(1)	Main cylinder (one in number)	
	Diameter of piston	1016mm (40.0")
	Stroke	7620mm (25.0 ft)
	Maximum Water pressure	3 tons/in^2 (6720 lbs/in^2)
(2)	Return cylinder (two in number)	
	Diameter of ram	305mm (12")
	Stroke	7620mm (25.0 ft)
	Water pressure	2400 lbs/in^2
(3)	Ejection cylinder (one in number)	
	Diameter of ram	305mm (12")
	Water pressure	2400 lbs/in^2
(4)	Speed of operation	
	Under load	2 m or 78.8"/min.
	No load (ahead)	2.3 m or 90.6"/min.
	(astern)	8.3 m or 327.0"/min.

Machine Tools

The final machining is carried out on lathes and boring machines. No grinding is employed. To machine the curved surface of the after ends of both the oxygen and fuel vessels a special setup is used having a round nosed tool holder with an adjustable tool.

The damage due to bombing was most extensive and it was impossible to make a detailed examination of the equipment. Two points were, however, noted:

(1) The machine tools were of antiquated design.
(2) All vises were of the blacksmith type. No evidence was seen of modern machine tool methods nor of any attempt to measure surface finish.

The appearance of the completed vessels was as good as that of Allied torpedoes.

Test Pressures of Oxygen Vessels

Test pressures were applied to the completed oxygen vessels hydraulically, using oil.

They were as undernoted:

FIGURE 47
RAM OF OPERATING MECHANISM

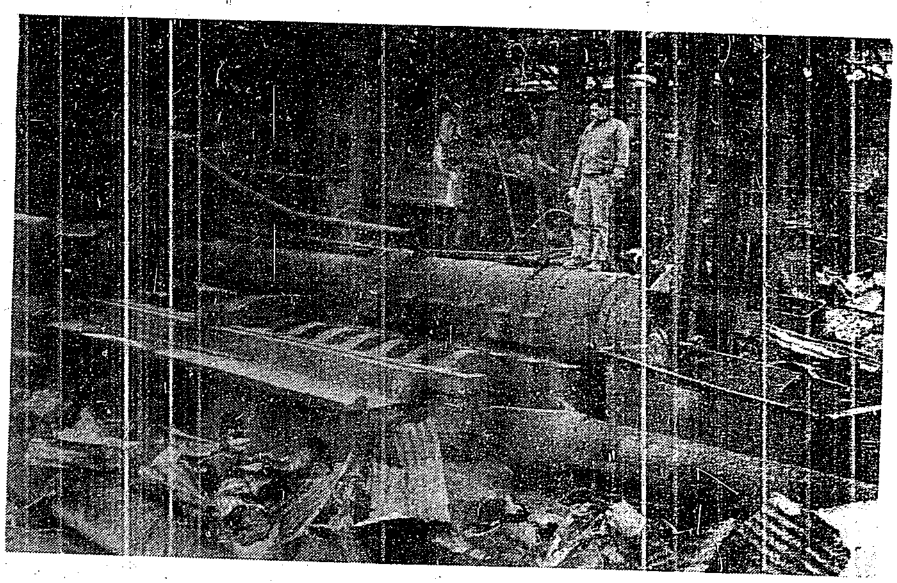


FIGURE 48
CONTAINER

For a working pressure of:	225 kg/cm2 (3200 lbs/in2)
Test pressure	330 kg/cm2 (4700 lbs/in2)
Bursting pressure	460 kg/cm2 (6540 lbs/in2)
Repeated test pressure	250 kg/cm2 (3550 lbs/in2)

Cycles before failure occurred:

Type 93, Model 1	Lowest	870
	Highest	1300
Type 95		3000
Type 02		5000

Repeated tests were carried out with a cycle of approximately 20 minutes.

No diagram of the pressure applications was made. The plant was operated manually, gauge readings being taken.

Only three or four vessels were subjected to the test, the series being repeated with each change in the material. At the start of the war, failure occurred in the Type 93 at 1300 cycles and fell to less than 1000 at the end of the war.

No attempt was made to ascertain the relation between the number of cycles and the size of the vessel. For a small vessel the figure is much higher than 3000.

At the bursting pressure, failure occurred in Type 93 in the middle of the vessel but not in the vicinity of the top stop. After repeated tests the fracture occurred at the section with increased thickness where the shoulder is formed to retain the vessel end.

The introduction of the repeated pressure tests indicates that the Japanese had realized that the failure would occur at a lower pressure and at a different point in the vessel due to the variation in the stressing. In addition, the use of pure oxygen would not minimize the damage done should a failure occur.

It is of interest to note that the position of the failure under repeated stressing is similar to that of the British air vessel failures in service.

It was stated that no oxygen vessel had burst in service during the war. One torpedo officer, a lieutenant, 22 years of age, who had seen service in submarines and cruisers and had fired both Type 93 and Type 95 oxygen torpedoes, stated that explosions had occurred with oxygen torpedoes when they were first introduced but not subsequently.

Storage and Preservation

When a new torpedo was sent from the manufacturer to naval storage, the air vessel was inspected, cleaned and preserved. Cleaning was carried out with a wire brush and petrol. A mineral oil was used as preservative. In the case of Type 95, the oxygen vessel was preserved by the electrolytic deposition of cadmium (about 0.1mm thick) internally. On account of the power required and the size and expense of the electrolytic apparatus this method was not used in the large vessel of the Type 93.

Power Unit

Type and Leading Particulars

The engine is of the standard Whitehead design and has two double-acting cylinders placed horizontally in line, with the reversing gear forming the connection between the two cranks. (See Figures 49-58.)

The leading particulars in the case of Type 93 are as undernoted:

Cycle	Wet heater, 100% oxygen, sea water diluent.
Number of cylinders	Two, double-acting
Bore	142mm (5.59")
Stroke	180mm (7.08")
Swept volume	684 in^3
Max. inlet pressure	38 kg/cm2 (540 lb/in^2)
Max. horse power	520
Max. RPM	1200
Oxygen consumption	4.4 - 4.2 lbs/BHP/hr
Expansion ratio	1.5
Weight	770 lbs (without generator)

It was stated that the engine was an improvement on the Whitehead, with suitable modifications for higher powers and to enable sea water to be used as diluent.

The undernoted table gives a comparison with British radial engines:

	Japanese	British	
	Type 93	21" Mark VIII	24.5"
Horsepower	520	320	240
BMEP (lbs/in^2)	245	377	-
Swept volume (in^3)	684	280	392
Weight	770	260	300
Hp/in^3 of swept vol.	0.760	1.14	0.612
Specific weight	1.48	0.81	1.25

Note: For the British engines the maximum horsepower in the torpedo has been taken, and an allowance of 50 pounds for the transmission has been added to the engine weight (without generator).

It is evident from these figures that the Japanese decided that the best overall efficiency can be obtained by the use of a large engine with a big swept volume, low expansion ratio giving a low inlet pressure but a poor specific oxygen consumption, i.e. that with a big vessel the gain due to a high thermal efficiency cannot compensate for the loss due to a larger weight of oxygen remaining in the vessel at the end of the run.

Construction

Cylinder Body

The cylinder block is a casting of the standard phosphor-bronze material used throughout the torpedo. (See Figure 52) In the casting are the two cylinders and valve chest; it is spigotted to the crankcase at the cylinders and valve chests and secured by ring nuts.

No cylinder liners are used, the bearing surfaces being machined in the body material. The cylinder crowns are of copper thickened to stand the hammering from the salt deposit. A knife-edge joint is used, the knife-edge being machined in the casting. The covers are secured by ring nuts.

Wear on the cylinder walls is not serious; the main problem is to prevent

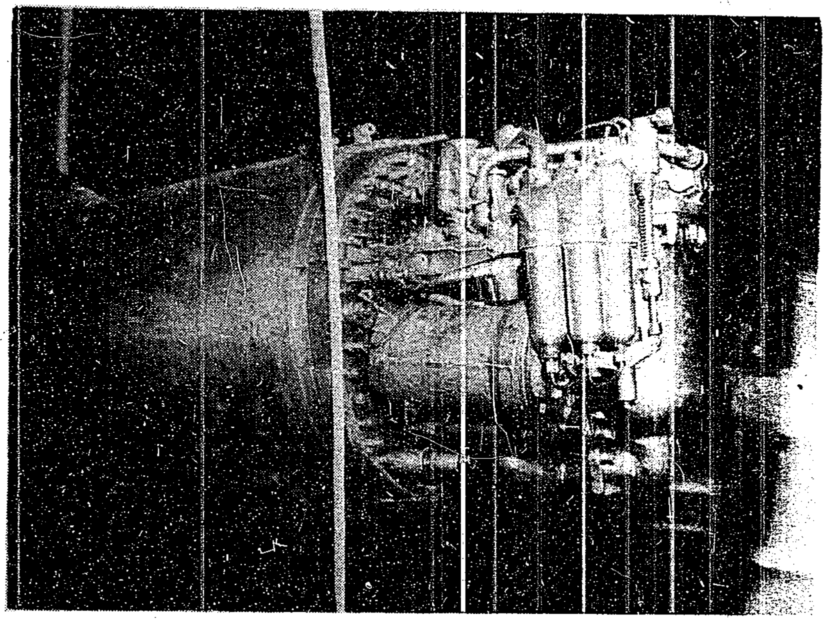


FIGURE 49
SIDE VIEW OF ENGINE, TYPE 93

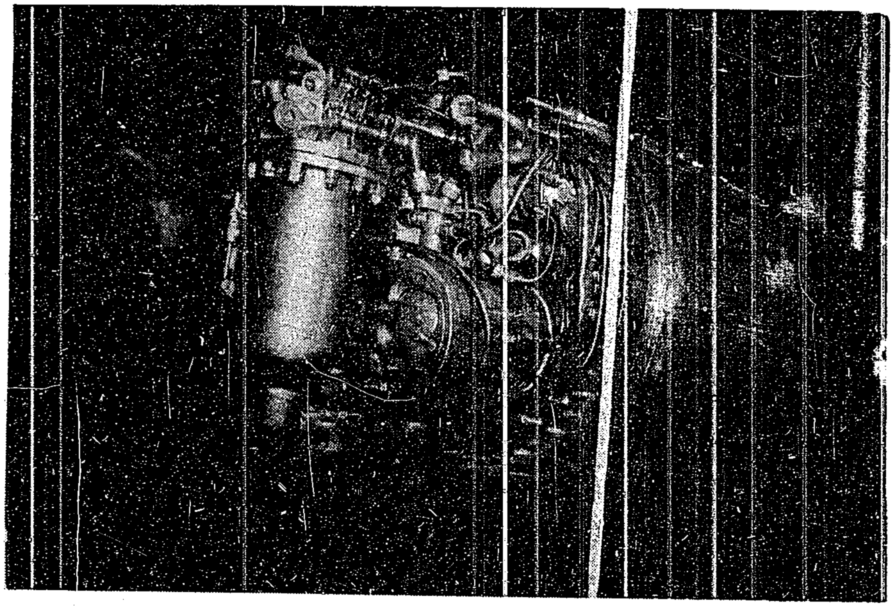


FIGURE 50
END VIEW OF ENGINE. TYPE 93

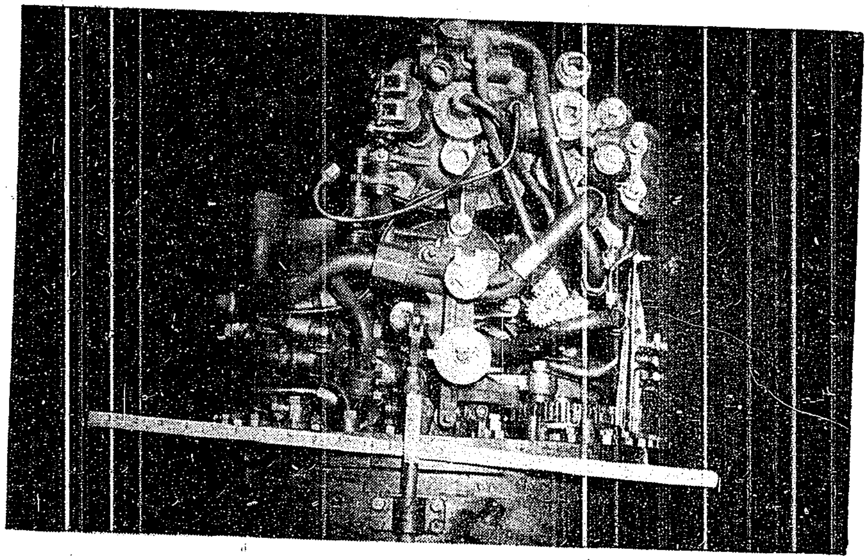


FIGURE 51
PLAN VIEW OF ENGINE. TYPE 93

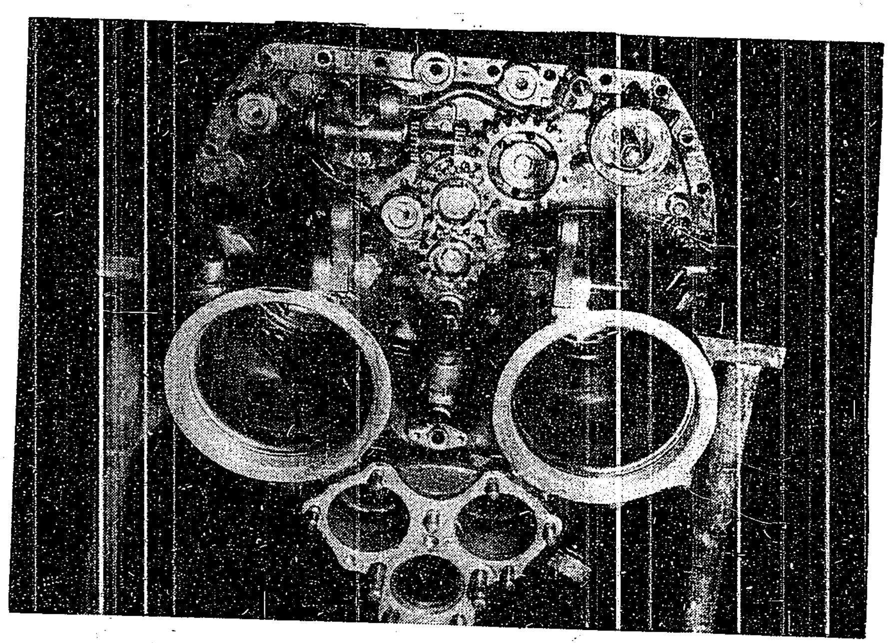


FIGURE 52
CYLINDER BARRELS OF ENGINE. TYPE 93

leakage past the piston rod. This is accomplished by using five uncut bronze packing rings having a total length of 48mm, water-cooled and lubricated from the distributor. The oil passes through the side of one ring onto the rod and the water is sprayed onto the piston rod forward of the packing gland. The rings are held in place by a lock nut and are a fairly loose fit on the rod. No attempt is made to get a tight fit, the oil film being relied upon to make a gas-tight joint. This modification was introduced by the Japanese.

Thickness of cylinder wall	8mm (0.315")
Thickness of cylinder cover	5mm (0.197")
Length of thread securing cover	14mm (0.55")
Port areas	
Number per cylinder	2
Width	12.5mm (0.49")
Length	37mm (1.46")
Packing rings	
First ring	
Diameter	47mm (1.85")
Length	7.2mm (2.76")
Remaining rings	
External diameter	44.8mm (1.76")
Bore	35.3mm (1.39")
Clearance	0.3mm (0.012")
Water spray	12 holes in lock nut

Crankcase

The crankcase (Figure 53) is a separate casting from the cylinder block; it is made of silicon bronze normally but toward the end of the war, owing to the shortage of bronze, steel was used. A great deal of difficulty was experienced with the latter.

It is flanged and bolted to the after body. The casting forms the crosshead guides and houses the valve gear shaft and helical gear in addition to the big ends and reversing gear. The end cover is a separate casting and is bolted to it.

Pistons

These are of the standard Whitehead design. (See Figure 54.) The pistons are dome-shaped and are integral with the piston rods. They are fitted with two cast iron piston rings positioned by stop pins. Replacement of the rings is hardly ever necessary. The clearance between the crown of the piston and the cylinder cover was formerly 1mm at each end but was increased to 3mm to accomodate the deposit of salt. It was admitted that this was too large but unavoidable and a loss of efficiency resulted.

The rod is threaded at the rear end and screws into the crosshead. It was originally 30mm in diameter but this was increased to 35mm. Failure also occurred at the change of section between the crown and the rod.

Piston diameter	141.5mm (5.57")
Clearance in liner	0.5mm (0.197")
Thickness of head	7mm (0.275")
Diameter of piston rod	35mm (1.38")
Rings	
Width	10mm (0.394")
Thickness	4mm (0.158")
Free gap	20.5mm (0.808")
Clearance in groove	0.1mm (0.0039")

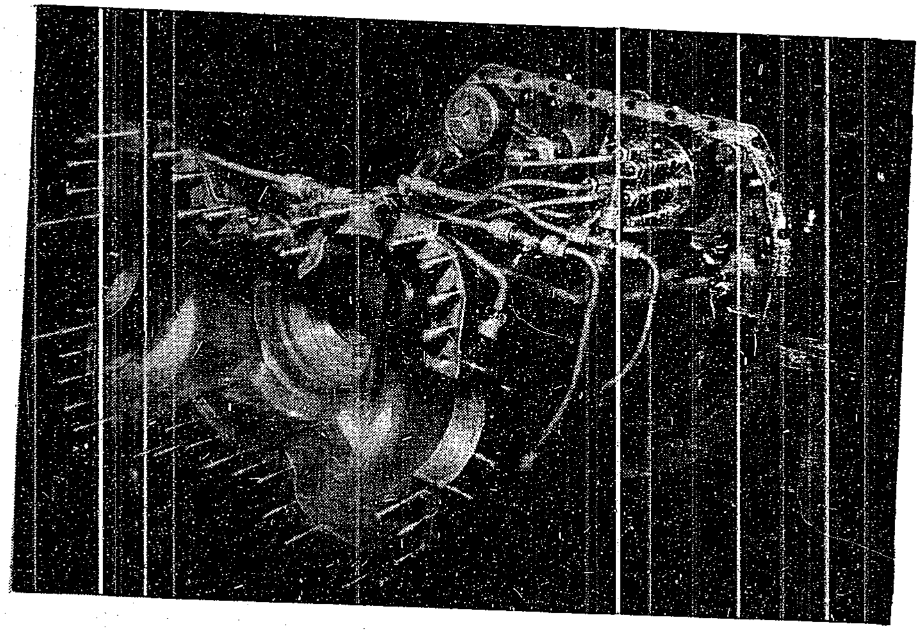


FIGURE 53
CRANKCASE, ENGINE, TYPE 93

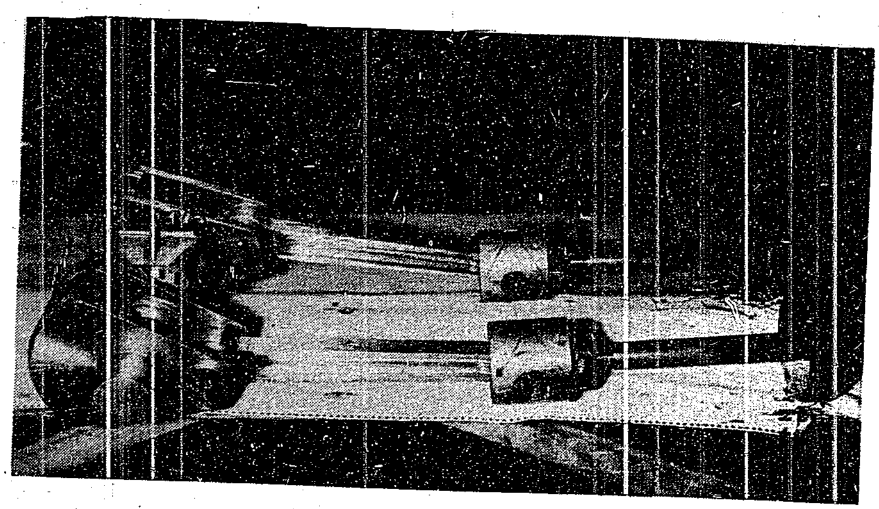


FIGURE 54
CRANKSHAFTS, PISTONS AND CONNECTING RODS, ENGINE TYPE 93

Crosshead

The crosshead is a steel forging into which the rod screws, the forging is split at the thread and the rod is locked by two set screws which clamp the head onto the rod. (See Figure 54.) The connecting rod bearing is a plain pin running in a white metal bush. The pin has a square head which falls into a recess in the crosshead and is secured by a grub screw.

The external surface of the head has oil grooves and oscillates on the bronze of the crankcase casting.

Diameter of crosshead	106mm (4.18")
Length	90mm (3.54")
Thickness of white metal	5mm (1.97")
Diameter of pin	35mm (1.38")
Length of pin	94.5mm (3.72")

Crankshaft

The crankshafts are of the standard Whitehead design incorporating the reversing mechanism with the worm drive for the valve rods between the two connecting rods. (See Figure 54.) The cranks rotate in opposite directions and are set with a phase difference of 90°.

The central mounting of the unit has two bearing pins each of which carries one side wheel. The gear wheel is retained in position by a thrust race secured to the end of the bearing pin. The inner web of the crankshaft is integral with the gear wheel. The connecting rod big-end journal is integral with the outer web and external main bearing. The junction, necessary to enable the rod to be assembled, consists of a square which is milled on the end of the big-end journal. The latter is a drive fit in a corresponding recess in the inner crank web.

The gear wheel at the end of the propeller shaft meshes with the two side wheels forward of the central mounting and the sleeve shaft aft of it.

The main thrust from the propellers is taken on the engine casting opposite the end of the propeller shaft. The thrust from the propeller shaft comes directly onto the casing, and to it has to be added that due to the gear wheel. The thrust from the sleeve shaft is partially balanced by that from the meshing of the teeth and operates in the opposite direction. The balance is transmitted through a subsidiary thrust race onto the central mounting. The latter is free to slide in its housing and hence transmits the balance onto the engine casing.

One modification introduced by the Japanese was the use of thrust races in place of thrust washers to absorb the additional thrust due to the increased output.

The main dimensions of these details are as shown:

External main bearing	
Diameter	70mm (2.75")
Length	49mm (1.93")
Internal main bearing	
Diameter	69.8mm (2.75")
Length	49mm (1.93")
Thickness of white metal	5mm (0.197")
Gear wheel (casehardened steel)	
Inside diameter	121.3mm (4.78")
Length	35mm (1.38")
Number of teeth	27
Type	20° involute

Connecting rod bearing	
Diameter	35mm (1.38")
Length	55.9mm (2.2")
Thickness of white metal	4mm (0.157")
Main thrust race	
Overall diameter	115.0mm (4.53")
Diameter of ball	12.75mm (0.502")

Valve Gear

The valve gear (Figure 55) consists of a steel lay shaft set at right angles to the longitudinal axis of the engine and is located in the lower side of the engine crankcase between the connecting rods. The shaft consists of a single forging with a central helical-toothed wheel having a crank pin and external web on each side of it. One valve rod is driven by each of these pins. The gear wheel meshes with a bronze wheel mounted on an extension of the propeller shaft.

Special materials for the helical drive were introduced to reduce the the wear due to the additional load from the salt deposit in the valves.

Piston Valves

The piston valves (Figure 55), which are tubular in shape and hollow, are of silicon steel to resist accelerated wear due to abrasion by salt. They operate in bronze guides which are machined in the engine body casting. Inlet gas supply is external to them and exhaust gases pass through the center of them.

The rear end of the valves are screwed to a crosshead on the end of the valve gear connecting rods.

Great difficulty is experienced in preventing wear. Frequent replacements are necessary. The normal life is about three runs. When the clearance exceeds 3mm a replacement is made. In the initial stages oversize or repaired valves are fitted and finally the engine body is renewed.

Poppet valves were tried in the 18" Type 94 (aircraft oxygen torpedo) and were abandoned because it was found that the valves would not close due to the salt in the guide.

The particulars of the valve are:

Maximum diameter	67.9mm (2.68")
Total length	288mm (11.34")
Diameter of exhaust passage	44.5mm (1.75")
Initial clearance	0.05mm (0.0019")

Lubrication

Two systems of lubrication are employed. The major portion of the engine is lubricated through the oil distributor (nine points). There is, however, a direct supply from the bottle to the two ends of the crankshaft for lubricating it and the valve gear, the delivery being controlled by a rated nozzle screwed into the casing. Oil passages are drilled in each component.

The oil is supplied by a reciprocating pump incorporated in the diluent sea water pump. It is of the double-acting type.

Bore	22mm (0.866")
Stroke	64mm (2.52")
RPM	Half engine speed

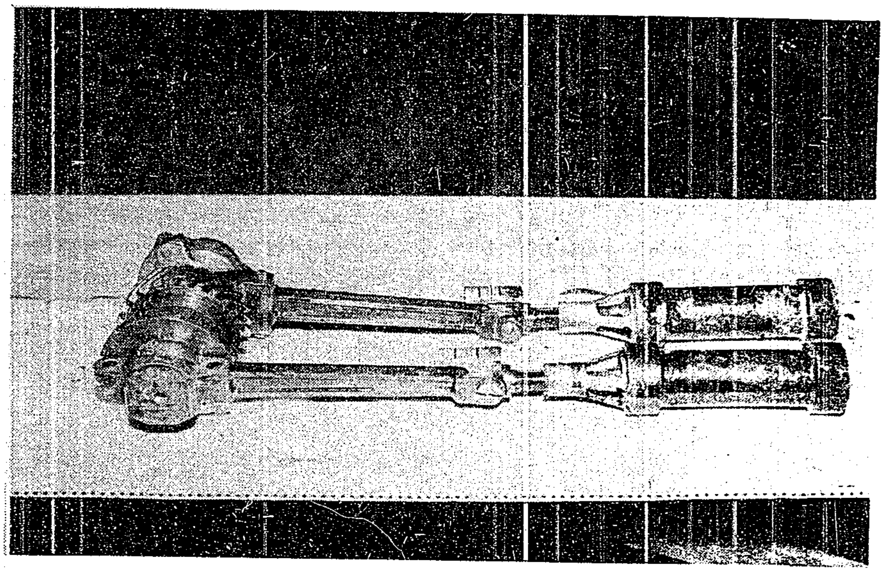


FIGURE 55
SLIDE VALVE AND VALVE GEAR, TYPE 93

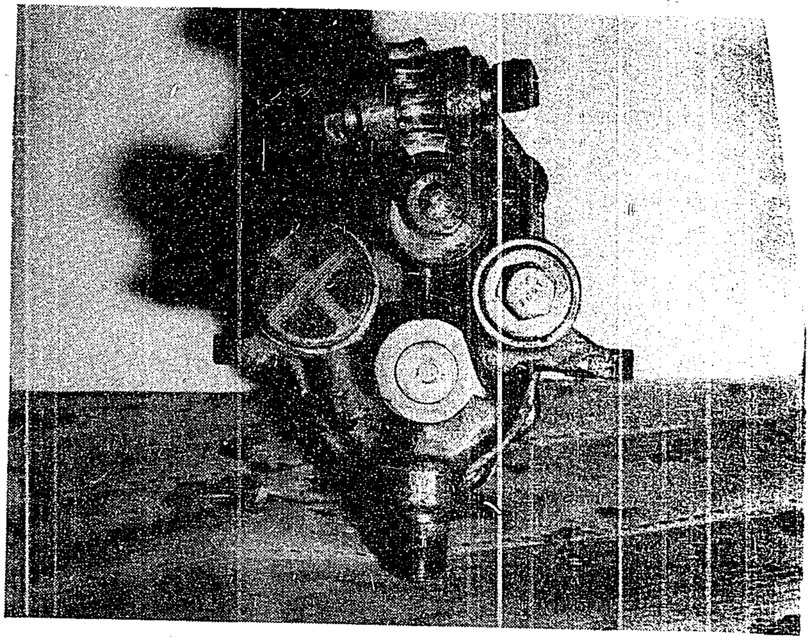


FIGURE 56
COOLING WATER PUMP, TYPE 93

Engine Cooling

The cooling of the cylinder body and cylinder head is by sea water admitted and flowing through the engine room. No attempt is made to raise the temperature of the water. The external surface of the remainder of the engine and transmission is not cooled but sea water is pumped into the crankcase and the valves. A separate pump is fitted for this purpose. (See Figure 56) It is housed at the bottom of the engine room between the two cylinders and is driven at engine speed from an extension of the propeller shaft. It is of the standard gear wheel type except that an extension of the idle wheel spindle is used to drive the sea water pump for diluent, etc. From this spindle the vertical shaft for range setting on the group and the oil distributor are also driven. The pump supplies cooling water for the valves and for the piston rods.

Length of gear wheel	47mm (1.85")
Diameter over teeth	76mm (2.99")
Number of teeth	16
Output	8 liters per 100 engine revolutions

Diluent Sea Water Pump

This is a double-acting, single-throw reciprocating pump, gear-driven at half engine speed. (See Figures 33 and 57.)

The special features are:

(1) The inclusion of a third non-return valve on the delivery side to damp out the pressure fluctuations in the delivery.
(2) The use of a small vent hole in the suction valve cover to obviate air locks in the case of above water discharge. (This was also found necessary in British torpedoes.)
(3) Extremely rigid method of attachment to the engine casing.

The pump supplies sea water:

(a) To the generator as diluent.
(b) To the fuel bottle to feed the fuel to the generator by displacement.
(c) To the engine crankcase for cooling the working parts.

The distribution is:

	Generator and Fuel Bottle	Engine Cooling
High speed	60%	40%
Medium speed	40%	60%
Low speed	30%	70%

The casing is of phosphor-bronze with no special features.

Bore	50mm (1.97")
Stroke	80mm (3.15")
Delivery pressure kg/cm2	40 kg/cm2 (568 lbs/in2)
HP required	17
Output	13 liters per 100 engine revolutions

Valve Timing

The timing of the engine is:

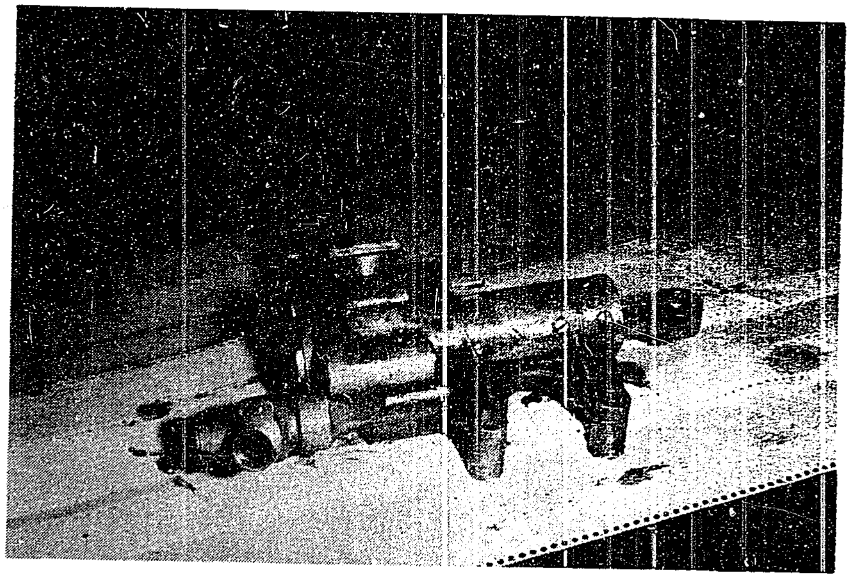


FIGURE 57
DILUENT SEA WATER PUMP, TYPE 93

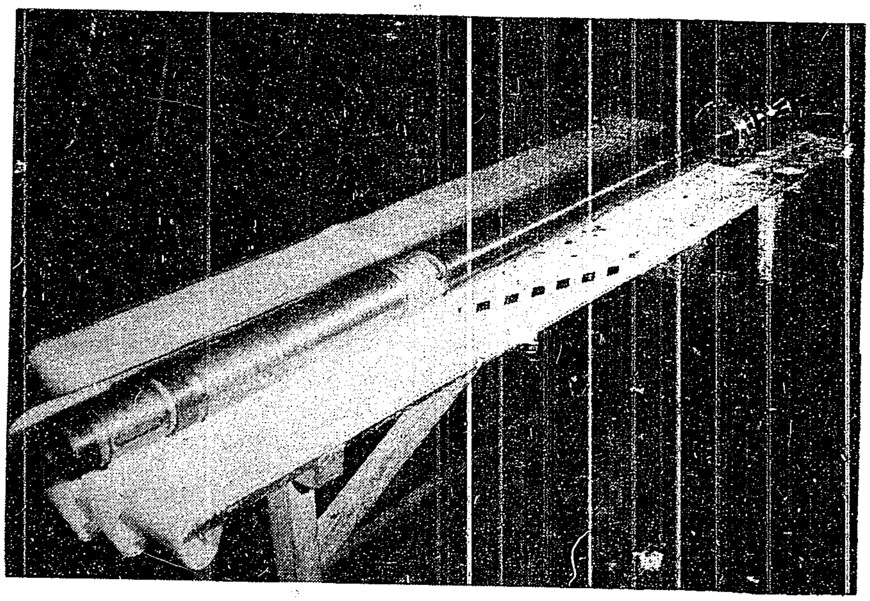


FIGURE 58
PROPELLER SHAFTS, TYPE 93

Admission	10° B.T.C.
Cut off	100° A.T.C.
Exhaust open	135° A.T.C.
Exhaust closed	315° A.T.C.

From this it is seen that:

Expansion occurs for 35° of crank angle.
Recompression takes place for 44° of crank angle.

The design of the engine using slide valves is such that it is not possible to avoid recompression without fitting an auxiliary exhaust valve. This was not done because of the additional complications.

It therefore became necessary to admit gas at all positions of crank angle; hence the use of an expansion ratio of 1.5. In view of the original decision to have a large low pressure engine, the low expansion ratio serves the double purpose.

Shafts and Propellers

The two shafts (Figure 58) are only supported at the rear end by white metal-lined bearings. Propeller cones are keyed to the shafts and the propeller drive is through two keys:

Bore of exhaust outlet	66.7mm (2.6")
Width of propeller bosses	88.9mm (3.5")
Maximum blade width	171.5mm (6.75")

Maintenance

The weak point in the engine was stated to be the piston valves and the worm valve gear.

With the introduction of pure oxygen and sea water it was found necessary to overhaul the engine, generator, reducing valve and group after each run because: (a) the ball bearings rusted, (b) the salt had to be removed from the generator and engine, and (c) the oil had to be cleaned off the group and reducer.

Materials

The materials used in the construction of the engine and their mechanical properties are:

Silchrome Steel

Chemical Composition

	Specification	Sample Test
Carbon	0.35%	0.35%
Silicon	2.3%	2.07%
Manganese	0.35%	0.30%
Phosphorus	< 0.03%	0.023%
Sulphur	< 0.03%	0.019%
Chromium	12.5%	12.44%
Tungsten	1.5%	1.69%
Nickel	-	0.28%
Copper	-	0.21%

Mechanical Tests

	Specification	Sample Test
Yield point		
kg/mm²	65-75	66.6
lbs/in²	9243-10,665	9471
Ultimate strength		
kg/mm²	90-100	86
lbs/in²	12,798-14,220	12,229
Elongation	18%	27.6%
Reduction in area	-	52%
50mm gauge length		
Izod ft-lbs	25	-
Brinell hardness	251/280	233

Non-Ferrous Material:

Phosphor-bronze	
Tin	14%
Phosphorus	1%
Copper	85%
"SILZIN" bronze	
Silicon	4.5%
Zinc	15.0%
Copper	80.5%

Oxygen vessel steel is used in the following components:

Pistons (and rods)
Connecting rods
Crankshafts

Weights of Components in Type 93 Engine.

	kg.	lb.
Cylinder block and crankcase	143.5	315.7
Slide valve (one)	2.0	4.4
Valve gear	14.5	31.9
Crankshaft	42.9	94.4
Propeller shaft	17.1	37.6
Sleeve shaft	21.0	46.2
Generator	40.0	88.0
End cover of crankcase and center tube	20.0	44.0

Design Detail

Indicator Diagram

A theoretical indicator diagram has been drawn based on the following data:

Inlet pressure (kg/cm²)	34 (483 lbs/in²)
Exhaust pressure (kg/cm²)	4 (57 lbs/in²)
Ratio of specific heats	1.3
Clearance volume	5% of swept volume

Engine Timing

Admission	10° B.T.C.
Cut-off	100° A.T.C.
Exhaust opens	135° A.T.C.
Exhaust Closes	315° A.T.C.

The diagram is shown in Figure 59.

Mean effective pressure = 22.8 kg/cm2 (325 lbs/in2)

Ratio $\frac{\text{Mean Pressure}}{\text{Max. Pressure}} = \frac{26.8}{34} = 0.79$

Theoretical indicated horsepower $= \frac{\text{Pm LAN} \times 4}{75 \times 60}$

$$= \frac{4 \times 22.8 \times 154 \times 18 \times 1200}{75 \times 1000 \times 60} = 674$$

When L = 180mm (7.1")
N = 1200 RPM
A = 154 cm^2 (23.9 in^2)

Assuming a diagram factor of 0.90,

Indicated horsepower for diagram = 674 x 0.90 = 606

Brake horsepower = 520

Mechanical efficiency $= \frac{520}{606} = 0.858$

This figure appears to be low because the reversing gear losses are included. Since the engine is a double-acting one, the indicator diagram for the work done on the rod side of the piston will need to be added.

Engine Balance

In the following claculations it has been assumed:
(1) 2/3 weight of connecting rod is taken as a rotating weight.
(2) 1/3 weight of rod is taken as reciprocating weight.

Piston and rod	4 kg (8.8 lbs)
Crosshead	2.7 kg (5.94 lbs)
Connecting rod	3.5 kg (7.7 lbs)

Since the web is perfectly balanced by choosing a suitable balance weight, the rotating masses can be balanced and can be neglected.

Reciprocating parts:
Weight = 4.0 + 2.7 + 1.2 = 7.9 kg (17.38 lbs)

Unbalanced Force

The unbalanced forces Q_1 have been calculated from:

$$Q_1 = \frac{W}{g} rw^2 \ (\cos a_1 + L\cos\ 2a_1)$$

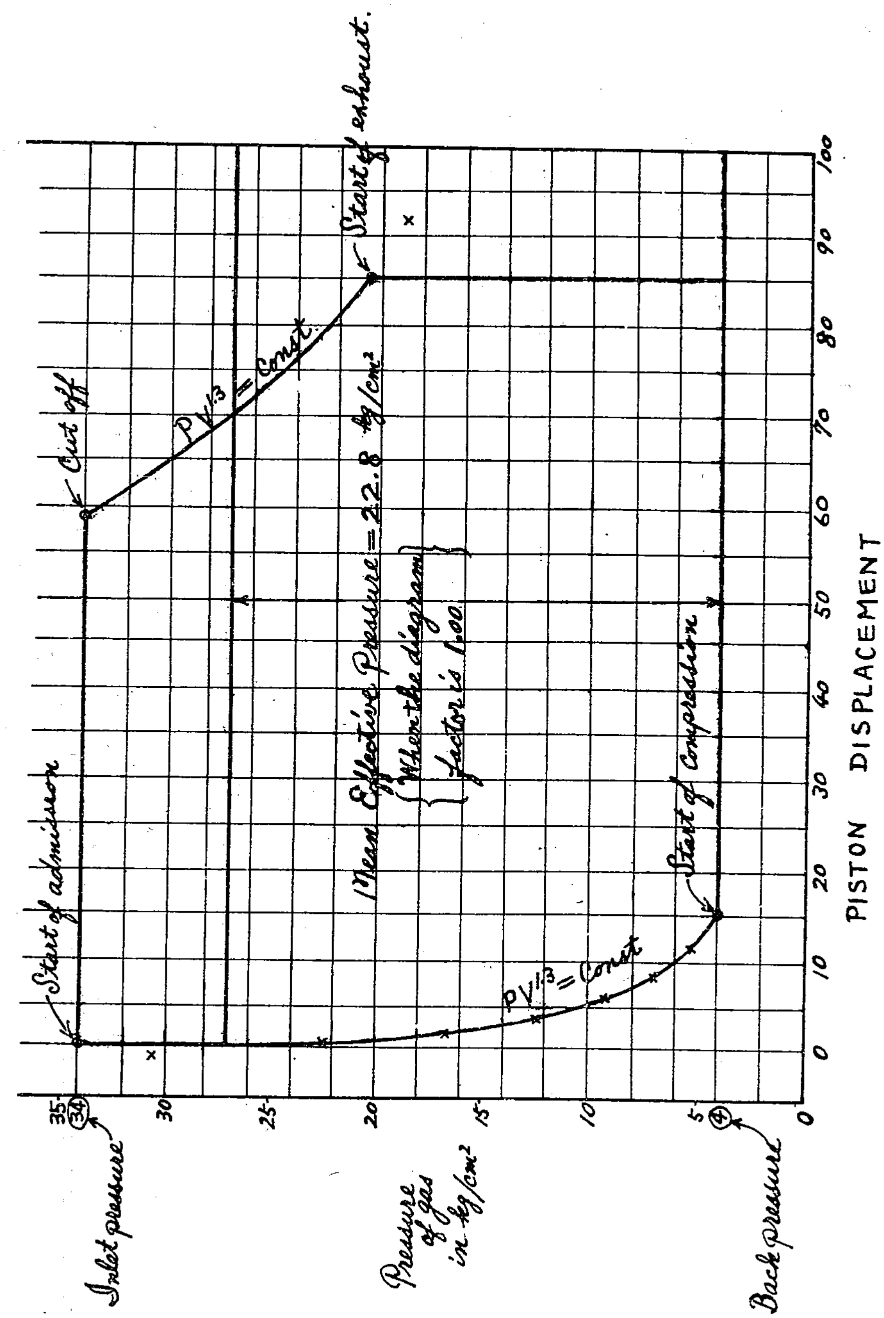


FIGURE 59
THEORETICAL INDICATOR DIAGRAM

Where: W = Weight of reciprocating parts
g = Force of gravity
r = Radius of crank
w = Angular velocity of crank
a = Crank angle
L = r/l where l = length of connecting rod
$= \frac{90}{400} = 0.225$

Since there are two cranks at 90° initially and have a phase difference of 90° the equation becomes:

$$Q = Q_1 + Q_2$$

Where Q_1 refers to the starboard cylinder and Q_2 refers to the port cylinder:

$$Q = \frac{W}{g} rw^2 \left\{(\cos a_1 + \cos a_2 + L(\cos 2a_1 + \cos 2a_2)\right\}$$

Substitute $a_2 = a_1 + 90°$

$$\cos a_2 = \cos(a_1 + 90°) = -\sin a_1$$

$$\cos 2a_2 = \cos(2a_1 + 180°) = -\cos 2a_1$$

$$Q = \frac{W}{g} rw^2 (\cos a_1 - \sin a_1)$$

As $\frac{W}{g} rw^2$ remains constant the equation can be written:

$$Q = K \cos a_1 - K \sin a_1$$

Differentiating:

$$\frac{dQ}{da_1} = -K(\sin a_1 + \cos a_1)$$

Equating to zero for maximum or minumum values:

$\sin a_1 = -\cos a_1$ or $\tan a_1 = -1$

Therefore, $a_1 = 135°$ or $315°$

The maximum can be separated from the minimum by a second differentiation:

$$\frac{d^2Q}{da_1^2} = -K(\cos a_1 - \sin a_1)$$

$$= K(\sin a_1 - \cos a_1)$$

Substituting $a_1 = 135°$:

$$\frac{d^2Q}{da_1^2} = \left\{\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right\} \quad \text{Positive}$$

Substituting $a_1 = 315°$:

$$\frac{d^2Q}{da_1^2} = K \left\{-\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}}\right\} \quad \text{Negative}$$

$a_1 = 135^o$ is a minimum.

$a_1 = 315^o$ is a maximum.

Thus Q is a maximum when $a_1 = 315^o$ and also when $a_1 = 135^o$ but in the latter case the force is in the opposite direction and therefore appears mathematically as a minimum.

Hence:

$$Q \max = \frac{W}{g} rw^2 (\cos 315^o - \sin 315^o)$$

$$= \frac{W}{g} rw^2 (2 \cos 45^o)$$

Substituting:

W = 7.9 kg
g = 9.8 m/sec²
r = 0.09 meters
w = 126 radian/sec
cos 45° = 0.707

Maximum unbalanced force:

Q = 1620 kg (3564 lbs)

Since the two cylinders are placed practically horizontally the whole of this unbalanced force acts parallel to the axis of the torpedo.

<u>Unbalanced Couple</u>

Both the pistons move in the same horizontal plane but are spaced a distance "b" apart, so there will be an unbalanced couple M where:-

$$M = \frac{b}{2} (Q_1 - Q_2)$$

$$= \frac{b}{2} \frac{W}{g} rw^2 (\cos a_1 + L \cos 2a_1 - \cos a_2 - L \cos 2a_2)$$

$$= \frac{b}{2} \frac{W}{g} rw^2 (\cos a_1 + \sin a_1 + 2L \cos 2a_1)$$

$$\text{Let } K = \frac{b}{2} \frac{W}{g} rw^2$$

$$\text{then } M = K(\cos a_1 + \sin a_1 + 2L \cos 2a_1)$$

Differentiating and equating to zero as before to get maxima and minima:

$$\frac{dM}{da} = K [-\sin a_1 + \cos a_1 + 2L (-2 \sin 2a_1)]$$

$$= K(-\sin a_1 + \cos a_1 - 8L \sin a_1 \cos a_1)$$

$$8L = \frac{\cos a_1 - \sin a_1}{\sin a_1 \cos a_1}$$

$$(8L)^2 = \frac{\cos^2 a_1 - 2 \sin a_1 \cos a_1 + \sin^2 a_1}{(\sin a_1 \cos a_1)^2}$$

$$(4L)^2 = \frac{1 - \sin 2a_1}{(\sin 2a_1)^2}$$

$$\therefore 16L^2(\sin 2a_1)^2 + \sin 2a_1 - 1 \leq 0.$$

$$\therefore \sin 2a_1 = \frac{-1 \pm \sqrt{1 + 4(16L^2)}}{32L^2}$$

$$L = r/l = 90/400$$

$$\therefore \sin 2a_1 = 0.655$$

$$2a_1 = 41^\circ,\ 139^\circ,\ 401^\circ,\ 499^\circ \text{ etc.}$$

$$a_1 = 20.5^\circ,\ 69.5^\circ,\ 200.5^\circ,\ 249.5^\circ \text{ etc.}$$

Substituting these values in:

$$M = K(\cos a_1 + \sin a_1 + 2L \cos 2a_1)$$

When:

$a_1 = 20.5^\circ$	$M = 1.63\ K$
$a_1 = 69.5^\circ$	$M = 1.0\ K$
$a_1 = 200.5^\circ$	$M = -1.0\ K$
$a_1 = 249.5^\circ$	$M = -1.63\ K$

The maximum couple occurs at $a_1 = 20.5^\circ$ and 249.5° but in opposite directions at these angles.

Using the values as before and with $b = 30$ cm:

Maximum couple = 282 kg-m or
2040 lb. ft.

It is impossible to balance either the force or the couple in the space available, since the forces will increase with the square of the speed. It now becomes clear why the engine cannot be run at powers over 350 hp.

Loads and Stresses

Piston rod

Maximum load = Piston area x (inlet pressure - back pressure)

= 154 x (34 - 4) = 4620 kg or 10,164 lbs.

From the inertia force and indicator diagrams the maximum load (gas pressure + inertia force) occurs when $a_1 = 100^\circ$.

Substituting in the equation which determines Q_1, the inertia is found to be 444 kg:

Maximum load $= 4620 + 444$ kg.
$= 5064$ kg or 11,141 lbs.

Using the final diameter of the rod of 3.5 cms

$$\text{Stress in rod} = \frac{5064 \text{ kg}}{\text{Area of cross section.}}$$

$$= \frac{5064 \text{ kg}}{9.62 \text{ cm}^2}$$

$$= 526 \text{ kg/cm}^2 \ (7470 \text{ lbs/in}^2)$$

Connecting rod and crosshead

$$\text{Maximum load} = \frac{5064}{\cos c}$$

Where c is the angle of the rod with the center-line when the value of a_1 corresponds to 100°:

$$\text{Maximum load} = \frac{5064}{0.975} = 5190 \text{ kg}$$

$$\text{Bearing pressure on crosshead pin} = \frac{5190}{3.5 \times 9.45}$$

$$= 157 \text{ kg/cm}^2 \ (2229.4 \text{ lbs/in}^2)$$

Side thrust on crosshead bearing

= Maximum load on rod/sin x

$= 5064 \times 0.222$

= 1124.2 kg or 2473 lbs.

Bearing pressure on crank pin

$$= \frac{\text{Max. load on rod}}{\text{bearing area}}$$

$$= \frac{5190}{3.5 \times 5.6} = 264.8$$

$$= 264 \text{ kg/cm}^2 \ (3760 \text{ lbs/in}^2)$$

The side thrust on the crosshead is surprisingly high being over one ton. The bearing pressure on the crank pin is also high. The temperature at which it runs must be low, otherwise the white metal bearing would not stand up to the working conditions.

Diagrams

From the data available some diagrams have been drawn because they are of interest.

The turning moment and inertia diagrams for each cylinder are plotted in Figure 60. The turning moment is the resultant of the gas pressure forces and the inertia forces. The two sets of curves are 90° out of phase. In Figure 61 the combined turning moments and inertia forces are shown. It will be seen that the torque varies much more than would be expected; from 330 kg meters to 560 kg meters. This is due to the inertia forces being

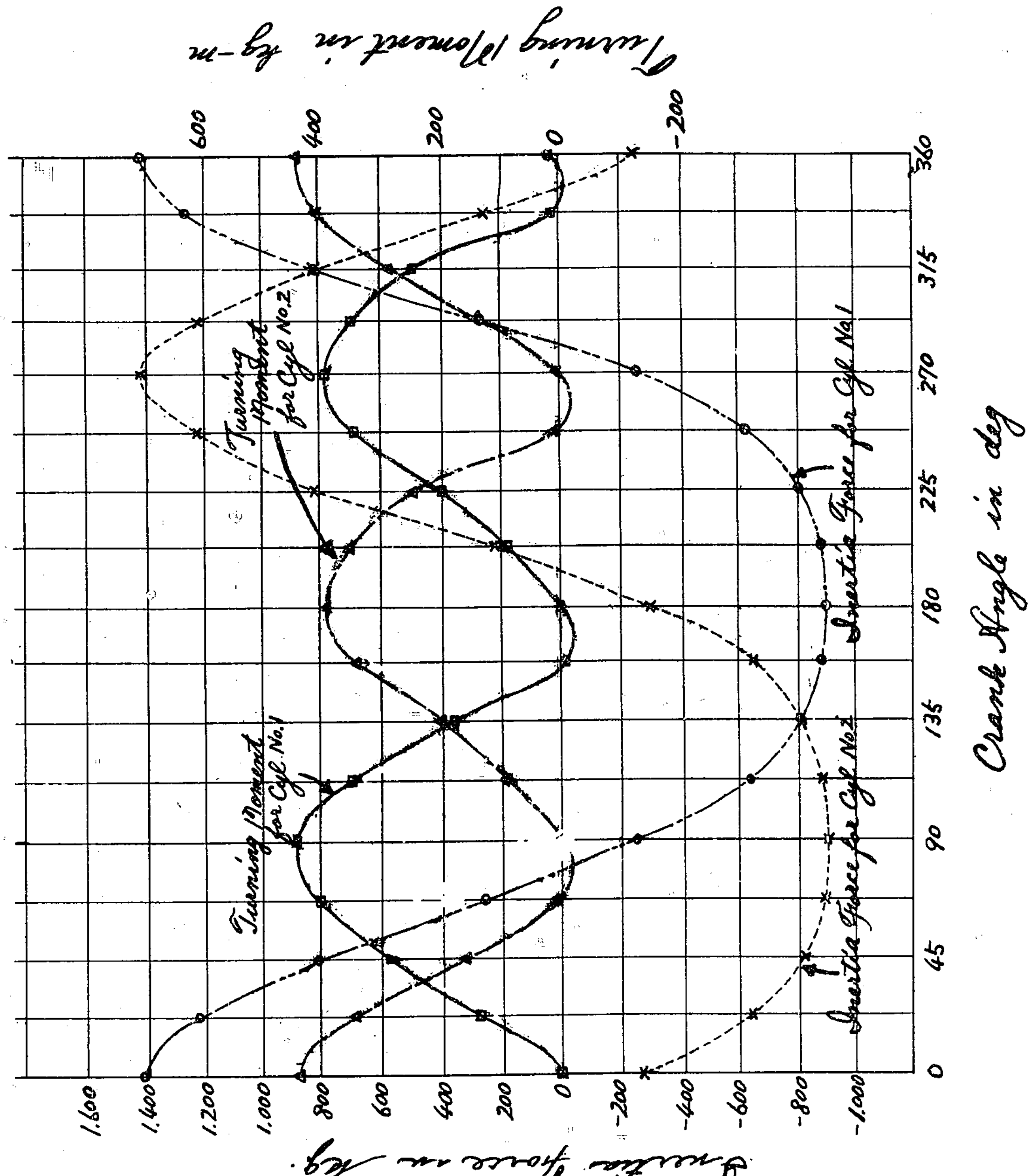


FIGURE 60
TURNING MOMENT AND INERTIA FORCE DIAGRAM

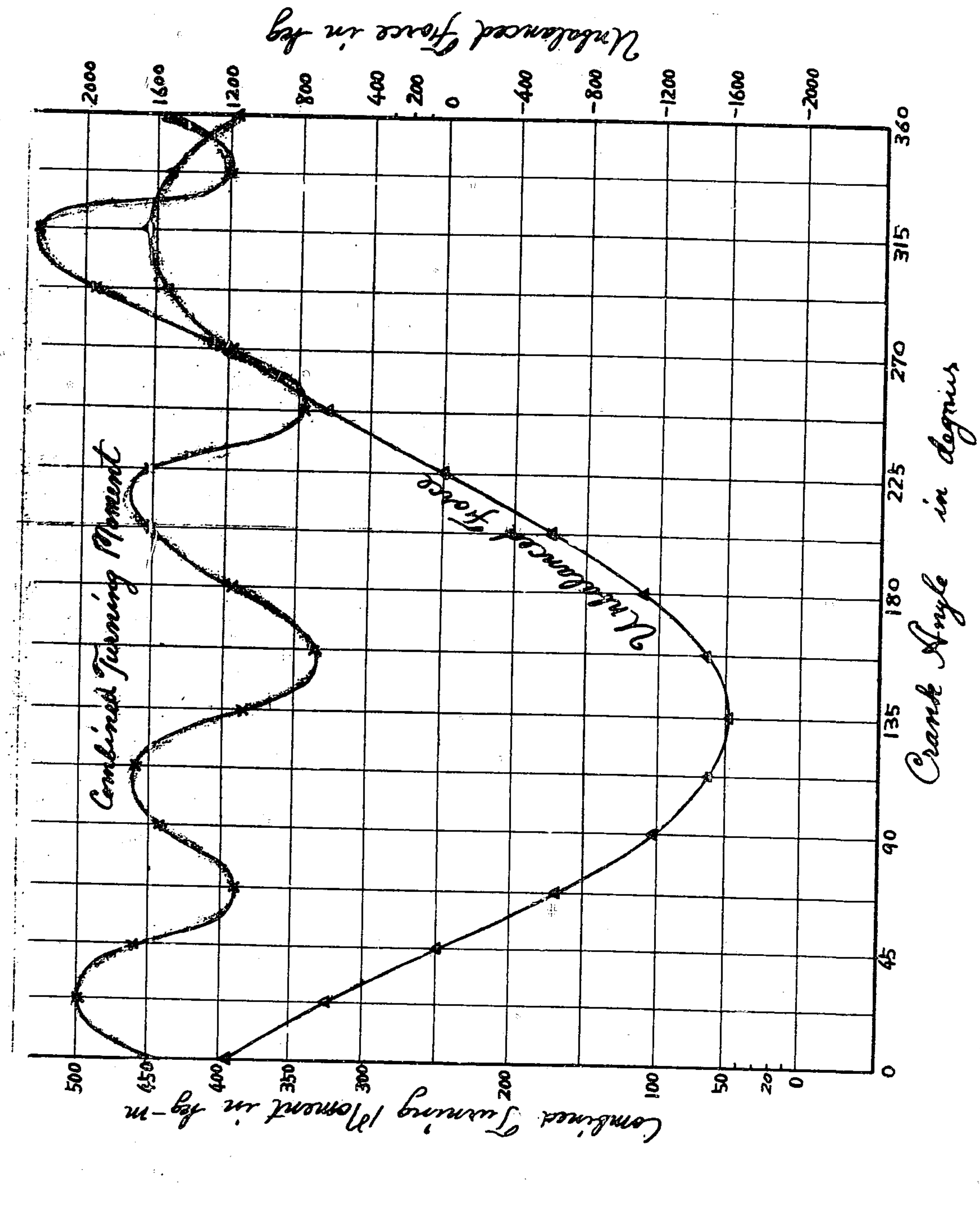


FIGURE 61
COMBINED TURNING MOMENT AND UNBALANCED FORCE DIAGRAM

a maximum and minimum at the dead centers on account of the 90° out-of-phase condition.

The diagram of the bearing load for the crank or main bearing pin shows that all the load is applied in the fore and aft direction. (Figure 62).

Thermodynamics

Oxygen/fuel ratio	= 2.8
Water/fuel ratio	= 8.0 (by volume)
	= 9.75 (by weight)
Speed	= 48 knots
Range	= 20,000 meters
Horsepower	= 520
Oxygen Efficiency	= 1800 hp secs/kg oxygen
Oxygen Consumption	$= \frac{520}{1800} = 0.289$ kg oxygen/sec.
Fuel Consumption	= 0.103 kg/sec
Water Consumption	= 1.00 kg/sec.

From Gas Analysis

	% by weight	Mols.
CO_2	16.0	0.364
CO	6.6	0.236
H_2O	77.0	4.28
O_2, H_2, N_2, etc.	0.4	Neglect

The Japanese could not supply the exact data of a gas analysis and these percentages (by weight) were estimated from data compiled from memory.

Composition of Fuel	86% Carbon	14% Hydrogen
Ratio of Atoms	C/H = 7.17/14	
	= 1/1.95	

Therefore, empirical formula of fuel - $CH_{1.95}$

O/F = 2.8 Ratio of mols = 1.22

W/F (by weight) = 9.75 Ratio of mols = 7.55

$$1.22\ O_2 + CH_{1.95} + 7.55\ H_2O = aCO_2 + bCO + cH_2 + dH_2O$$

$\underline{C}$ $a + b = 1$

$\underline{H}$ $2c + 2d = 1.95 + 15.10$

$\underline{O}$ $2.44 + 7.55 = 2a + b + d$

Gas analysis Mol. ratio $\frac{CO_2}{CO} = \frac{a}{b} = 1.54$

Solving these equations:

$a = 0.606$ $b = 0.394$

$c = 0.12$ $d = 8.38$

Therefore, $1.22\ O_2 + CH_{1.95} + 7.55\ H_2O = 0.606\ CO_2 = 0.394\ CO + 0.12\ H_2 + 8.38\ H_2O$

Neglecting the diluent water for the present we have:

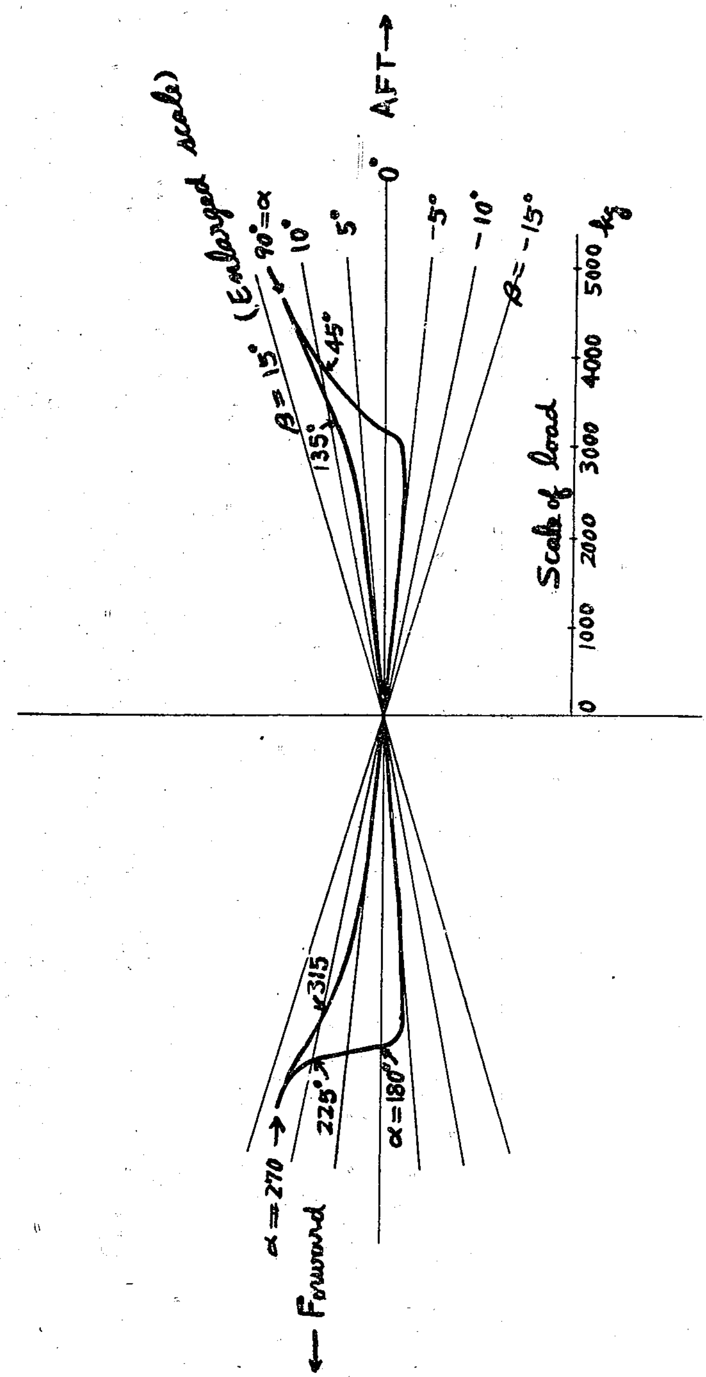


FIGURE 62
BEARING LOAD DIAGRAM

$$1.22\ O_2 + CH_{1.95} = 0.606\ CO_2 + 0.394\ CO + 0.12\ H_2 + 0.83\ H_2O$$

Heats of Formation

These values are for a temperature of 25°C and are the heats of formation of 1 gm. mol.

$CH_{1.95}$ = 4.185 K calories

$0.606\ CO_2$ = (94.25) 0.606 = 57.1 K calories

$0.394\ CO$ = (26.15) 0.394 = 10.3 K calories

$0.83\ H_2O$ = (57.83) 0.83 = 48.0 K calories

Total heat evolved (neglecting latent heat of fuel)

= (57.1 + 10.3 + 48.0) - (4.185) K calories/gm. mol. fuel

= 111.22 K calories/gm. mol. fuel

= 821.2 K calories/second

Now consider heat required to supply latent heat to the diluent.
Take the pressure in the generator as 34 kg/cm² (about 34 atmospheres)
Latent heat of water at this pressure = 415 K cals/kg
= 415 K cals/sec
Assume final temperature to be about 600°C
Mean specific heat of water from 25°C to 600°C = 8.63 cals/gm mol
= 0.479 K cal/kg
= 0.479 K cal/sec
Therefore, total heat given to diluent = 415 + 0.479 (T_2-T_1)K cals/sec,
Where T_1 and T_2 are the initial and final temperatures respectively.
Now consider heat given to products of reaction.
Mean specific heats (1) CO_2 from 25° to 600°C = 11.12 cal/gm mol/°C
(2) CO from 25° to 600°C = 7.26 cal/gm mol/°C
(3) H_2O from 25° to 600°C = 8.63 cal/gm mol/°C

Heat to raise temperature of products.

$= (T_2 - T_1)(0.606 \times 11.12 + 0.394 \times 7.26 + 0.83 \times 8.63)$

$= (T_2 - T_1)$ 16.76 calories

$= (T_2 - T_1)$ 0.01676 K calories/gm mol of fuel

$= (T_2 - T_1)$ 0.1237 K calories/second

Balance

$821.2 = 415 + 0.479\ (T_2 - T_1) + 0.1237\ (T_2 - T_1)$

$406.2 = 0.6027\ (T_2 - T_1)$

$T_2 - T_1 = \frac{406.2}{0.6027}$

$= 674°C$

Final temperature of generator = 659°C

Heat Loss From Generator

This problem must take into consideration a thin film of diluent water in contact with the inside of the generator and a film of cooling water in contact with the outside wall of the generator.

Therefore, conduction of heat takes place through a relatively stagnant film of water on the inside of the wall, then through the wall and finally through a stagnant film of water on the outside of the wall - similar to the action in a steam pipe.

The overall conductance (H) of the system will be given by:

$$H = \frac{1}{\frac{1}{H_1} + \frac{L}{K} + \frac{1}{H_2}}$$

Where H_1 and H_2 = Conductance of fluid films
K = Coefficient of conductivity of wall
L = thickness of wall

It is difficult to find a value for H, since it will be affected by the evaporation and condensation on the inner wall, the rate of flow of gas, and the temperature differences at various points on the wall. Assuming the system to be similar to a steam coil, a value has been taken for H of:

55 K cals/m^2/hour/°C.

Heat loss $= HA(T_1 - T_2)\,t$

Where H = overall conductance

A = surface area = (approx.) 0.155 m^2.

$T_1 - T_2$ = temperature drop across wall = 600°C

t = time

$$\text{Heat loss} = \frac{55 \times 0.155 \times 600}{3600}$$

$$= 1.42 \text{ K cals/sec.}$$

$$\text{Percentage loss} = \frac{1.42}{821.2} \times 100$$

$$= 0.17\%$$

Because of the above-mentioned factors which are very difficult or impossible to estimate, the figure obtained for percentage heat loss from generator walls can give no more than an indication of the true value.

It is safe to assume, however, that the heat lost from the walls is a great deal less than that estimated on the conduction of the metal alone (this comes to about 16%); therefore, for the purpose of this calculation, it will be neglected.

Thermal Efficiencies and Heat Balance Sheet

Theoretical Thermal Efficiency

The theoretical indicator diagram has been drawn and is shown in Figure 59. Since the motive fluid is about 80% steam, the estimation of the heat balance has been made using the Rankine cycle.

Now the Rankine efficiency $= \frac{H_1 - H_2}{H_1 - H_3}$

When:- H_1 = Total heat of the steam at inlet
H_2 = Total heat of steam after release
H_3 = Total heat of the water at initial pressure and final temperature

For the torpedo engine H_3 is usually taken as the total heat of the steam at exhaust since there is not a condenser and feed pump.

From the engine timing, cut-off takes place at 110° of crank angle and release at 135° from which the piston displacement can be deduced.

Taking swept volume as unity, and clearance volume at 5% = 0.05, volume at cut-off = 0.05 + 0.5 + 0.087 = 0.637

Volume at release = 0.05 + 1.0 - 0.067 = 0.983

Inlet temperature = 660°C

Inlet pressure = 34 kg/cm²

From $P_1 V_1^r = P_2 V_2^r$ the pressure at release can be obtained.

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^r$$

$$= 34 \left\{\frac{0.637}{0.983}\right\}^{1.27}$$

Where r = 1.27 for the motive fluid

$$P_2 = 34\ (0.648)^{1.27}$$

$$P_2 = 34 \times 0.5764 = 19.5 \text{ kg/cm}^2$$

Now the specific volume of steam at 34 kg/cm² and temperature 660°C is 0.125 m³/kg. Temperature at release $T_2 = \frac{P_2 V_2}{R}$

Where R = gas constant for the mixture

= 42.7 kg-m/kg

$$T_2 = \frac{19.5 \times 10^4 \times 0.125 \times 0.983}{0.637 \times 42.7}$$

$$= 880°K = 607°C$$

Total heat at pressure 34 kg/cm² and temperature 660°C = 910 kg cal/kg.
Total heat of saturated steam at exhaust:

Pressure 4.5 kg/cm² = 655 kg cals/kg

$$\text{Rankine Efficiency} = \frac{910 - 875}{910 - 655}$$

$$= \frac{35}{255} - 13.8\%$$

The total heat quantities are only approximate since they had to be estimated by extrapolation from a small chart. They are sufficiently accurate to indicate the order of the efficiency.

When compared with the actual efficiency of the semi-internal combustion cycle of 25%, the inherent disadvantage of the wet heater cycle becomes apparent.

Overall Thermal Efficiency

One lb oxygen on being burnt with kerosene yields 6000 B.T.U. or 3326 kg cal. Therefore heat produced per second in the generator of Type 93

$$= 0.289 \times 3326$$
$$= 961.2 \text{ kg cal}$$

Energy produced in generator $= \dfrac{961.2 \times 3087}{550}$

$= 5400$ hp

Measured shaft horsepower of engine = 520

Heat to work $= \dfrac{520}{5400} \times 100\%$

$= 9.6\%$

Heat Balance Sheet

Heat input -	
Per kg of oxygen	3326 kg cals
Heat output -	
To work 3326 x 0.096	319 kg cals

To exhaust

Water to fuel ratio by vol. 9.75; by wt. oxygen fuel ratio 2.8
Therefore, oxygen to water ratio = 3.48
At exhaust total heat = 655 kg cals
Heat to exhaust = 655 x 3.48 = 2279 kg cals
(Neglecting the heat carried away by the CO_2, CO and unburnt oxygen in view of the small quantity and low temperature)

To cylinder walls by difference 731 kg cals

Heat input	100%
Heat to exhaust	68.4
Heat to cylinder wall etc.	22
Heat to work	9.6
	100%

Examining these figures it will be seen that any attempt to reduce the external heat losses will result in little improvement in performance and that the main gain can only be obtained by reducing the exhaust losses.

The easiest method is to increase the expansion ratio but this is not possible when using this design of engine.

Lubricants and Fuel

Lubricants

Prior to the war, the Japanese used a blend of mineral oil (No. 1) and rape seed oil for general torpedo lubrication. The use of two oils in a blend was troublesome, since in each case the lubricant had to be blended to suit the operational zone of the ship to which the torpedoes were being issued.

Name	Saybolt Universal Seconds (S.U.S.)	
	100°F	210°F
No. 1 mineral oil	15,000	300
Rape seed oil	1,000	90

These oils have approximately straight line temperature/viscosity curves parallel to one another. The standard viscosity range used was 10,000-15,000 S.U.S. The practical useful range was 5000 - 26,000 S.U.S.

In order to avoid the trouble of blending, H. KAWASE undertook experiments to find a single lubricant. The First Naval Fuel Factory at OFUNA supplied No. 4 mineral oil which had characteristics very similar to rape seed oil.

	Saybolt Universal Seconds	
	100°F	210°F
No. 4 mineral oil	1,130	95

KAWASE carried out tests using No. 4 mineral oil alone as a torpedo lubricant. Owing to its low viscosity the stroke of the oil pump was reduced and, in the case of the Type 93, an orifice was also placed in the pipe line. By these methods the consumption of oil was kept within the normal limits. Tests were run in summer and winter and all gave satisfaction.

The only disadvantage in the method lay in the fact that, at the end of the run, the lubricant would be washed away by sea water and light corrosion occurred in crank chamber. For this reason the method was not adopted, but KAWASE is of the opinion that it is superior to the blending method. Corrosion protection, while the torpedo is on board ship, can be afforded by a grease.

The gyroscope is lubricated by a thin, colorless, mineral watch oil, supplied by Aichi Clock Co., NAGOYA and the First Naval Fuel Factory, OFUNA.

Fuel

In all their torpedoes the Japanese used kerosene which was generally referred to as "No. 1 Petroleum."

Composition	%
Carbon	86
Hydrogen	13
Oxygen	0
Sulphur	1

Specific gravity	0.80 - 0.85
Boiling range	125° - 300°C
Flash point	30°C
Calorific value	11,000 - 11,500 cal/gm

Ignition Temperatures

The Japanese carried out a number of experiments on ignition temperatures of materials in pure oxygen at various pressures.

The apparatus used consisted of a common type "Bomb" calorimeter. The sample of material under test was placed in an electrically heated dish. Temperature was measured by a thermocouple. The ignition temperature was indicated by a sudden rise in the reading of the thermocouple.

The following materials were tested:-

Graphite	Lead
Lignumvitae	Tin
Fibre	Solder
Bakelite	Nickel
No. 1 Mineral Oil	Tungsten
Asphalt	Copper
Ebonite	Rubber
Leather	Rape Seed Oil

The relation obtained between ignition temperature and pressure of oxygen is shown in Figures 63 (a) (b) (c).

Torpedo Drag and Shaft Horsepower

Theory

The method used by the Japanese in calculating the drag and shaft horsepower of their torpedoes is given below:

The resistance of a body is given by:

$$F = \frac{AV^2 CS}{2}$$

Where: F = resistance of the body (kg)
A = density of the medium in which the body moves (kg/m^3)
V = velocity (meters/sec)
C = drag coefficient
S = Surface area (meters^2)

Then the effective horsepower is:

$$EHP = \frac{F\ V}{75}$$

Where 1hp = 75 kg meters/sec

The area S is taken as the surface area in the case of a body which has a good streamlined form such as the torpedo.

For the value of C it is considered that the major portion of F is due to surface friction and the remaining part is eddy resistance. From experience this latter is considered to be 10% of the total.

For the value of the drag coefficient Schlichting's formula:

$$C = \frac{0.455}{(\log_e R)^{2.58}}$$

is used for turbulent motion at the higher torpedo speeds, where R = Reynold's number and has a value of about $1.5\text{-}2.0 \times 10^8$

$$EHP = \frac{A}{2}(1 + 0.1)\ \frac{0.455 \times S \times V^3}{(\log_e R)^{2.58} \times 75}$$

Substituting the value of A for sea water

$$A = 1026\ kg/m^3$$

The formula becomes:

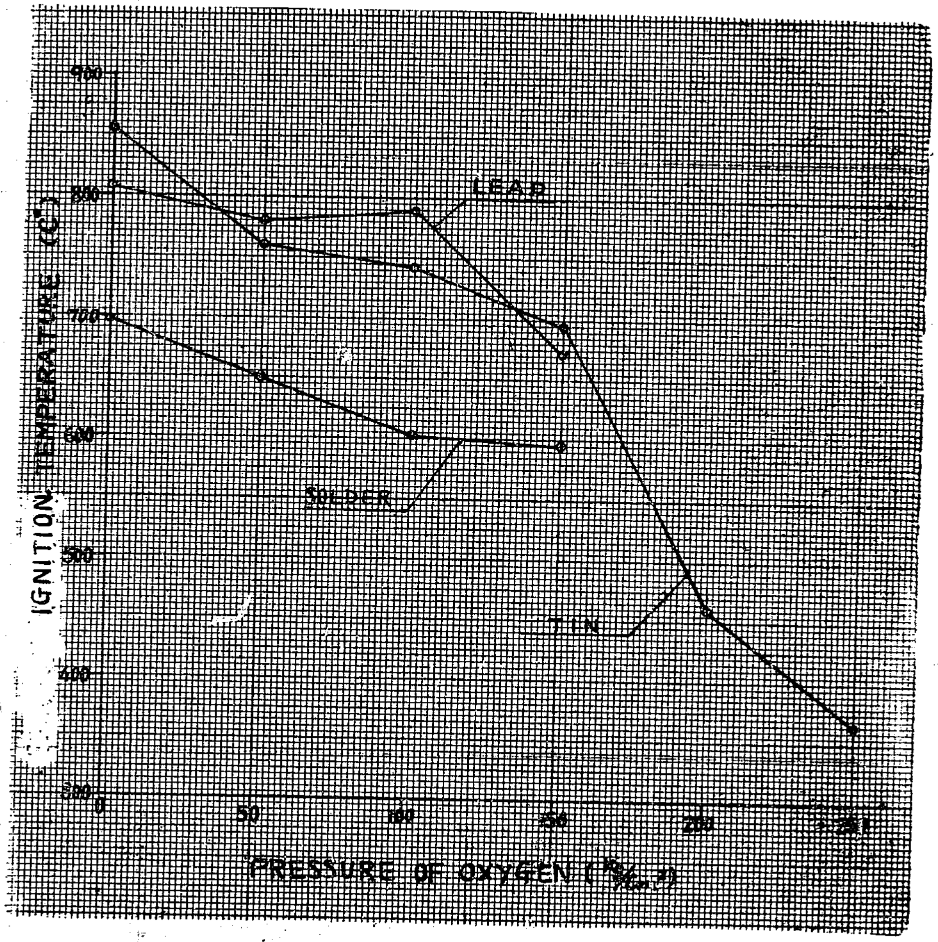


FIGURE 63(a)
IGNITION TEMPERATURES IN HIGH PRESSURE OXYGEN

$$EHP = \frac{1026 \times 1.10 \times 0.455 \times S \times V^3}{2 \times 75 \times (\log_e R)^{2.58}}$$

$$SHP = \frac{EHP}{E_p}$$

Where E_p = propulsive (hull and propeller) efficiency.

Test Results

As has already been stated, the out-of-balance forces are too big to permit the engine of the Type 93 torpedo to be tested in the engine dynamometer at outputs greater than 350 hp.

Tests of the torpedo in the tank were carried out, however, with the 21" Type 95 torpedo at 50 knots. It was first run with tanking propellers the pitch and diameter of which were calculated to allow for the difference in water flow between the sea and the tank. The RPM and reducer pressure were noted and the test repeated, at the same RPM and pressure, with the propellers removed and the shafts connected to a dynamometer mounted outside the tank.

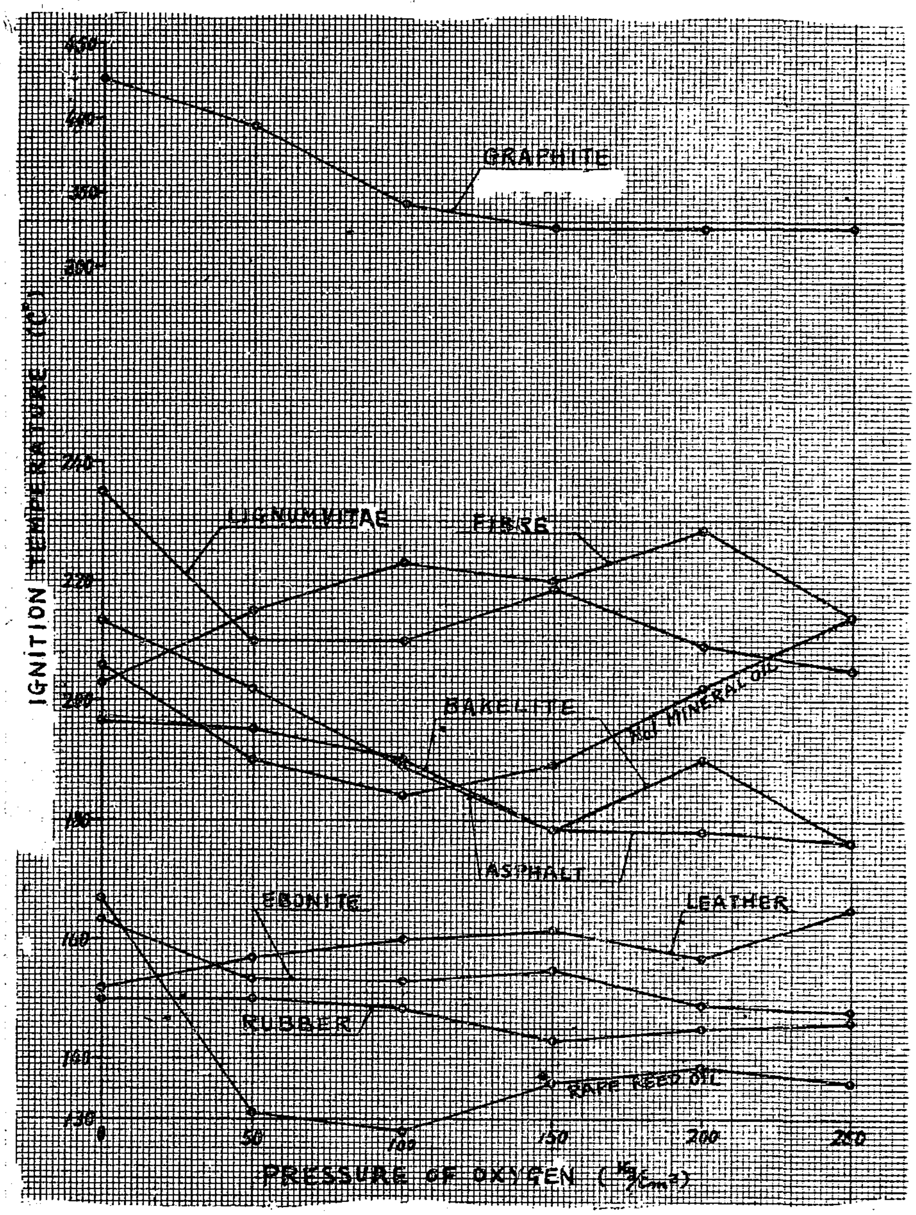


FIGURE 65 (b)
INGNITION TEMPERATURES IN HIGH PRESSURE OXYGEN

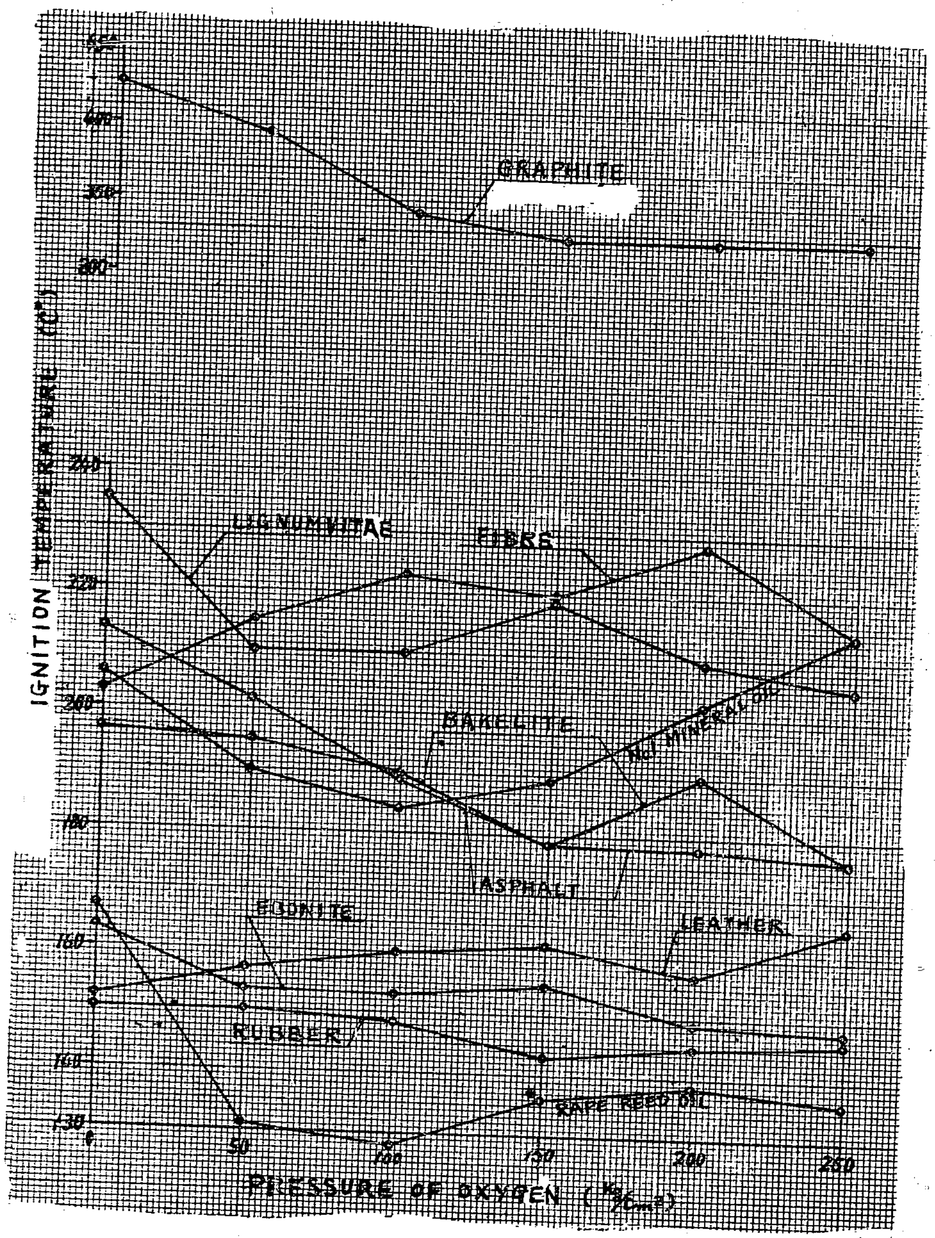


FIGURE 65 (b)
INGNITION TEMPERATURES IN HIGH PRESSURE OXYGEN

In actual tests confirmed by engine dynamometer tests, 1000 hp was required so the value of the propulsive efficiency E_p was only 0.83.

Taking this value of 0.83 the BHP for the Type 93 at an instantaneous speed of 62 knots was found to be 1040.

Similar calculations were made, using E_p = 90%, for 40 and 30 knots for both the Type 93 and turbine torpedo F3 and the curves shown in Figure 64 were drawn.

Determination of Propulsive Efficiency

As a check on the formula, a determination of the propulsive efficiency E_p has been made for the British 21" Mark IX torpedo.

Length (L)	= 291" (7.4m)
Diameter (D)	= 21" (53cms)
Speed (V)	= 35 knots
Horsepower	= 160
Total surface area	= Constant x π D L
	= 0.945 x π D L
	= 18,100 in^2
	= 11.7m^2

Speed (V) = 35 knots = 0.514 x 35 = 18.0 meters/sec

Reynolds number $R = \frac{VL}{\mu}$

Where μ = kinematic viscosity of medium

= 0.0113 cm^2/sec for sea water

= 0.0113×10^{-4} m^2/sec

$$R = \frac{18.0 \times 7.4}{0.0113 \times 10^{-4}} = 1.18 \times 10^8$$

$$\log_e R = 2.3 \times \log_{10} R$$

$$= 2.3 \times 8.0719 = 18.44$$

$$\log (\log_e R)^{2.58} = 2.58 \times \log_{10} 18.44 = 3.2656$$

$$(\log_e R)^{2.58} = 1844$$

$$EHP = \frac{3.42 \times 11.7 \times (18.0)^3}{1844}$$

$$= 126.6$$

$$\text{Propulsive efficiency} = \frac{126.6 \times 100}{160} = 79.1$$

The corresponding figures for the Japanese Type 93 are:

EHP = 468
SHP = 530
E_p = 88

The lower figure of the British torpedo is partly due to losses in the reversing gear which are not included since the horsepower in the dynamometer is measured immediately behind the engine.

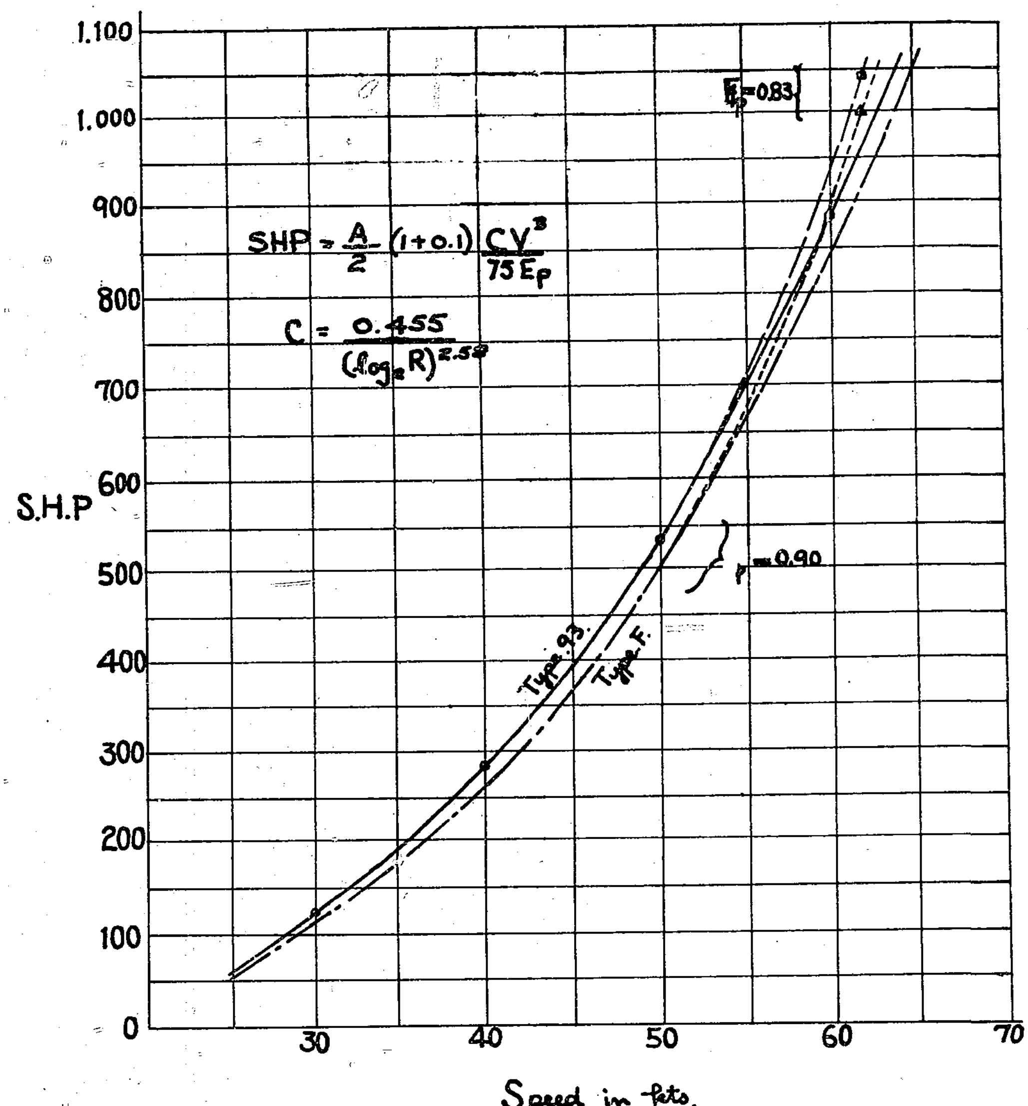


FIGURE 64
POWER SPEED CURVES

It is considered that these losses will not exceed 5% so that the propulsive efficiency is less than that of the Japanese torpedo.

Propeller Development

The problem of propeller design became most important during the development of Type 93, Model 1, because the speed approached 50 knots. Calculation showed that the output of the engine was sufficient for the speed but the figure could not be obtained in the sea. The performance of the torpedo was:

Depth	Speed
3 meters (9.84 ft)	46 knots
6 meters (19.6 ft)	48 knots
12 meters (39.4 ft)	50 knots

The Japanese realized that cavitation was occurring at shallow depths. Many experiments were carried out with modified propeller forms including:

Constant pitch
Varying pitch increasing towards blade tip
Blade area
Blade form
Blade section

Tests were not completed due to the difficulty in manufacturing experimental propellers.

The effect of all the modifications was less than 2 knots. Some improvement resulted from:

Varying Pitch, Decreasing at the Tip - A mean pitch of 1.3 meters is maintained, the pitch at the two ends of the blades being less than that in the center.

Elliptical Blade Form - The normal blade is wide at the tip and decreases uniformly to the root; with the elliptical form the maximum width occurs at 0.7 of the radius and decreases at the root and the tip.

Increase in Blade Area - The normal form was retained but the width generally increased.

Single Arc Section - The use of a single radius to get the curved surface on the back of the blade in place of two radii.

About five or six years ago, while the tests were in progress, an Italian 50-knot torpedo was imported. It was found that the torpedo had no special feature except a streamlined head, Fiume tail and comparatively thin propeller blades. The torpedo was tested in the dynamometer and in the sea.

The conclusion reached was that the short elliptical head was not suitable for high-speed and that the streamlined form was very important for maintaining propeller efficiency. It was explained that the propellers themselves did not cavitate but that a poor torpedo form prevented water from reaching the blades. The Italian streamlined form as shown in Figure 132 was adopted.

Speeds up to 52 knots were obtained with both Type 93 and Type 95. It was also stated that by the use of this head it was possible to obtain 50 knots with an engine output corresponding to 48 knots with the standard head.

The results of the tests were used in the design of the turbine torpedo and a speed of 60 knots was stated to have been reached with comparative ease.

Commander HORI was of the opinion that the efficiency of the propeller of the turbine torpedo was slightly less than that of Type 93 but that the bigger jet reaction of the former compensated for this loss. In view of the low velocity of the exhaust steam this is doubtful.

He was further of the opinion that speed increase would continue up to about 65 knots without serious decrease in propeller efficiency. As regards initial heel this could be prevented by:-

Decrease in the pitch of the rear propeller
Increase in blade area of the rear propeller

The amount of the decrease is about 5% in the case of the high-speed torpedo such as the turbine torpedo F3.

Experiments were carried out by torpedo tests only, and the results were deduced from measurement of speed, consumption, and the recorder results.

Commander HORI is of the opinion that fundamental data must be obtained in the model tank with contra-rotating propellers.

Design of Standard Propellers

The design of the standard propellers was obtained by the measurement of a pair of propellers from a Type 93 torpedo.

P, the pitch can be obtained from the formula:

$$\frac{P}{2\pi r} = \frac{b}{a} \quad \text{or} \quad P = \frac{2\pi r b}{a}$$

Where r = radius of the blade at the section under consideration
a = projection of the blade section along the axis of the torpedo
b = projection length of the blade

Four sections were taken for each propeller.

Forward propeller

Section A

r = 120mm)
a = 67mm) Pitch 1.140 meters
b = 101mm)

Section B

r = 170mm)
a = 99mm) Pitch 1.240 meters
b = 115mm)

Section C

r = 220mm (0.76 R)
a = 124mm) Pitch 1.360 meters
b = 122mm)

Section D

r = 270mm a = 131mm b = 116.5mm	Pitch	1.490 meters

After Propellers

Section A

r = 97mm a = 60mm b = 105mm	Pitch	1.060 meters

Section B

r = 143mm a = 85.5mm b = 115mm	Pitch	1.190 meters

Section C

r = 189mm (0.7 R) a = 111mm b = 121mm	Pitch	1.300 meters

Section D

r = 235mm a = 130mm b = 122mm	Pitch	1.380 meters

From the results the distribution of the pitch has been drawn. It will be seen that it increases from 1.020 meters at root to 1.540 at the tip and is the same for both propellers. Figures 65-66 give the full details.

Material

The propellers are made of steel having the undernoted composition:

Carbon	0.3 - 0.4%
Silicon	<0.3
Manganese	<0.7
Phosphorus	<0.045
Sulphur	<0.040
Brinnel hardness after quenching in water	180 ± 20

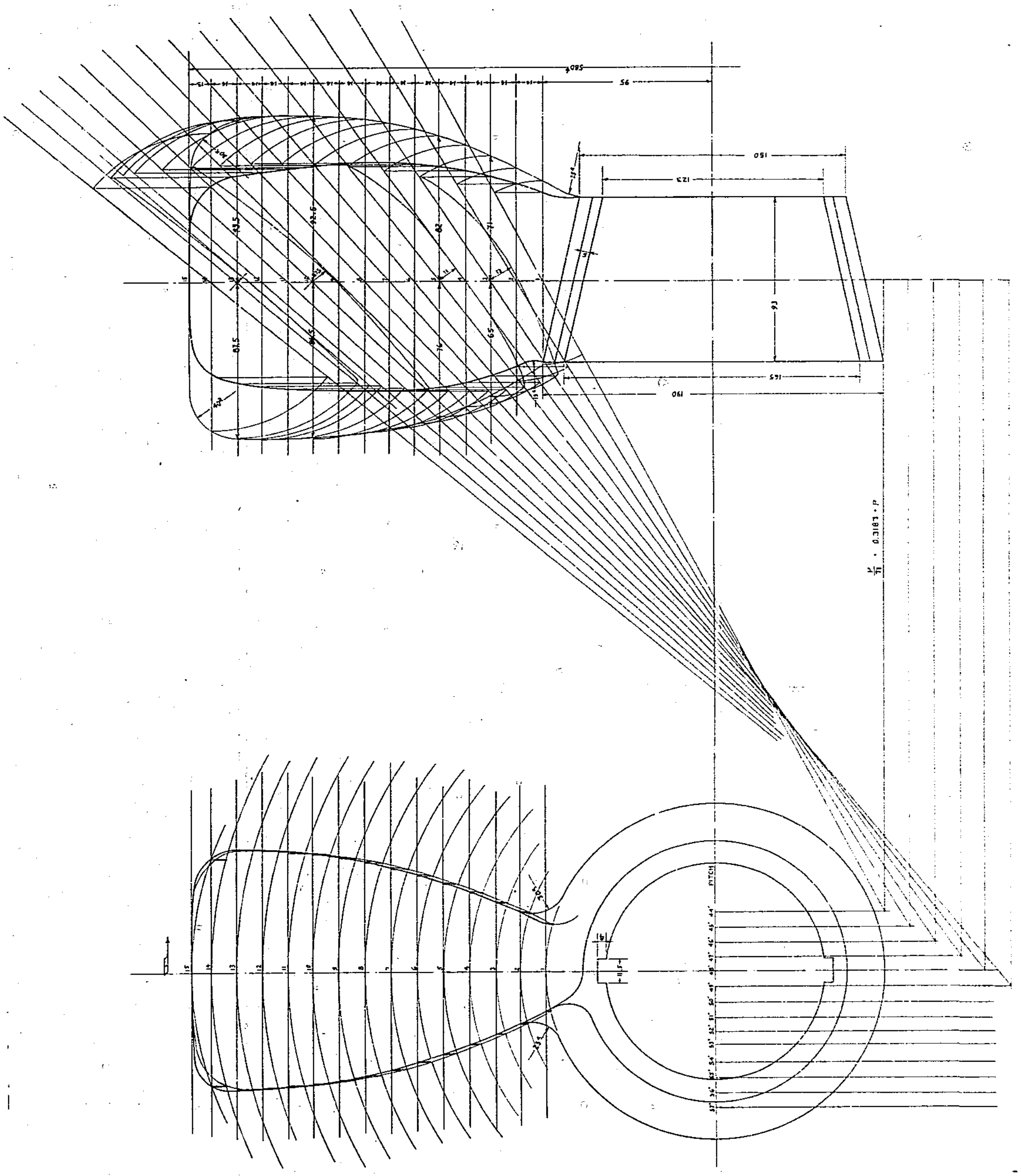


FIGURE 65
FORWARD PROPELLER. TYPE 93

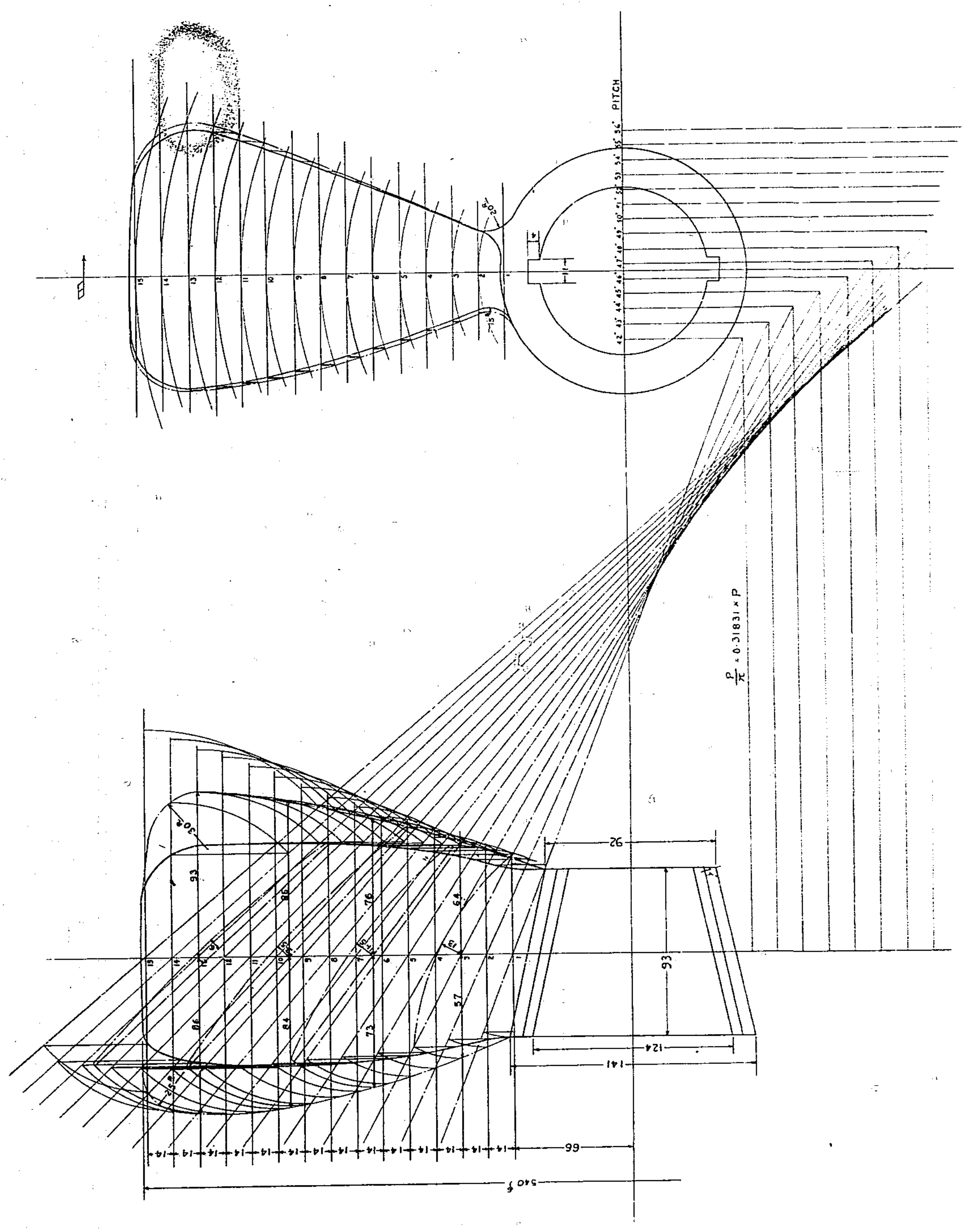


FIGURE 66
AFTER PROPELLER. TYPE 93

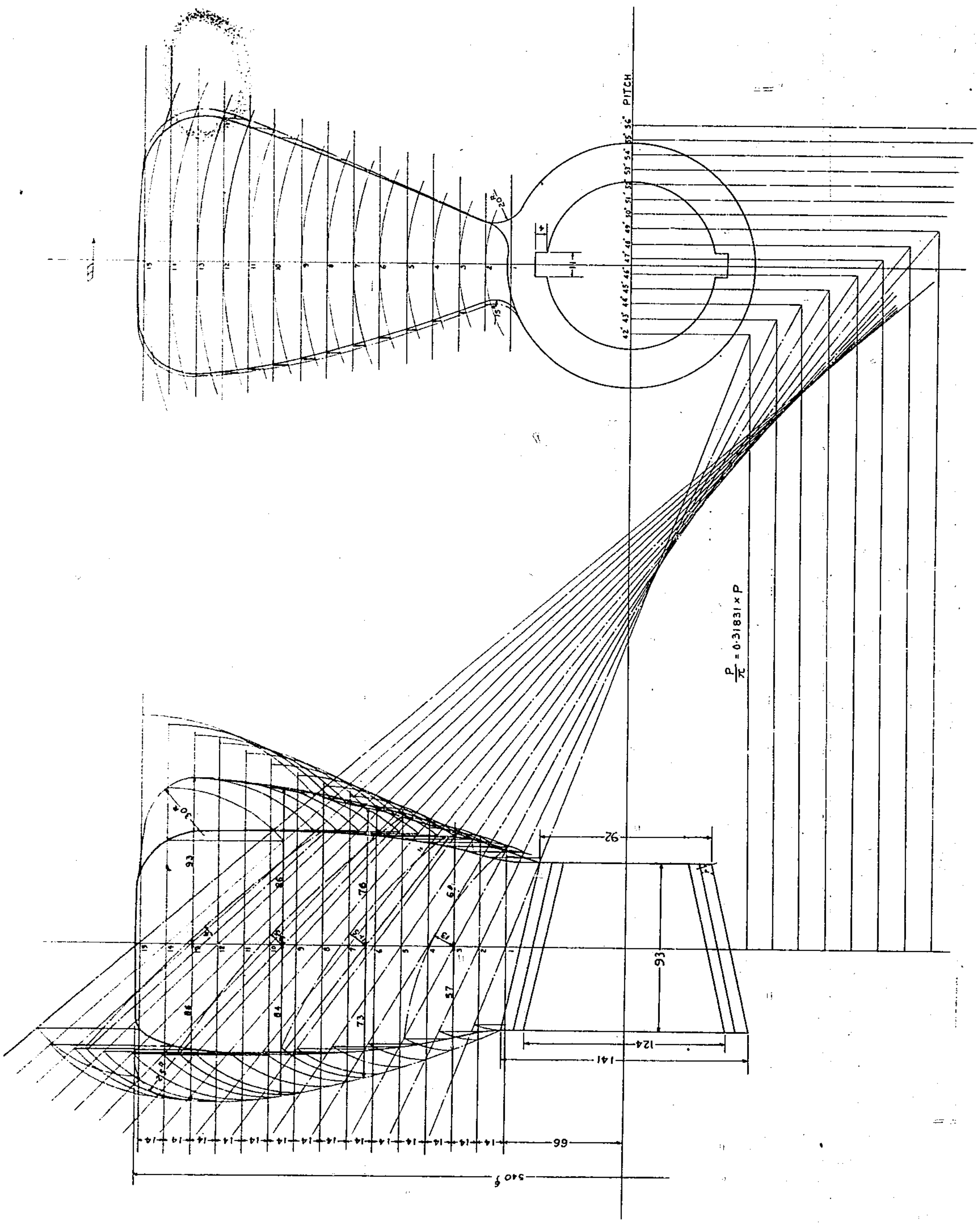


FIGURE 66
AFTER PROPELLER. TYPE 93

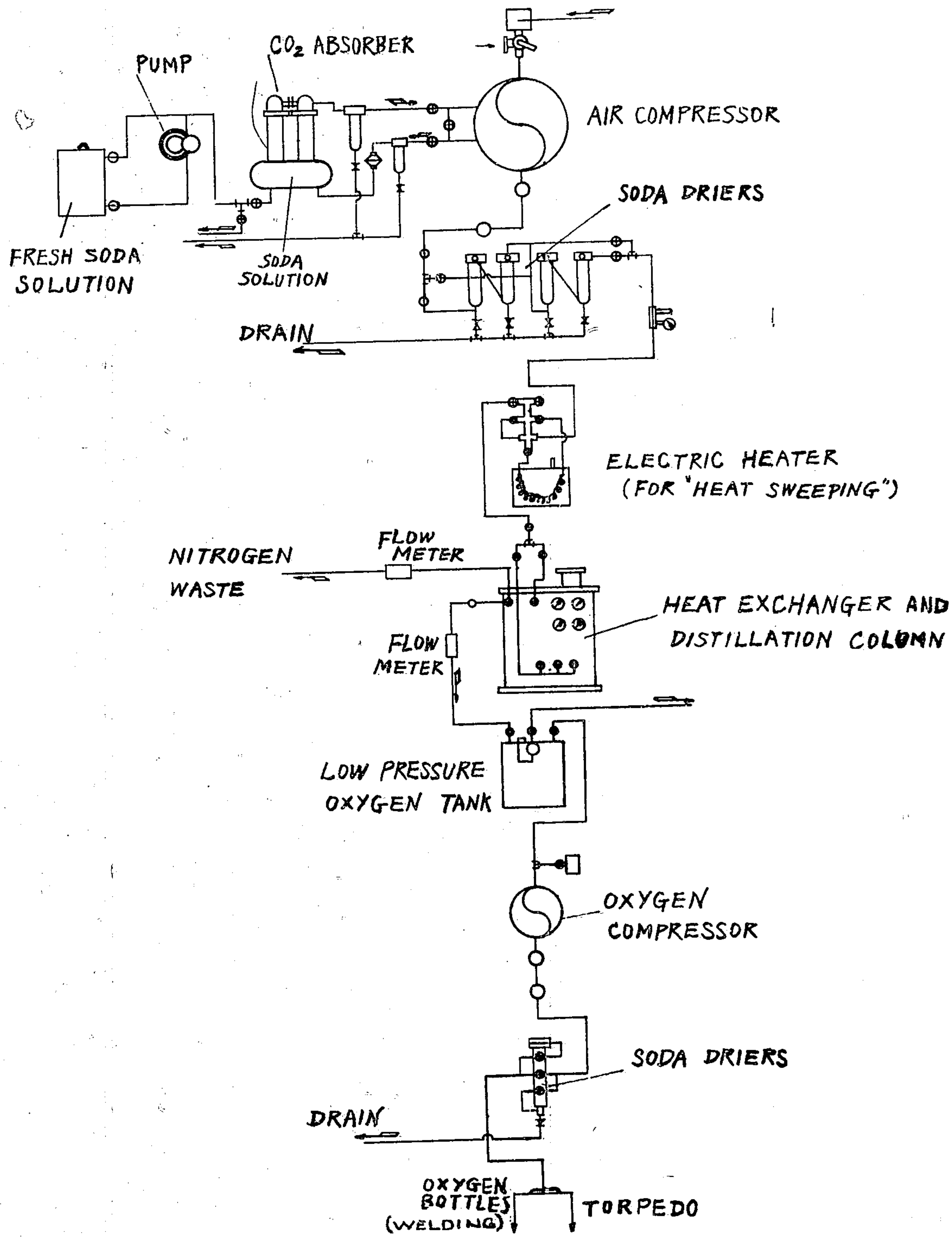


FIGURE 67
OXYGEN FLOW DIAGRAM

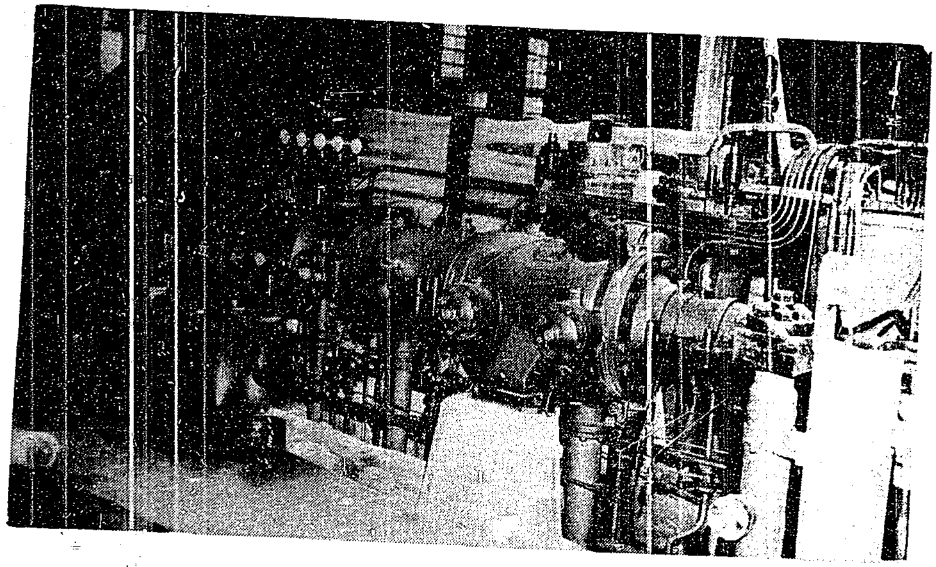


FIGURE 68
AIR COMPRESSOR, KAMPON 2 TYPE, LAND OXYGEN PLANT

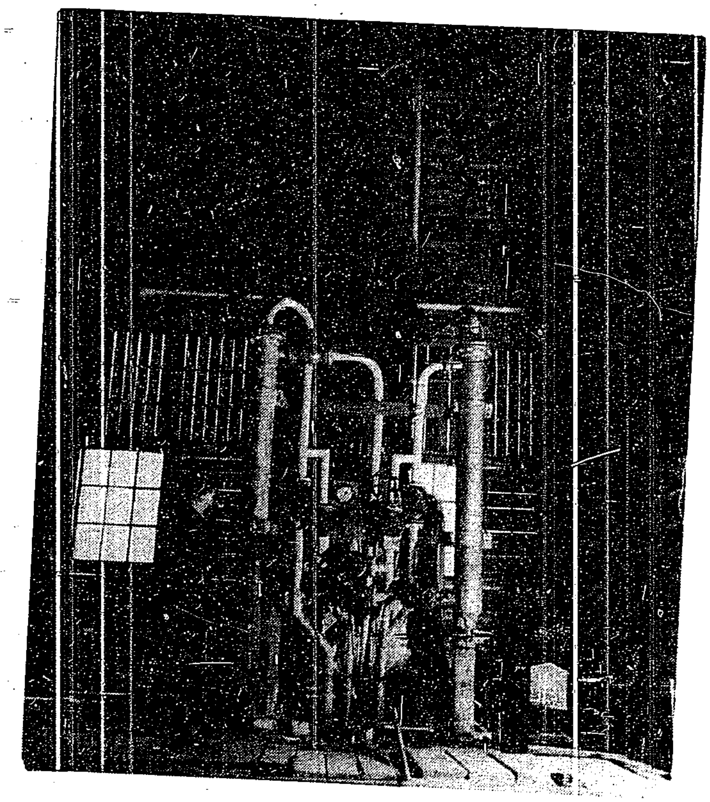


FIGURE 69
CARBON DIOXIDE ABSORPTION TOWER

Water cooling is carried out between each stage. The cooling water is cooled in a large concrete tank after use, and then reused.

CO_2 Absorption

This is carried out in a tower filled with an aqueous solution of caustic soda; concentration 18 - 20 Be. (See Figure 69).

Heat exchanger and rectification column

These units are shown in Figure 70. The heat exchanger is made of copper, insulated with slag wool and encased with mild steel plate. A precooling valve is fitted to the lower part of the exchanger.

The rectification column is made of copper and is divided into three main parts, lower column, condenser and upper column. The lower column is packed with Raschig rings and is separated from the upper column by the condenser. The upper column contains 42 plates designed on the "bubble plate" system.

Operation

The cooled compressed air from the heat exchanger passes through a coil at the bottom of the lower column (evaporator) and then is allowed to expand into the middle of the lower column, where it cools and liquefies.

The more volatile nitrogen distills to the top of the lower column where it is condensed to a liquid. The oxygen and some nitrogen pass to the bottom of the column forming a liquid mixture containing about 50% oxygen. This liquid is continually heated and evaporated by the compressed air from the heat exchanger which passes through the evaporator.

A pipe leads from the bottom of the lower column to the middle of the upper column. By the existing pressure difference this pipe conveys liquid "air" (50% O_2) to the middle of the upper column where it is fractionated, and nitrogen (with a few percent of oxygen) passes out of the top of the column. Pure oxygen collects in the bottom of the upper column (in the condenser tubes) and serves as condensing fluid to condense the nitrogen in the top of the lower column.

Increased reflux for the upper column is supplied by a pipe which conveys liquid nitrogen (by the existing pressure difference) from the lower column to the top of the upper column.

When in full operation, oxygen (99% purity) is drawn form the top of the condenser, and nitrogen (with 3% oxygen) is passed from the top of the upper column.

Oxygen Compressor (See Figure 71)

KAMPON Model 4

Electric motor	70 hp, "V" belt drive, 500 RPM
Highest working pressure	300 kg/cm^2; 4260 lbs/in^2
Capacity (oxygen at 300 kg/cm^2)	360 liters/hour; 12.7 ft^3/hr

The operation of this type of oxygen plant presents little difficulty. The results of an experimental run made on 28 December 1945 with a plant of this type installed at KABURAZAKI, near KURE, is shown on page 179

Sampling tubes are provided for taking samples of oxygen, waste nitrogen, liquid air and liquid oxygen.

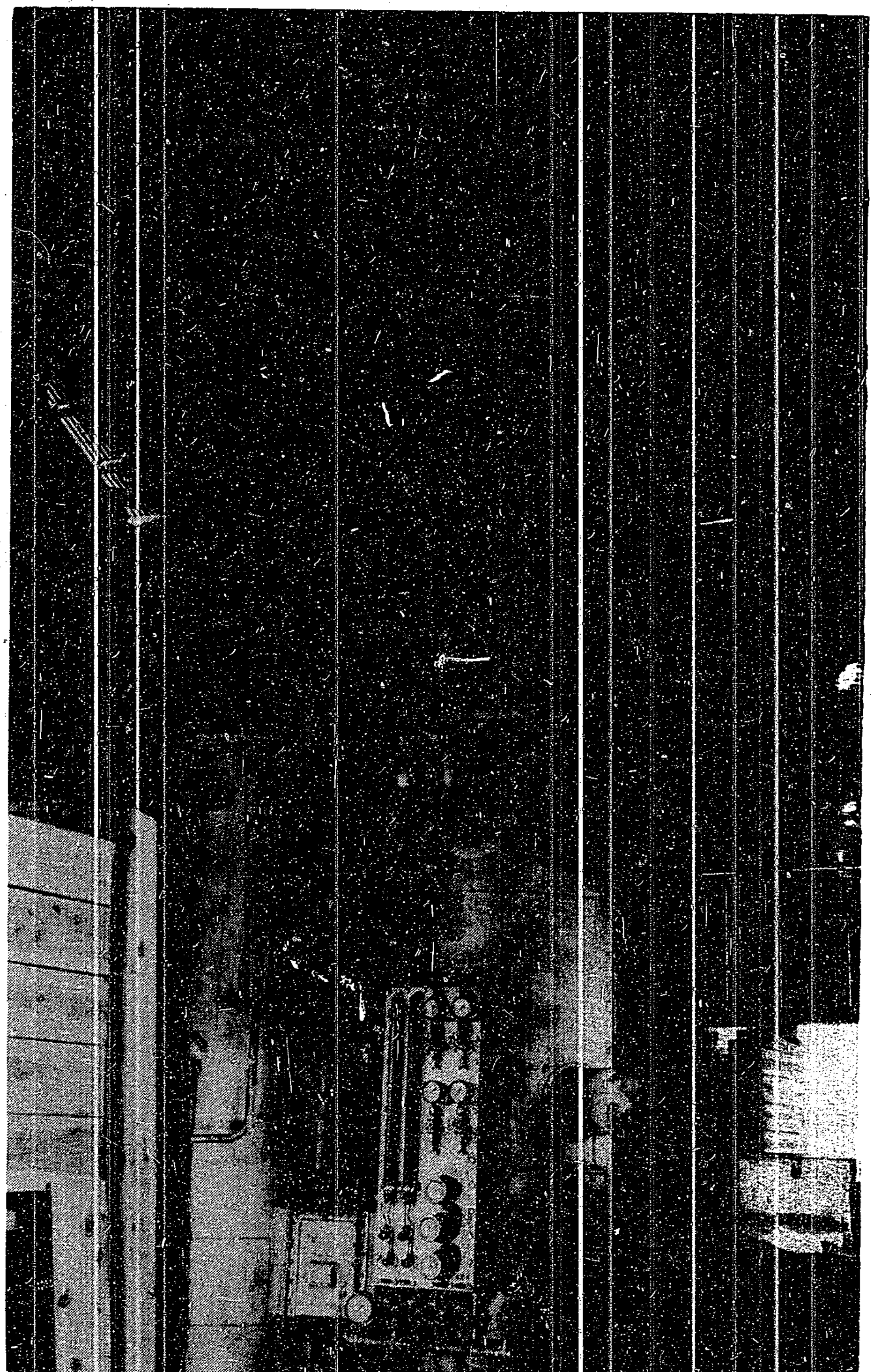


FIGURE 70
HEAT EXCHANGER AND COLUMN

EXPERIMENTAL RUN OF LAND PLANT

TIME	PRESSURE GAUGE KG/CM²					VOLUME GAUGE		OPENING OF VALVES (DEGREES)				PERCENT OXYGEN		
	H.P. PUMP	HEAT EXCHANGER		LOWER COLUMN	UPPER COLUMN	LIQUID AIR (CM)	LIQUID OXYGEN (CM)	EXPANSION VALVES				OXYGEN	LIQUID AIR	EXHAUST GAS
hrs-min		INLET	OUTLET					1ST	2ND	3RD	PRE-COOLING			
00 - 00	30			0	0.25			shut	shut	shut	shut			
01 - 00	30			0	0.25			shut	shut	shut	shut			
02 - 00	200	200	195	0.1	0.15	shut	shut	shut	360° x 17	360° x 17	175			
03 - 00	195	185	180	0.1	0.15	shut	shut	shut	360° x 17	360° x 17	140			
04 - 00	180	180	175	0.05	0.1	shut	shut	shut	360° x 17	360° x 17	130			
05 - 00	195	200	200	1.8	0.27	9.5	shut	60	360° x 17	360° x 17	shut			
06 - 00	173	185	192	1.25	0.2	15	shut	40	360° x 17	360° x 17	shut	97.1%	54%	18%
07 - 00	170	180	185	1.4	0.25	15	shut	22-40 42	360° x 17	360° x 17	shut	97.5%	53.5%	19%
08 - 00	170	180	185	1.4	0.25	15	14	23-45 45	360° x 17	360° x 17	shut	95.9%	55%	20%
09 - 00	180	185	190	1.4	0.25	15	58	23-45 45	360° x 17	360° x 17	shut		56%	
09 - 37				3.3	0.22	15	86	23-45 45	200	50	shut			
09 - 42							66		200	50	shut			
09 - 47				3.7	0.22		65		200	50	shut			
09 - 52				4.7	0.38		59	57	201	50	shut	95%		
10 - 00	135	145	150	4.7	0.4	16	50	57	200	50	shut			
10 - 05	137	150	150	4.05	0.25	16	53	50	200	50	shut	98.6%	69%	17%
10 - 30												98.9%		
10 - 40	120	125	127	4.4	0.28	16	53	55	205	50	shut	99.1%	45%	5.6%
11 - 00	Oxygen Production ceases.													
11 - 30	Heat Sweeping Begins.													
15 - 00	Heat Sweeping Ends.													

Time	Valve Opening		Room Temperature (°C)	Electric Power		Record
hrs-min.	Oxygen	Exhaust Gas		V	A	
00-00	full open	full open	9	3300	40	Note: When exhaust gas temperature rises to 40°C the heat sweeping stops.
01-00	full open	full open	10	3300	40	
02-00	full open	full open	10	3300	45	00-00 Heat sweeping begins
03-00	shut	full open	9.8	3300	43	01-45 Blowing 01-55 High pressure air sent to the distillation column
04-00	shut	full open	9.5	3300	43	
05-00	shut	full open	10.5	3300	43	04-10 The 1st exp. valve opened
06-00	shut	full open	9	3300	42	04-25 Liquid air produced 07-35 Liquid oxygen produced
07-00	shut	full open	8	3300	42	
08-00	shut	full open	8	3300	42	
09-00	shut	full open	5	3300	42	
09-37		full open				
09-42		full open				
09-47		full open	5			
10-00	full open	full open	6			
10-45	full open	full open	6	3300	41	
11-30	full open	full open	6	3300	41	

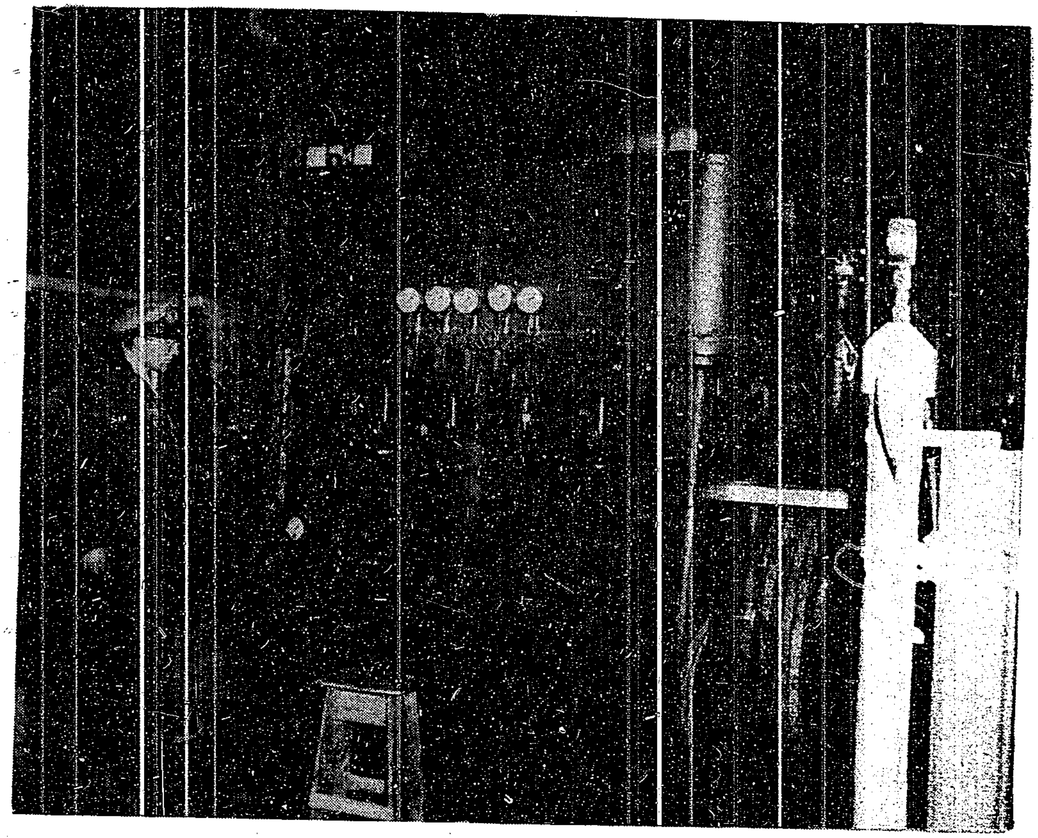


FIGURE 71
OXYGEN COMPRESSOR

Oxygen

This is absorbed in a Hempel gas absorption bulb using the following absorbing solution:

Ammonium carbonate	500gm
Ammonia solution (sp. gr. 0.88)	1000cc
With water, make volume up to	2000cc

The absorption bulb is packed with copper wire which absorbs oxygen in the presence of the above solution giving the deep blue color of the copper complex $Cu(NH_3)_4$. About three minutes are required to complete the absorption.

Acetylene

It is very inportant that the site of the plant should be as far away as possible from welding operations or other sources of acetylene. The presence of the latter in the plant may result in explosions, particularly if copper acetylide should be formed with the wall of the column.

Ilosvay's reagent is used for the detection of acetylene.

A.	Crystalline copper nitrate	2gm
	20% ammonia solution	8cc
	Water	100cc
B.	Hydroxylamine hydrochloride	6gm

The presence of acetylene is detected by the development of a pink color on the mixing of reagents A and B and bubbling the oxygen through the mixture.

Ship Plant

The main features of the ship's oxygen plants are their compactness, and relative lightness. On the other hand, the rectification column being small, it is necessarily less efficient than the land plant, and the compressors, which have a high rate of revolutions, are more subject to breakdown.

No attempt has been made in the design to maintain the column in a vertical position, and by this means to render the oxygen production independent of the roll of the ship. In the plate design, attempts have been made to keep the bubble holes in the plates covered with liquid, when the ship pitches or rolls. This is only successful when the departure of the column from the vertical is of the order of a few degrees.

Free oxygen is manufactured in two plants of capacities 30 m^3/hr (1060 ft^3/hr) and 15 m^3/hr (530 ft^3/hr) of free oxygen respectively. The former is used aboard cruisers and aircraft carriers, the latter aboard destroyers. The differences between these two plants are mainly dimensional, and in the following, the 30 m^3/hr capacity plant will be discussed.

One of these plants was inspected aboard the aircraft carrier KATSURAGI, (completed 1943). The plant was installed in two adjacent rooms, five decks below the flight deck and about 100 feet from the bow. The approximate dimensions and contents of the two rooms were:

I. (a) Dimensions

Deck area	18' x 13'
Height	7'

(b) Contents
- Two air compressors with motors
- CO_2 absorption tower
- Fresh soda reservoir
- Air filters
- Compressed air storage bottles
- Soda driers

II. (a) Dimensions

Deck area	18' x 13'
Height	7'

(b) Contents
- Heat exchanger and rectifying column
- Soda driers
- Electric heater for heat sweeping
- Low pressure oxygen storage tank
- Compressed oxygen storage bottles
- Oxygen compressor with motor

The flow sheet for this type of plant is shown in Figure 72 (a)(b)(c).

Heat Exchanger and Rectification Column

These are combined in one outer case of mild steel plate and are insulated with slag wool. (See Figure 73). See Figure 74 for CO_2 absorption tower.

Heat Exchanger

This unit is about six feet in height and is of copper construction. See Figure 75 for details.

Column

The upper and lower column casings are made of copper and the condenser casing is made of brass. There are nine plates in the lower column (stated to be equivalent to five theoretical plates), and 25 plates in the upper column (stated to be equivalent to 20 theoretical plates). These plates consist of flat brass discs which have been perforated with a large number of 0.9mm holes. The surface of each plate is divided into sections by copper partitions 9mm high. In the lower column these partitions run at right angles to each other and divide the surface of a plate into about 40 sections. (See Item B of Figure 76). In the upper column the partitions have a wavy form and they divide the surface into about 400 sections. (See Item B of Figure 77).

By this design, the plate surfaces remain covered with refluxing liquid even when the column is not exactly vertical.

To obtain increased contact between the ascending gas and the reflux, each plate is covered with a corrugated brass plate which has been stamped with a large number of slotted holes. (See Items A of Figures 76-77).

The reflux can flow from one plate to the next by means of four connecting copper pipes which run from each plate to the one below.

At the top of the column, above the liquid nitrogen reflux inlet, about 6,000 brass Raschig rings are packed.

Figure 78 shows a plan view of the evaporator located in the bottom of the lower column.

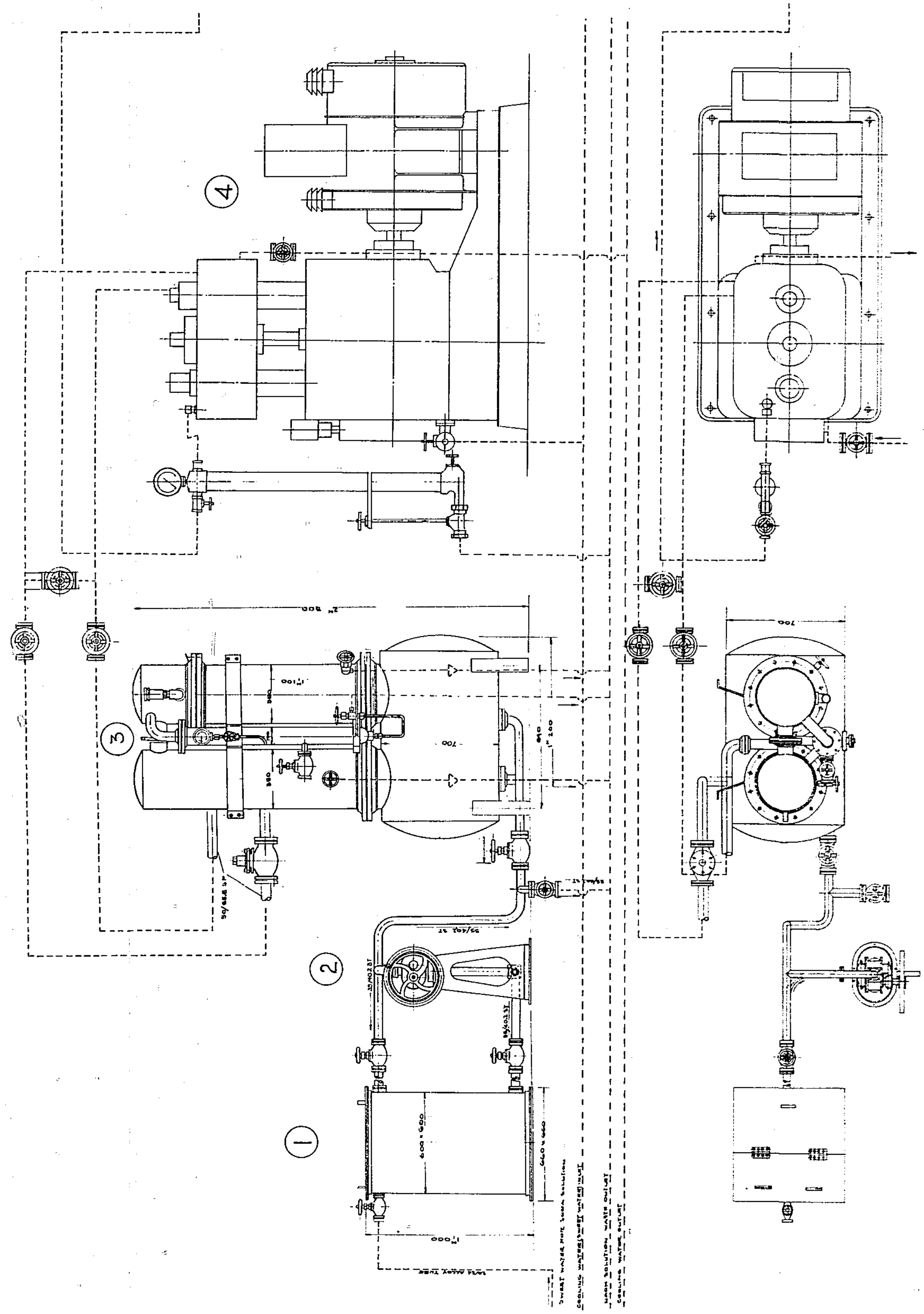
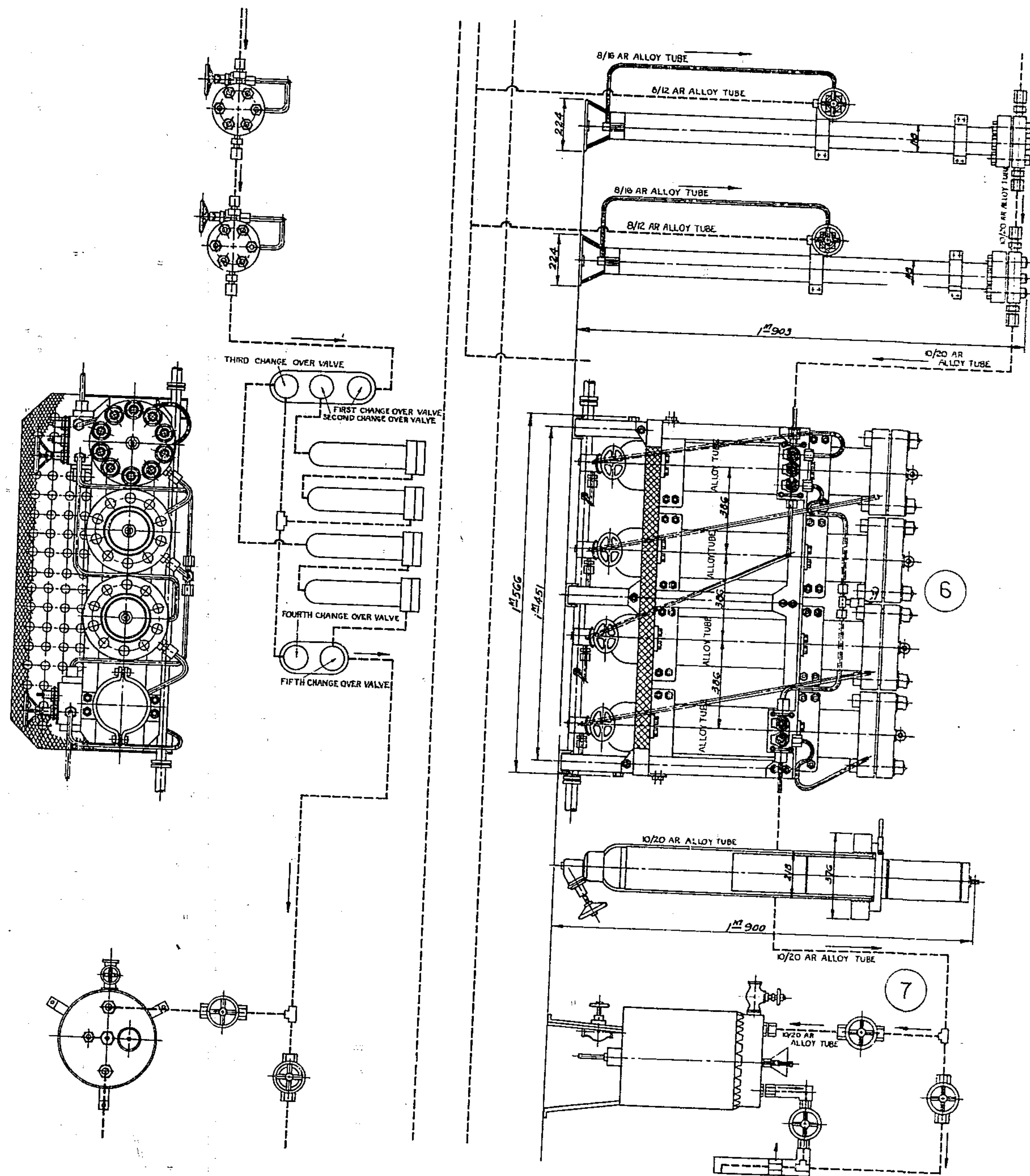


FIGURE 72 (a1)
LARGE FLOW SHEET OF OXYGEN PLANT

LARGE FLOW SHEET OF OXYGEN PLANT



LARGE FLOW SHEET OF OXYGEN PLANT

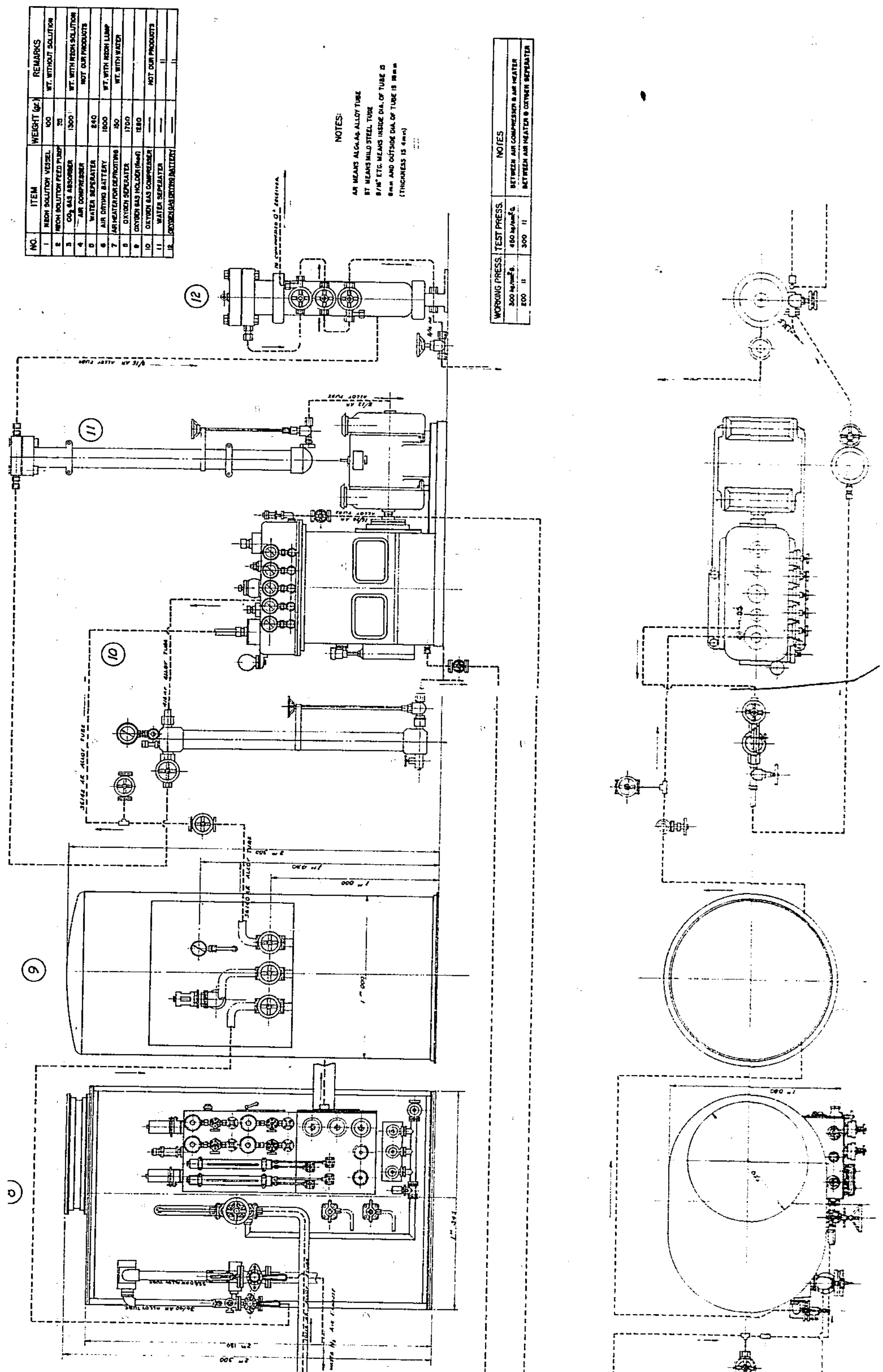


FIGURE 72(c1)
LARGE FLOW SHEET OF OXYGEN PLANT

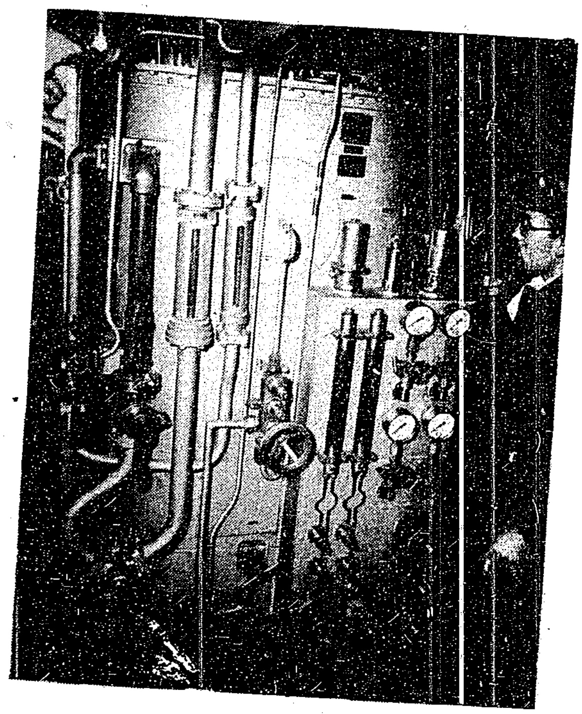


FIGURE 73
HEAT EXCHANGER AND COLUMN

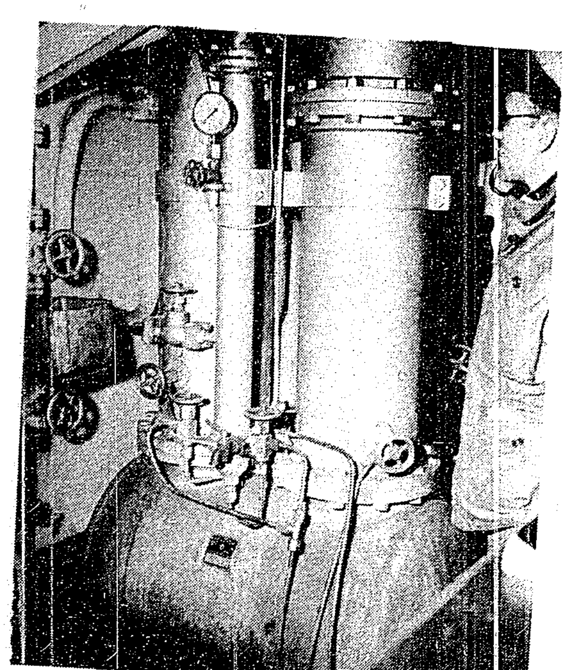


FIGURE 74
CARBON DIOXIDE ABSORPTION TOWER

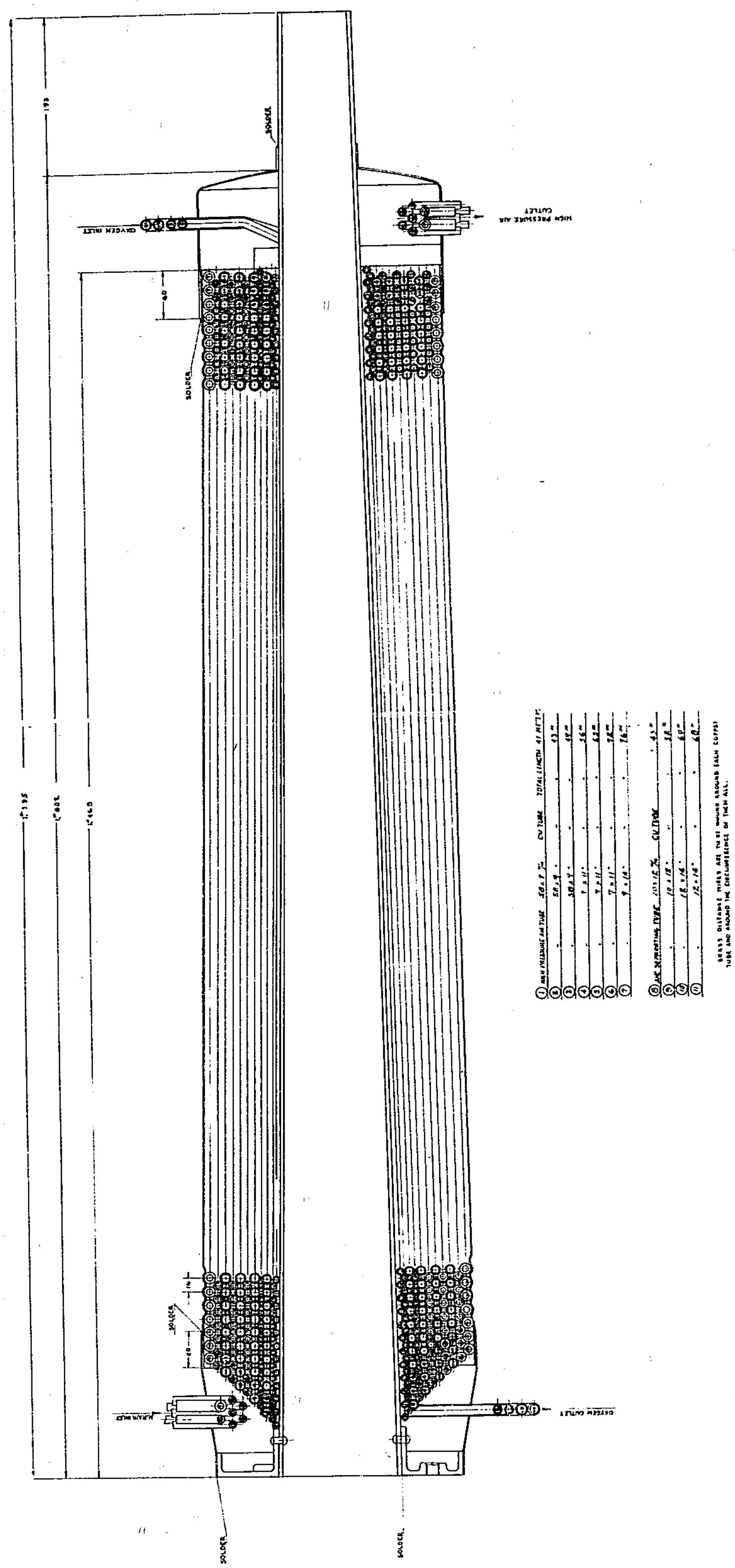


FIGURE 75
DIAGRAM OF HEAT EXCHANGER

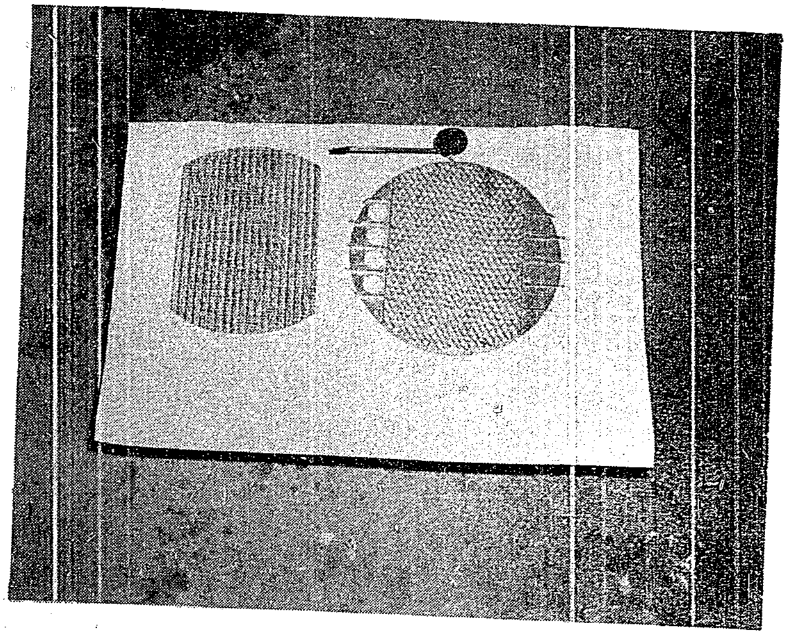


FIGURE 76
PLATE OF UPPER COLUMN

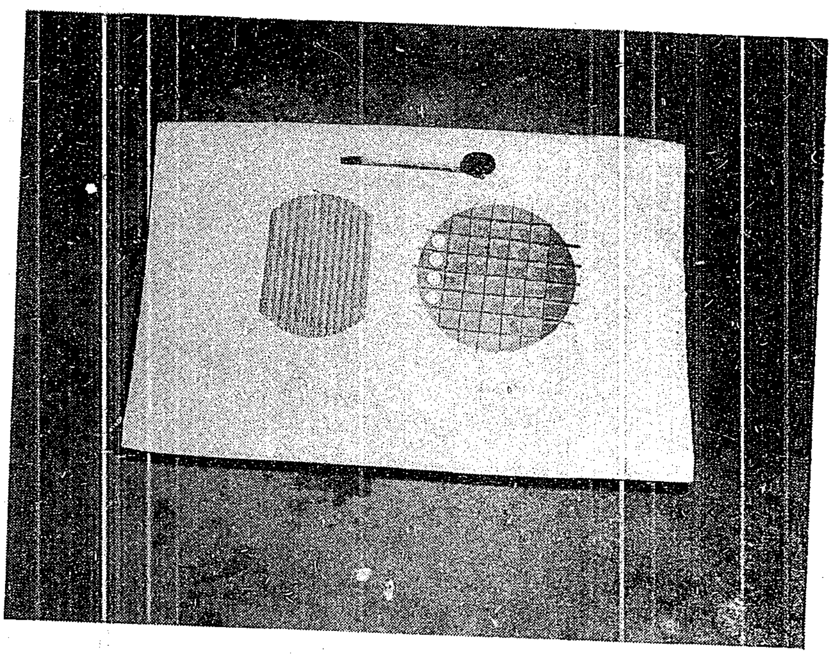


FIGURE 77
PLATE OF LOWER COLUMN

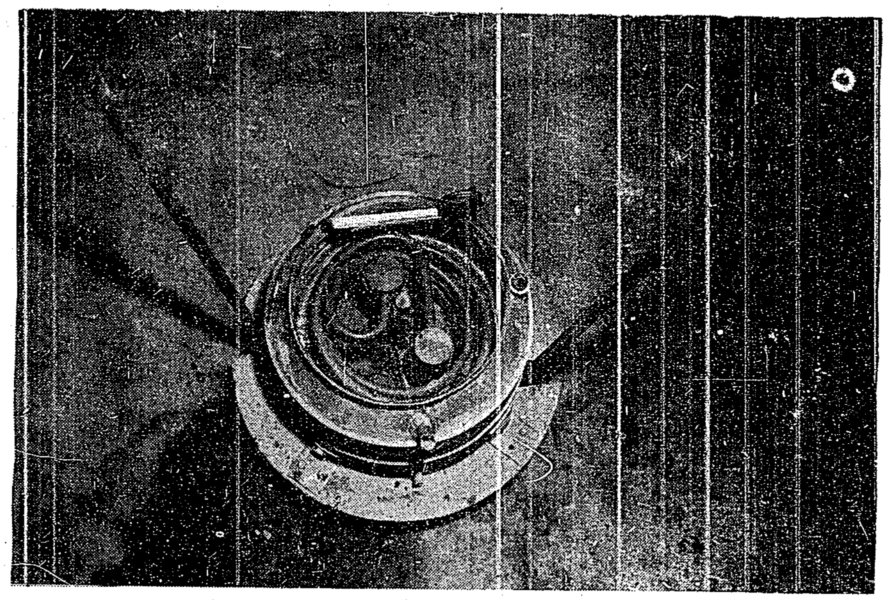


FIGURE 78
EVAPORATOR

A general view of the rectifying column is shown in Figure 79.

In oxygen plants designed for cruisers, it is usual to use a KAMPON Model 3 air compressor and a KAMPON Model 2 oxygen compressor.

These compressors were manufactured to Navy specifications by:

(1) Kobe Seiko Co., KOBE
(2) Mitsui Seiki Co., TOKYO
(3) Yokosuka Dockyard

Both of these compressors are five-stage, with sea water cooling between each stage. Power is supplied by an electric motor directly coupled to the compressor shaft. Details are given below.

<u>Air Compressor</u>

KAMPON Model 3. (See Figure 80).
Used by cruisers and aircraft carriers.

Volumetric efficiency	85%
Highest working pressure	300 kg/cm^2 (4200 lbs/in^2)
Capacity (air at 300 kg/cm^2)	700 liters/hr (24.7 ft^3/hr)
RPM	500
Number of stages	5
Stroke of piston	120mm (4.73 in)

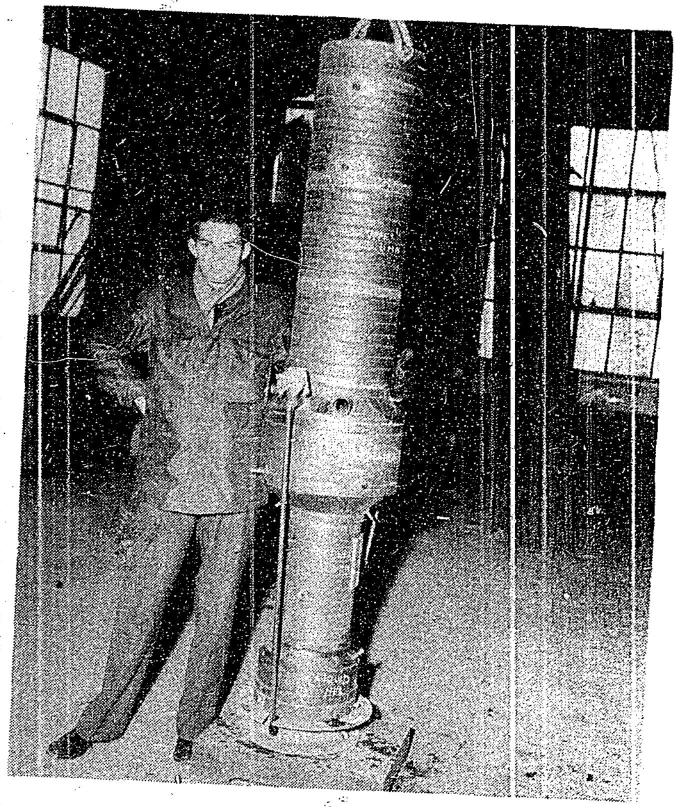


FIGURE 79
GENERAL VIEW OF COLUMN

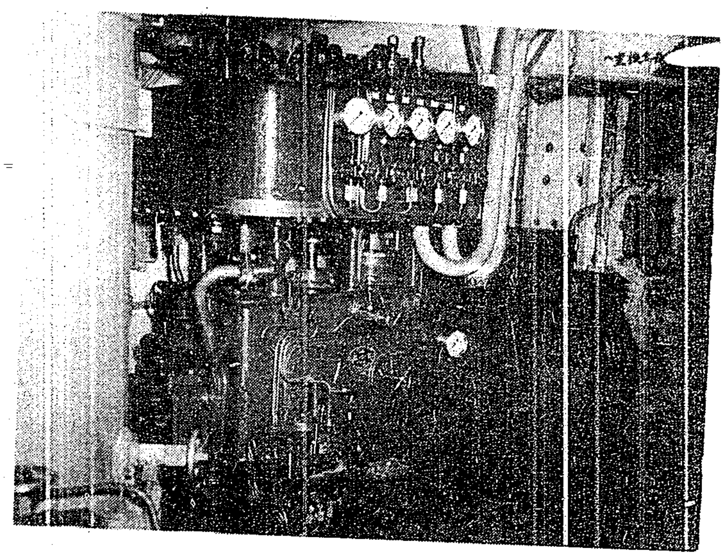


FIGURE 80
AIR COMPRESSOR, KAMPON

Cylinders

Stage	Diameter of cylinder		Working pressure		Hydraulic test pressure		Safety load of relief valve	
	(mm)	(in)	(kg/cm^2)	(lbs/in^2)	(kg/cm^2)	(lbs/in^2)	(kg/cm^2)	(lbs/in^2)
1	228	8.98	2	28	10	142	4	57
2	178	7.98	8.5	121	20	284	13	185
3	178-144	7.01-5.67	29	412	60	752	42	596
4	58	2.29	94	1335	180	2256	145	2060
5	58-46	2.29-1.81	300	4260	450	6390	330	4686

Stroke of Valves

Stage	Inlet		Outlet	
	(mm)	(in)	(mm)	(in)
1 upper	4	0.16	5	0.20
lower	4	0.16	4	0.16
2	4	0.16	4	0.16
3	2.5	0.10	5	0.20
4	1.5	0.06	3	0.12
5	1.5	0.06	1.5	0.06

Cooling Tubes

All are made of copper.

Stage	Diameters Internal		Diameters External		No. of pipes	Length of pipes		Cooling surface area	
	mm	in	mm	in		metres	feet	cm^2	in^2
1	36	1.42	42	1.65	4	13.11	52.0	14827	2302
2	36	1.42	42	1.65	2	5.38	21.2	6120	950
3	28	1.10	34	1.34	1	3.82	15.1	3362	522
4	16	0.42	26	1.02	1	3.68	14.5	1853	288
5	10	0.39	30	1.18	1	3.64	14.3	1190	185

Cooling Water Pump

Double-acting, reciprocating, sea water pump

Capacity	382 lit/min (13.5 ft^3/min
Working pressure	1 kg/cm^2 (14.2 lbs/in^2)
Test pressure	3 kg/cm^2 (42.6 lbs/in^2)
Diameter of feed pipe (1) internal	36mm (1.42 in)
(2) external	42mm (1.65 in)

Electric Motor

Horsepower	95
RPM	500
Volts	220
Amperes	360

Both DC and AC motors are used.

Weights

	kg	tons
KAMPON 3 air compressors	2765	2.76
Accessories	910	0.91
Motor	1485	1.48
Accessories	138	0.14
Total	5298	5.3

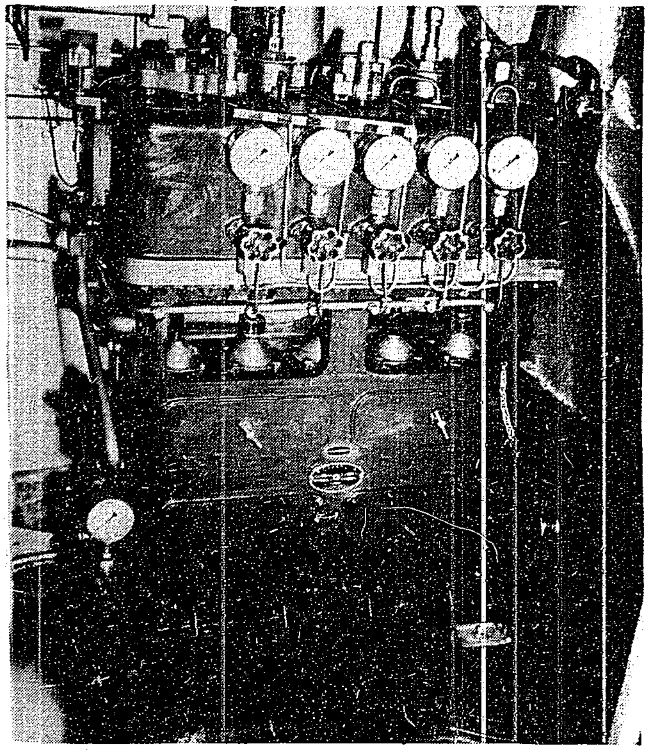
When a DC motor is used the total weight of plant is increased by about one-half ton.

On the next page are shown the data of a test on a KAMPON 3 air compressor. This test was carried out on land and therefore a high voltage motor was used.

Oxygen Compressor

KAMPON Model 2 (See Figure 81).
Used by cruisers and aircraft carriers.

Volumetric efficiency	85%
Highest working pressure	300 kg/cm^2 (4260 lbs/in^2)
Capacity (1) free oxygen	39 m^3/hr (1378 ft^3/hr
(2) oxygen at 300 kg/cm^2	130 lit/hr (4.6 ft^3/hr)
RPM	600
Number of stages	5
Stroke of piston	19mm (0.75 in)



TEST DATA OF AC KAMPON MODEL 3

PRESSURE OF VESSEL	PRESSURE OF AIR (KG/CM^2) 1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE	5TH STAGE	OIL PRESSURE (KG/CM^2)	TIME (MIN. SECS)	TOTAL REVS	MEAN RPM	ELECTRIC POWER VOLTS	AMPS	KW
50	2.4	9.5	28	70	70	1.9	5-30	2645.5	481	3300	11.8	67.44
100	2.5	10	29.5	80	115	2	12-0	5772	481	3300	12.5	71.35
150	2.5	10.2	29.8	80	162	2	18-0	8652	480	3300	13	74.3
200	2.5	10.2	30	87	212	2	24-0	11508	576	3300	13.5	77.16
250	2.5	10.2	30.2	95	265	2	29-30	14153.5	481	3300	14.2	81.16
300	2.5	10.4	30.2	100.3	305	1.9	34-17	16457.5	480	3300	14.8	84.59

Symbol	Quantity	Unit	Value
t_0	Temperature of room	°C	11
t_1	Final temperature compressed air in vessel	°C	36
a	Mean displacement of 1st stage	liters	10.23
A_0	Volume of vessel	liters	510
A_1	Calculated vol. of compressed gas at 300 kg/cm^2 and room temp	liters	471.6
N	Total revolutions	Revs	16457.5
T	Time to charge	Min Sec	34-17
Y	Volumetric efficiency	%	84
Q	Production capacity at 300 kg/cm^2	liters/hr	833.8

Cylinder Details

All the stages are single-acting.

Stage	Diameter of cylinder (mm)	Diameter of cylinder (in)	Working pressure kg/cm²	Working pressure lbs/in²	Hydraulic test kg/cm²	Hydraulic test lbs/in²	Safety load relief valve kg/cm²	Safety load relief valve lbs/in²
1	142	5.59	2.10	29.8	10	142	4	57
2	81	3.19	8.77	124.5	20	284	13	185
3	47	1.85	29.67	421.3	60	752	42	596
4	27	1.06	95.33	1353.7	180	2256	145	2060
5	16	0.63	300.0	4260.0	450	6390	330	4686

Cooling Tubes

All are made of copper.

Stage	Diameter Internal mm	Diameter Internal in	Diameter External mm	Diameter External in	No. of pipes	Length of pipe meters	Length of pipe ft	Cooling surface area cm²	Cooling surface area in²	Hydraulic test pres. kg/cm²	Hydraulic test pres. lbs/in²
1	30	1.18	34	1.34	1	3.73	14.7	3512	545	10	142
2	20	0.79	26	1.02	1	2.62	10.3	648	101	20	284
3	10	0.39	14	0.55	1	1.29	5.1	406	63	60	752
4	6	0.24	12	0.47	1	0.71	2.8	134	21	180	2256
5	4	0.16	12	0.47	1	0.44	1.7	55	8	450	6390

Cooling Water Pump

Double-acting, reciprocating, sea water pump.

Capacity — 55 liters/min (1.9 ft^3/min)
Working pressure — 1 kg/cm^2 (14.2 lbs/in^2)
Tested pressure — 5 kg/cm^2 (71.0 lbs/in^2)
Diameter of feed pipe (1) internal — 20mm (0.79 in)
(2) external — 26mm (1.02 in)

Electric Motor

Horsepower — 95
RPM — 600
Volts — 220 DC
Amperes — 360

General

Circumstances did not permit making a trial run of a ship's oxygen plant, but some data of experimental runs were obtained from the manufacturers, Nippon Rika K.K. These data are shown below.

It will be seen that the purity of oxygen rapidly falls off as the column departs from the vertical. About 5° is the maximum angle, though the output of oxygen may have to be reduced to attain the necessary purity (which should not be less than 98%). Under certain circumstances, a lower purity of oxygen may be accepted if the tactical situation so demands. The decision to use low purity oxygen (say 93%) rests with the captain of the ship. He must make a compromise among the factors involved, speed of oxygen production, purity of oxygen, resulting performance of the torpedoes, and the zero hour by which the torpedoes must be in readiness for firing.

The big decrease in purity on inclination to left or right may be due to the reflux liquid running along the corrugations on the slotted plate, thus leaving part of the plate uncovered. The column is so placed on

TYPICAL TESTING RESULTS OF MARINE TYPE OXYGEN PLANT (CAPACITY 30 m^3/hour)

Position of Column	Time	Pressure (kg/cm^2 gauge)				Height of level gauge (cm)		Degree of opening of expansion valve (degrees)				Purity of gas and liquid (% volume)					Temperature (°C)			Degree of opening of main cock (degrees)		Volume of air and gas m^3/hr-n.t.p.			Remarks
		Compressed air heat exchanger inlet	Compressed air heat exchanger outlet	Lower (1st) rectifying column	Upper (2nd) rectifying column	Liquid air	Liquid oxygen	Precooling expansion valve	High pressure expansion valve	Liquid air expansion valve	Liquid Nitrogen expansion valve	Gaseous Oxygen (product)	Gaseous Nitrogen (waste)	Liquid air (at evaporator)	Liquid Oxygen (at condenser)	Liquid Nitrogen (at condenser)	Room temperature	Compressed air heat exchanger inlet	Waste gas heat exchanger outlet	Gaseous Oxygen	Gaseous Nitrogen	Compressed Air	Gaseous Oxygen (product)	Gaseous Nitrogen (waste)	
Vertical	00-00	200	200	3.0	0.2	0	0	90	0	360 x 15	360 x 15						20	18	15	closed 0	full open	210	0	210	Start
	01-00	200	200			0	0	0	90	360 x 15	360 x 15						20	18	15	0	full open	210	0	210	Open Expansion Valve
	02-00	200	200			1	0	0		360 x 15	360 x 15						20	18	15	0	full open	210	0	210	Liquid Air
	03-30	200	200				1	0		360 x 15	360 x 15						20	18	15	0	full open	210	0	210	Liquid Oxygen
	05-00	200	200					0		360 x 1	360 x 1						20	18	15	0	full open	210	0	210	
	05-30							0									20	18	15	0	full open	210	0	210	Gaseous Oxygen
	06-00							0				99.0					20	18	15	90	full open	210	10	200	
	06-30	100	100	4.7	0.32	13	10	0	150	140	40	99.3	92.0	58.0	99.4	91.4	20	18	15	full open	45	210	30	190	Typical Running state
Inclination	Forward 1°											99.15	91.0	56.0	99.2	90.0							30	180	1 - 2 hours for each testing angle
	Forward 3°											97.5	83.0	54.0	98.7	90.0							10	200	
	Backward 1°											99.05	90.5	50.0	99.1	90.5							30	180	
	Backward 3°											92.0	83.0	49.0	98.5	87.0							10	200	
	Left 1°											98.5	90.0	56.0	98.6	91.0							29	181	
	Left 3°											71.0	74.0	56.0	93.0	88.0							10	200	
	Right 1°											98.5	91.0	58.0	98.9	91.0							29	181	
	Right 3°											79.0	81.0	53.0	84.0	90.0							10	200	
Oscillation	Forward											98.7	90.0	46.0	99.0	89.0							30	180	Period of Oscillation 15 Secs. Maximum Angle 5° ½ hour for each test
	Backward											99.45	92.0	51.0	99.5	91.0									
	Port &											96.0	89.0	45.0	96.8	90.0									
	Starboard											99.2	91.0	52.0	99.3	91.0							30	180	

board ship that the controls on the front face the side of the ship and the corrugations in the plates run fore and aft.

Weight of Marine Type Oxygen Plant (Capacity 30 cubic meters of free oxygen per hour)

Parts	Weight (kg)	Remarks
CO_2 Gas absorber	1,300	With NaOH solution
NaOH solution feed pump	35	
Fresh NaOH solution vessel	100	Without NaOH solution
Water separator	240	
Drying battery	1,800	With NaOH lumps
Column & heat exchanger	1,700	
Heater for sweeping	150	With water
Oxygen gas holder	280	
Air compressor	5,298	
Oxygen compressor (With motor & water separator)	2,000 (approx)	
Weight of pipes etc.	500 (approx)	
Total Weight (kg)	13,403 (approx) or about 13 tons	

Figures 82-98 give additional information on components of the oxygen plant.

Notes on Destroyer Plant

The only special feature of the oxygen plant for destroyers is the air compressor. The other units of the plant differ only in dimensions from the corresponding units of the cruiser plant.

Air Compressor

From about 1935 to 1938 a W8 (similar to KAMPON) five-stage air compressor, steam-driven, was used on destroyers. After 1938, however, a German designed four-stage Junker compressor was installed. This compressor was diesel-driven and was light and compact.

Overall Dimensions

Length	2150mm (85 in)
Diameter	335mm (13.4 in)
Length of 1st stage water cooler	2000mm (78 in)
Diameter of 1st stage water cooler	150mm (5.9 in)
Length of 2nd, 3rd, 4th, stage cooler	1700mm (67 in)
Diameter of 2nd, 3rd, 4th, stage cooler	105mm (4.1 in)
Weight	800 kg (1760 lbs)
RPM	900

Capacity

Highest working pressure	300 kg/cm^2 (4260 lbs/in^2)
Normal working pressure	200 kg/cm^2 (2840 lbs/in^2)
Output (at 300 kg/cm^2)	360 liters/hr (12.7 ft^3/hr)

Normal pressure in each stage (kg/cm^2)

1st stage	2nd stage	3rd stage	4th stage
2.5	14	50	200

Fuel consumption 9 liters/hr (0.32 ft^3/hr)

Construction

The compressor casing is a bronze casting. One water jacket is used for cooling between the first and second stages. A second water jacket is used for cooling between the second, third and fourth stages and after the fourth stage.

On the front side is the fuel injection pump; on the back side are the cooling water pump and the lubricating oil pump.

General

Normally three Junker compressors are installed in destroyers. One is used for the operation of the oxygen plant.

Due to the high pressure working of the Junker compressor, as used by the Japanese, frequent breakdown occurs. The following troubles have been experienced

(1) Fracture of engine piston
(2) Burning of first piston ring on engine piston
(3) Severe wear in fourth stage cylinder and fracture of piston rings
(4) Fuel pump and injector gave considerable trouble due to poor material used in manufacture. Only recently have the Japanese succeeded in manufacturing a fairly reliable pump to the German design.

Weights

The approximate weights of oxygen plant for destroyers are shown below:

Junker compressor	800 kg (1760 lbs)
CO_2 absorption tower	800 kg (1760 lbs)
Drying battery	500 kg (1100 lbs)
Heat exchanger and column	1500 kg (3300 lbs)
Heater, water separators etc.	300 kg (660 lbs)
Piping etc.	500 kg (1100 lbs)
Oxygen compressor (KAMPON 5)	1000 kg (2200 lbs)
Total	5400 kg (11,880 lbs) or approximately 5½ tons.

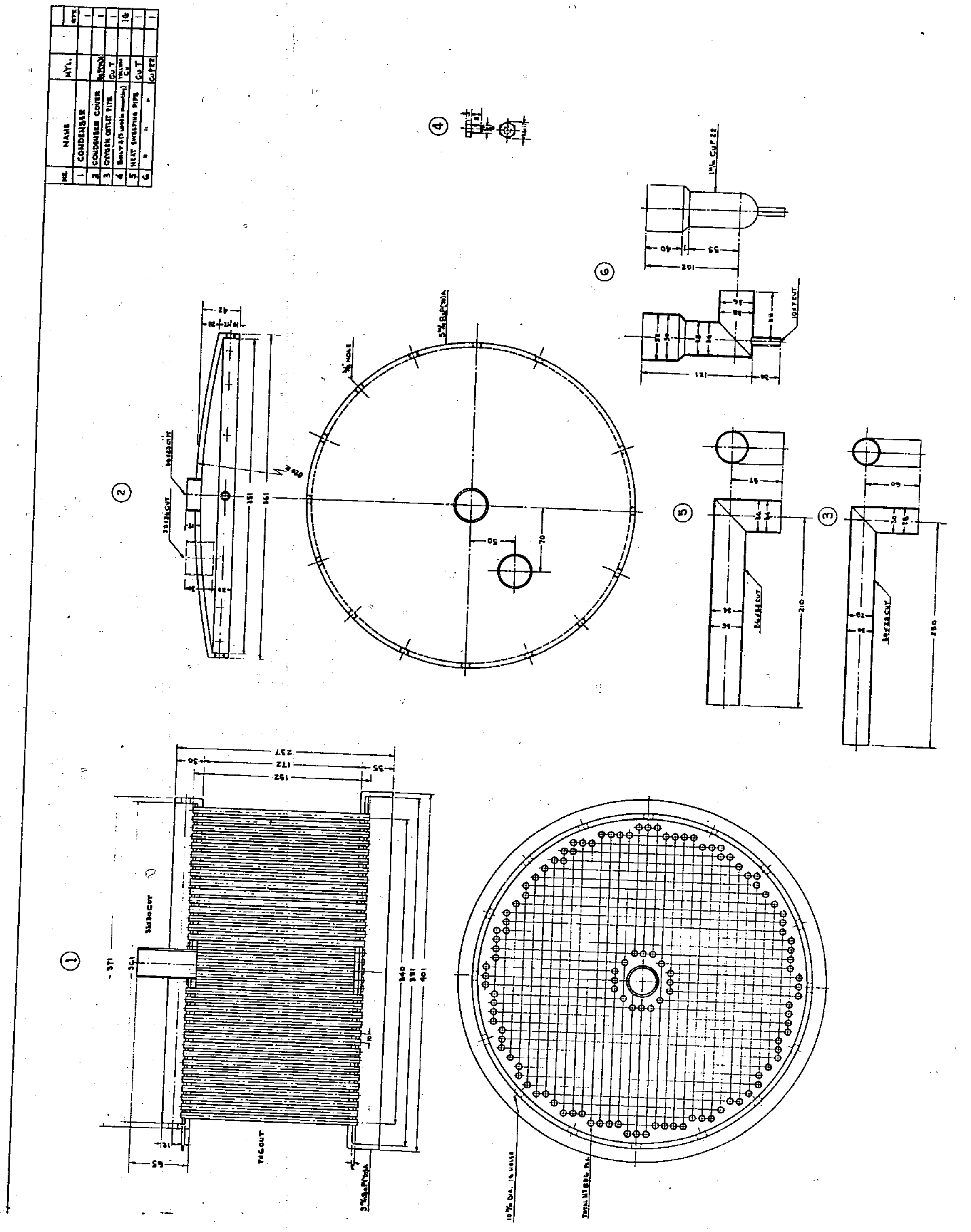


FIGURE 82(a)
GENERAL VIEW AND DETAILS OF CONDENSER IN COLUMN

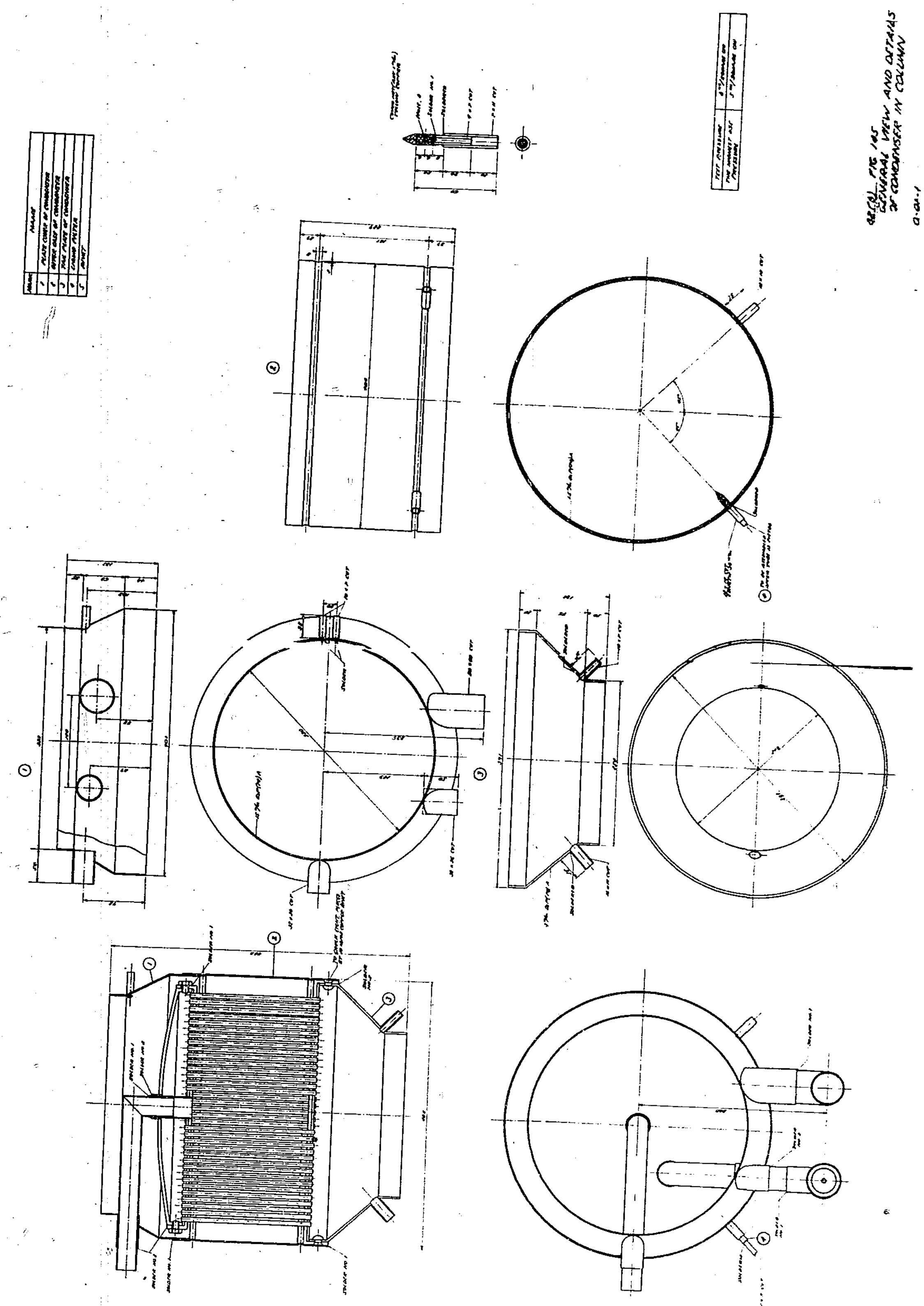
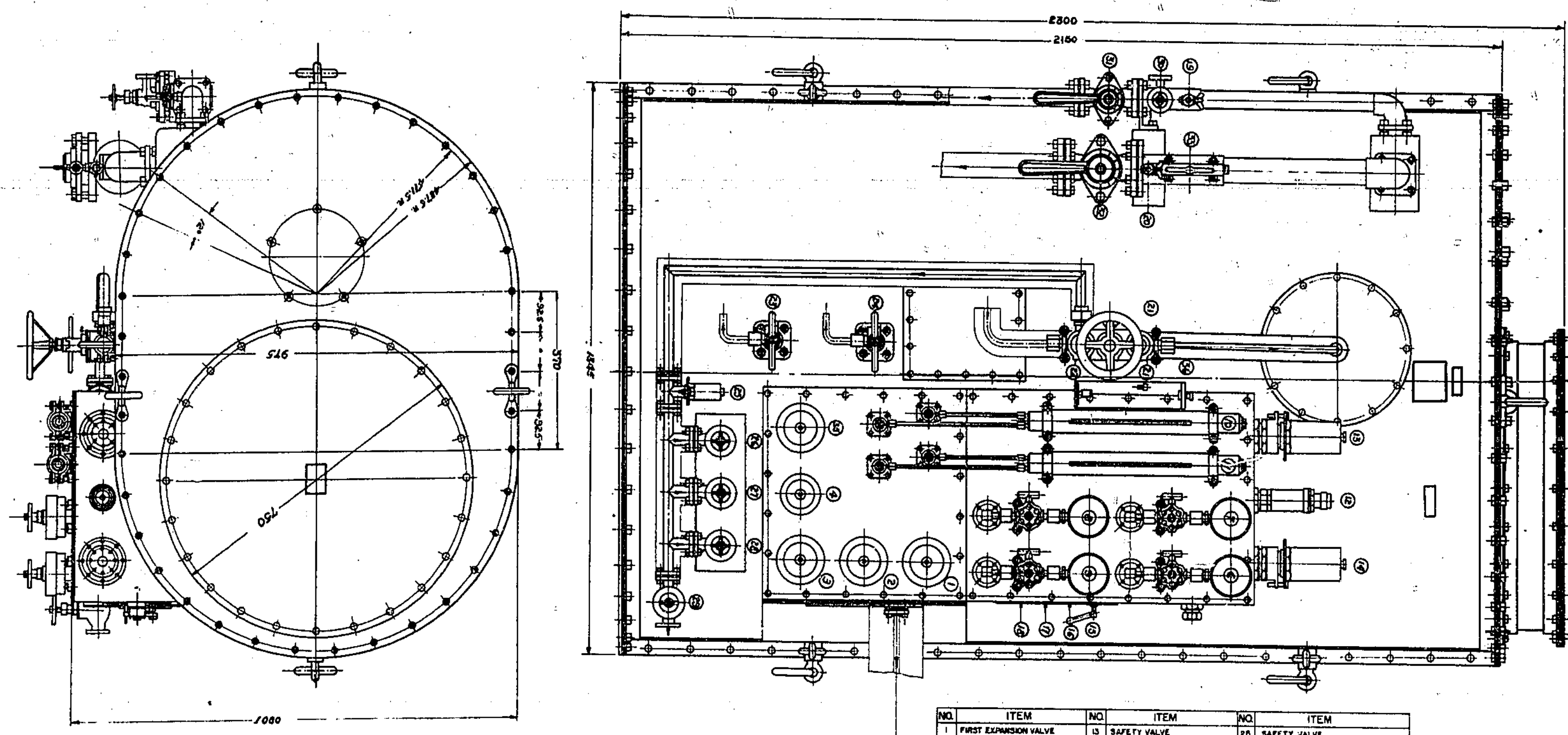


FIGURE 82(b)
GENERAL VIEW AND DETAILS OF CONDENSER IN COLUMN



NO.	ITEM	NO.	ITEM	NO.	ITEM
1	FIRST EXPANSION VALVE	13	SAFETY VALVE	25	SAFETY VALVE
2	SECOND EXPANSION VALVE	14	SAFETY VALVE	26	HEAT SWEEPING VALVE
3	THIRD EXPANSION VALVE	15	LIQUID OXYGEN ANALYSIS VALVE	27	" " "
4	LIQUID OXYGEN DRAW-OFF VALVE	16	LIQUID AIR ANALSIS VALVE	28	" " "
5		17	LIQUID NITROGEN ANALYSIS VALVE	29	BLOW THROUGH
6	HIGH PRESSURE MANOMETER	18	LOW HEAT EXHAUST AIR VALVE	30	OXYGEN EXHAUST VALVE (SECONDARY)
7	" " "	19	OXYGEN'S ANALYSIS COCK	31	OXYGEN EXIT COCK (SECONDARY)
8	MANOMTER (LOWER COLUMN)	20	EXHAUST GAS ANALYSIS COCK	32	EXHAUST EXIT COCK
9	MANOMETER (UPPER COLUMN)	21	HIGH PRESSURE AIR INLET VALVE	33	EXHAUST GAS METER
10	LIQUID AIR INDICATOR	22	HEAT SWEEPING VALVE	34	WASHING LIQUID SUPPLY ENTRANCE
11	LIQUID OXYGEN INDICATOR	23	FIRST JET AIR VALVE	35	PRE COOLING VALVE
12	SAFETY VALVE	24	SECOND JET AIR VALVE	36	LEVEL GAUGE

FIGURE 83
GENERAL VIEW OF COLUMN

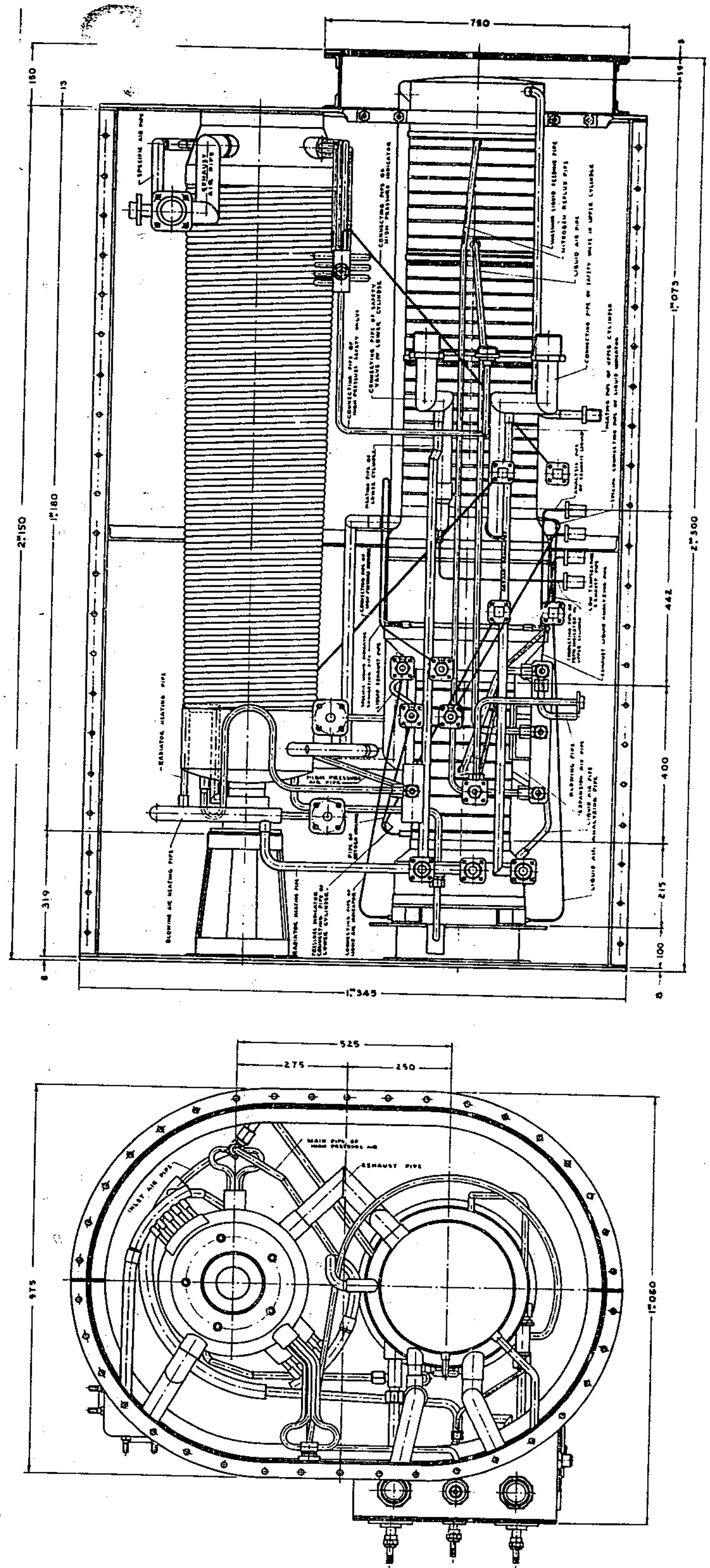


FIGURE 84
PIPE ARRANGEMENT IN COLUMN AND HEAT EXCHANGER

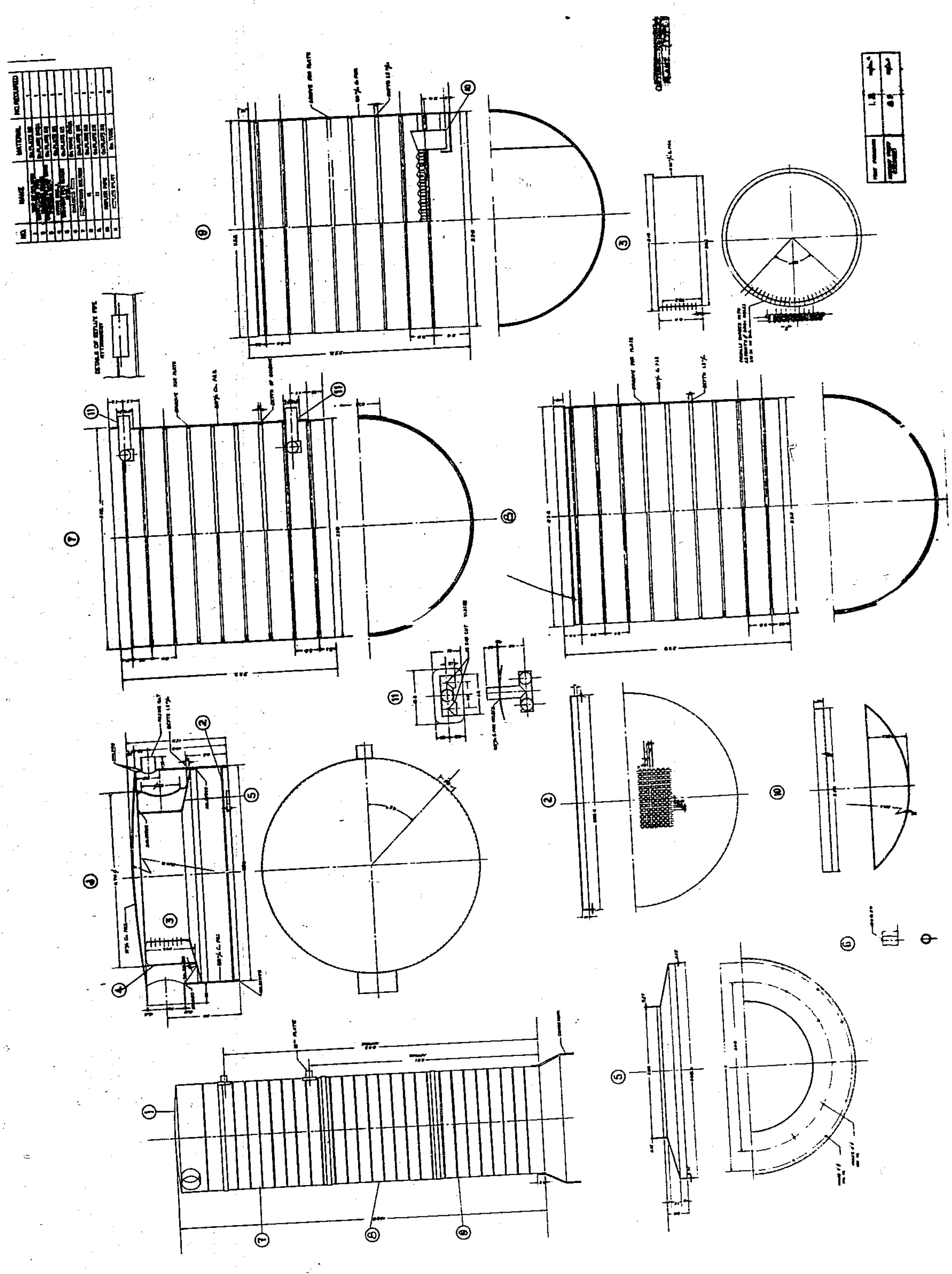


FIGURE 85
VIEW OF UPPER COLUMN

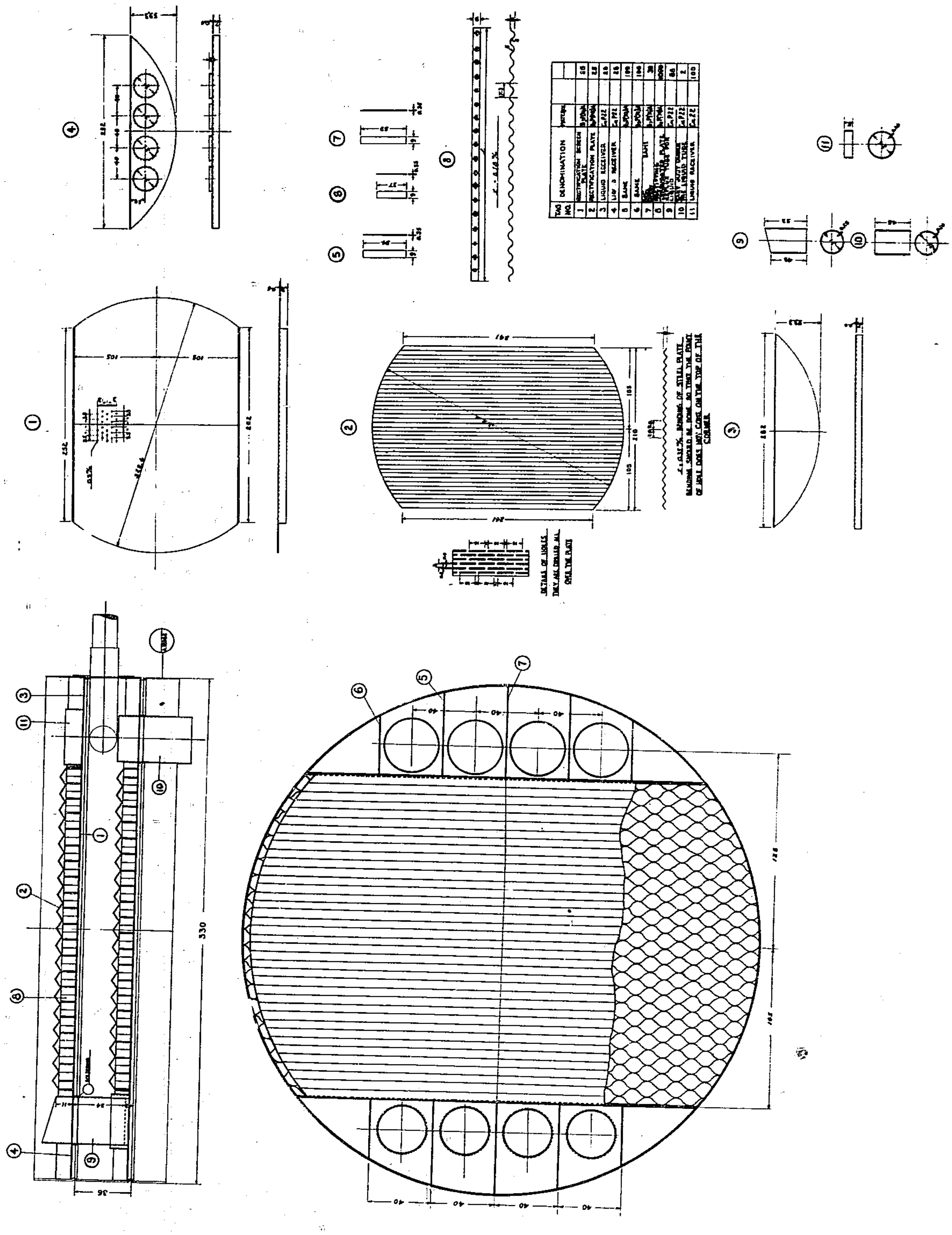


FIGURE 86
DETAILS OF PLATE FOR UPPER COLUMN

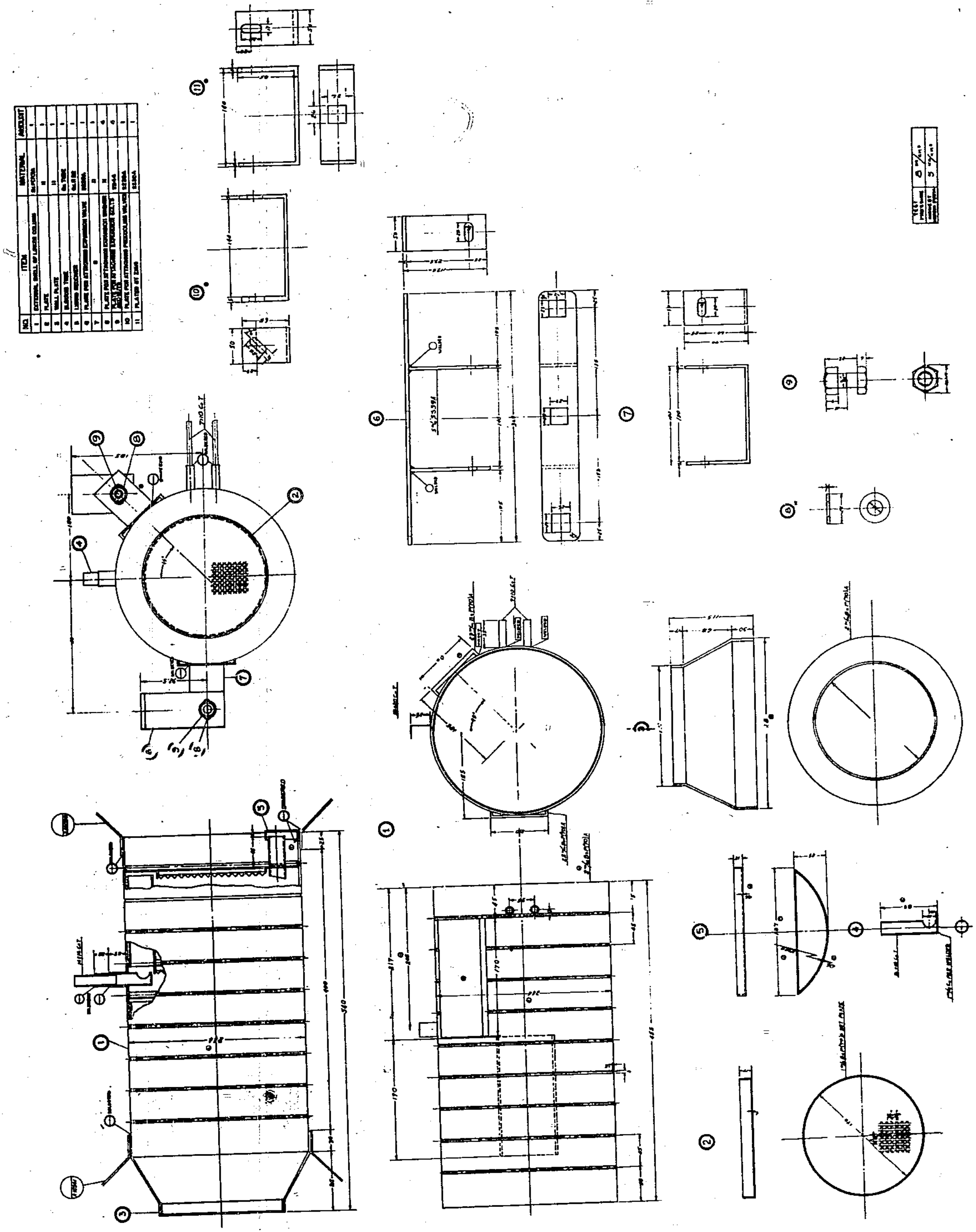


FIGURE 87
VIEW OF LOWER COLUMN

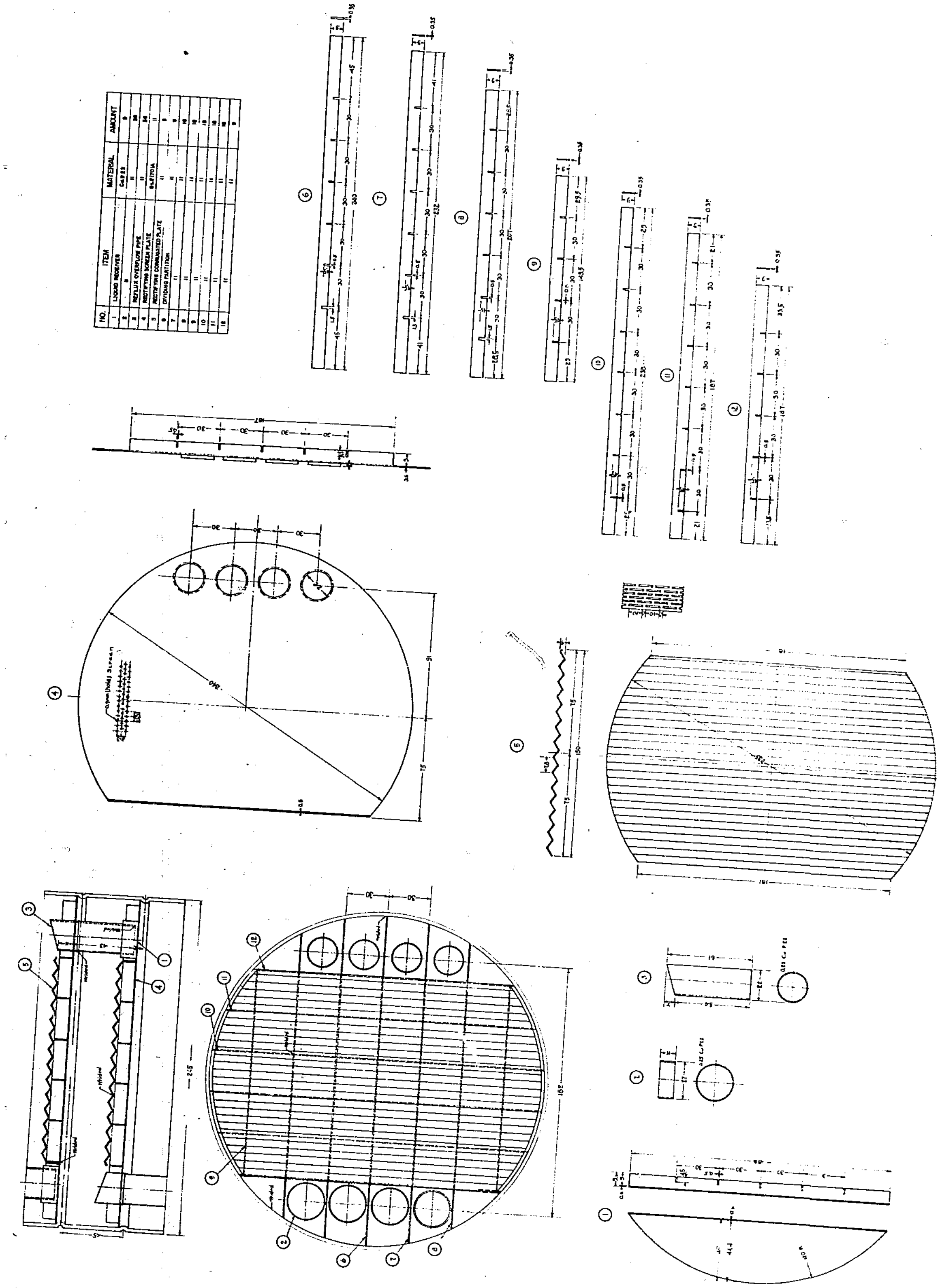


FIGURE 68
DETAILS OF PLATE FOR LOWER COLUMN

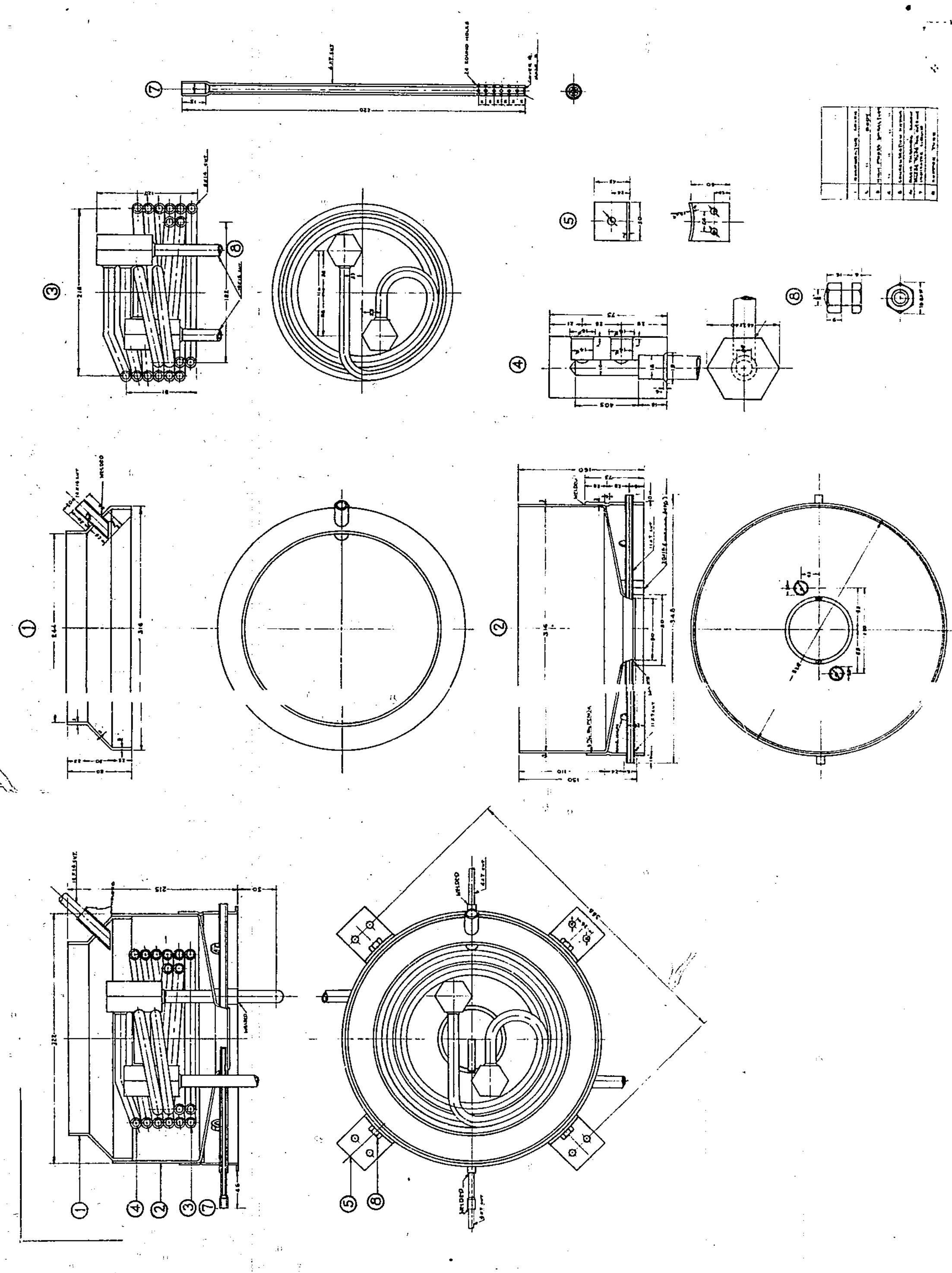


FIGURE 89
VIEW OF EVAPORATOR

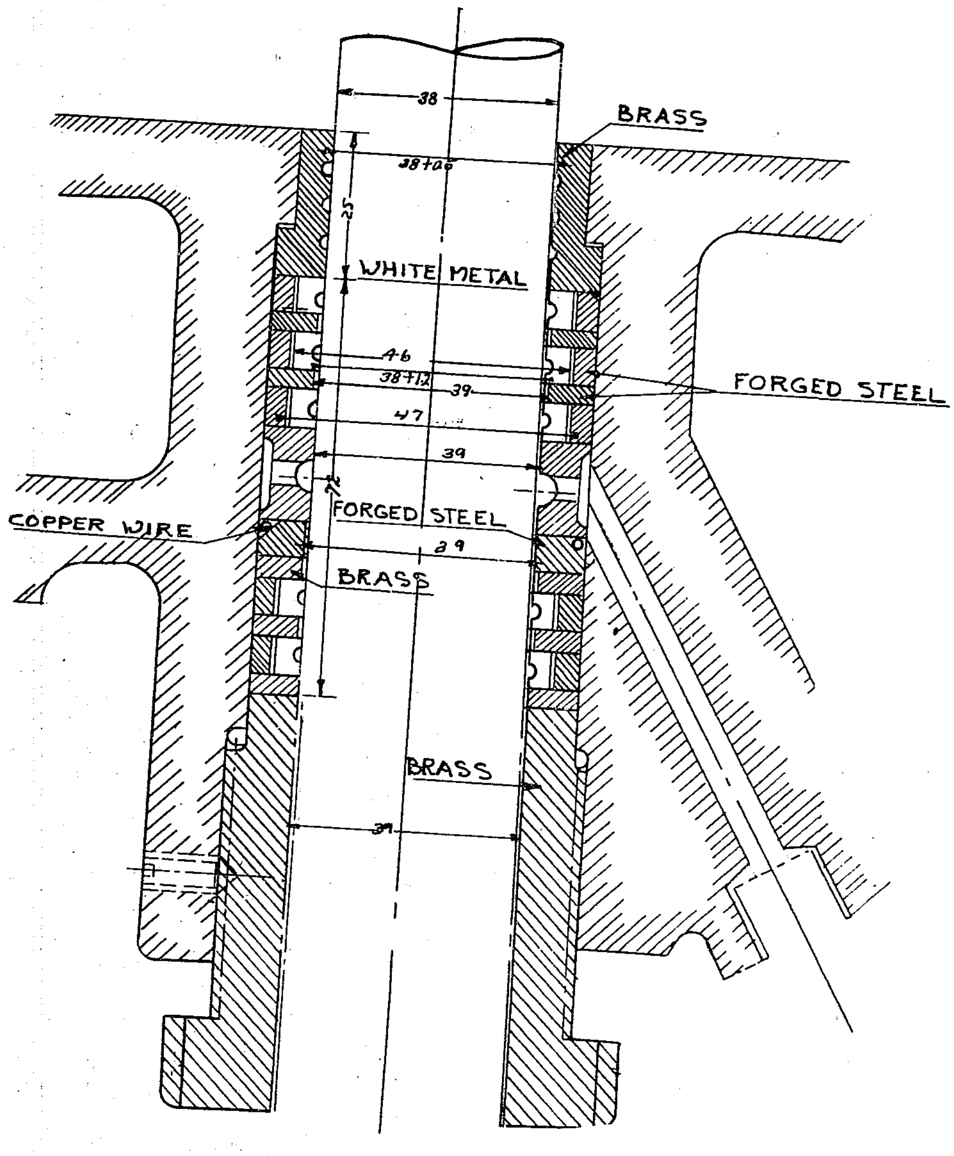


FIGURE 90
A.C. KAMPON 3. PACKING GLAND. LOW PRESSURE

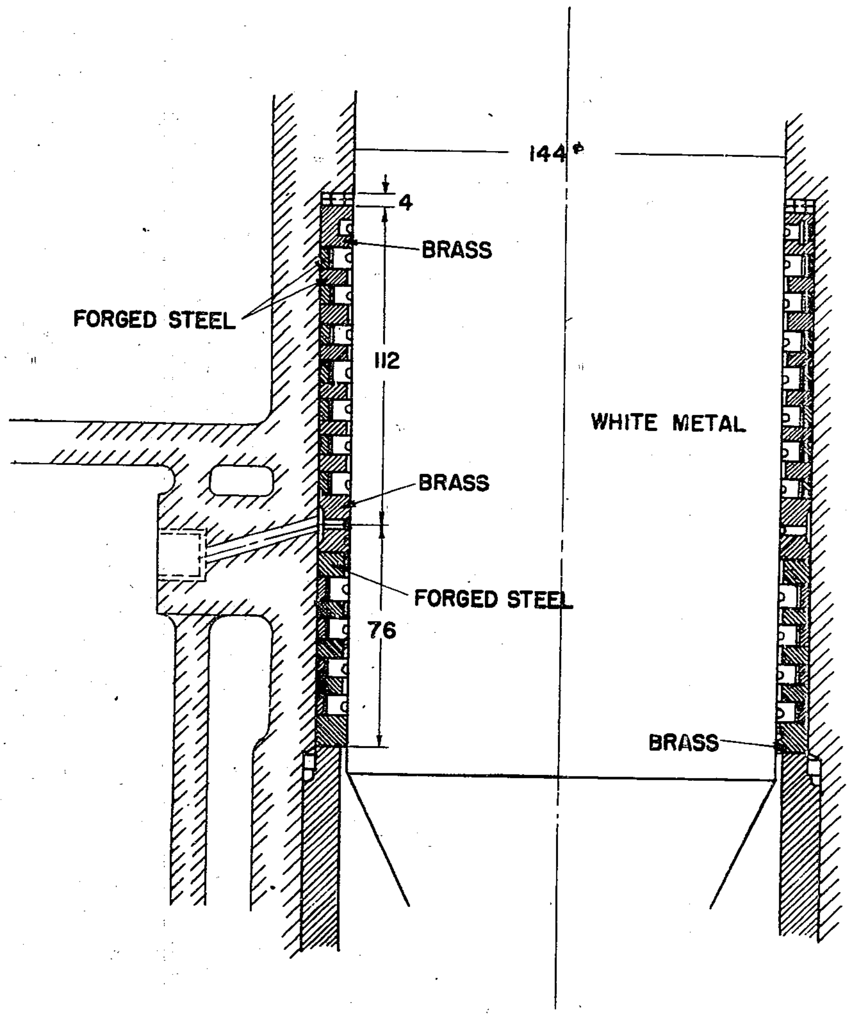


FIGURE 91
A.C. KAMPON 3, PACKING GLAND, MEDIUM PRESSURE

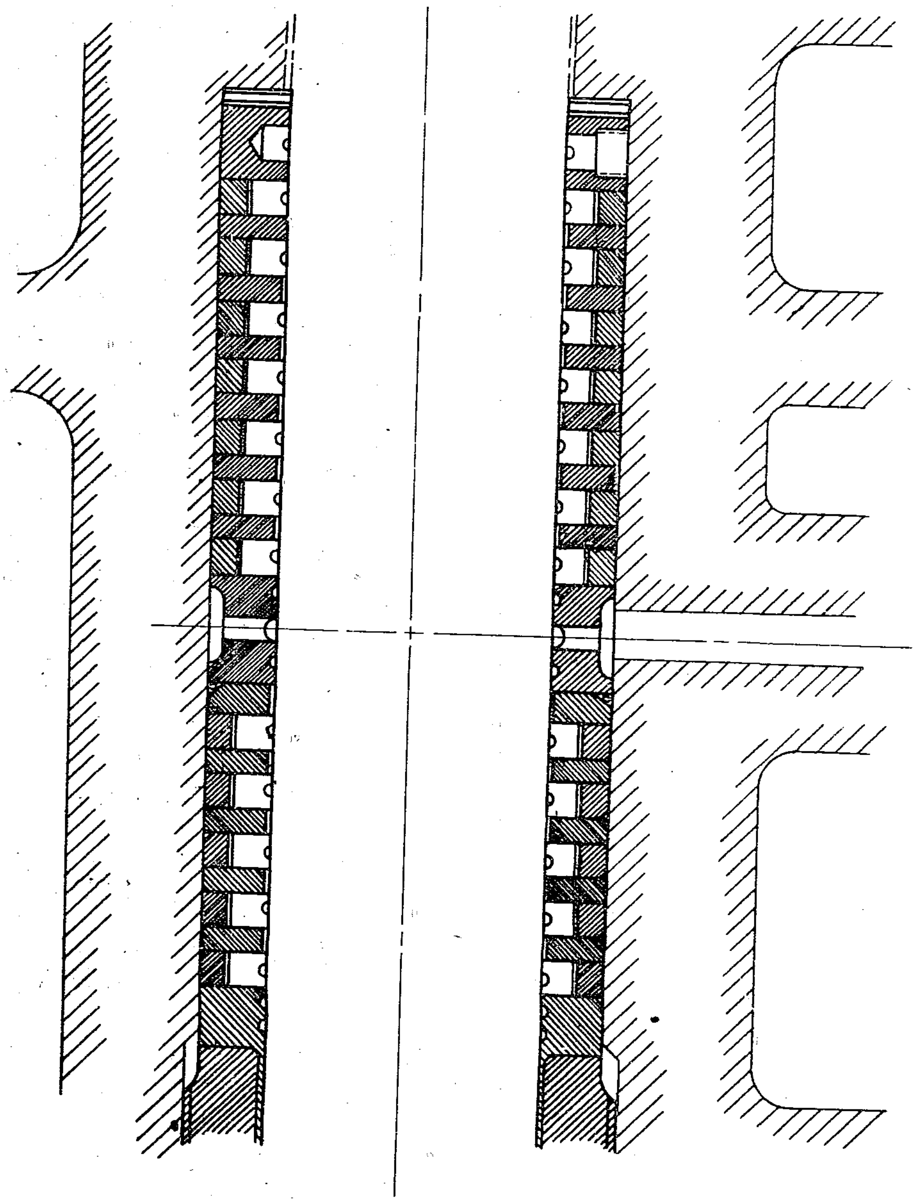


FIGURE 92
A.C. KAMPON 3. PACKING GLAND. HIGH PRESSURE

	1ST STAGE UPPER	1ST STAGE LOWER	2ND S.	3RD S.	4TH S.	5TH S.
TOTAL AREA OUTLET	2419 mm²	1156	1432	491	153.9	63.6
TOTAL AREA INLET	3300 mm²	1714	1932	610	190.5	70.7

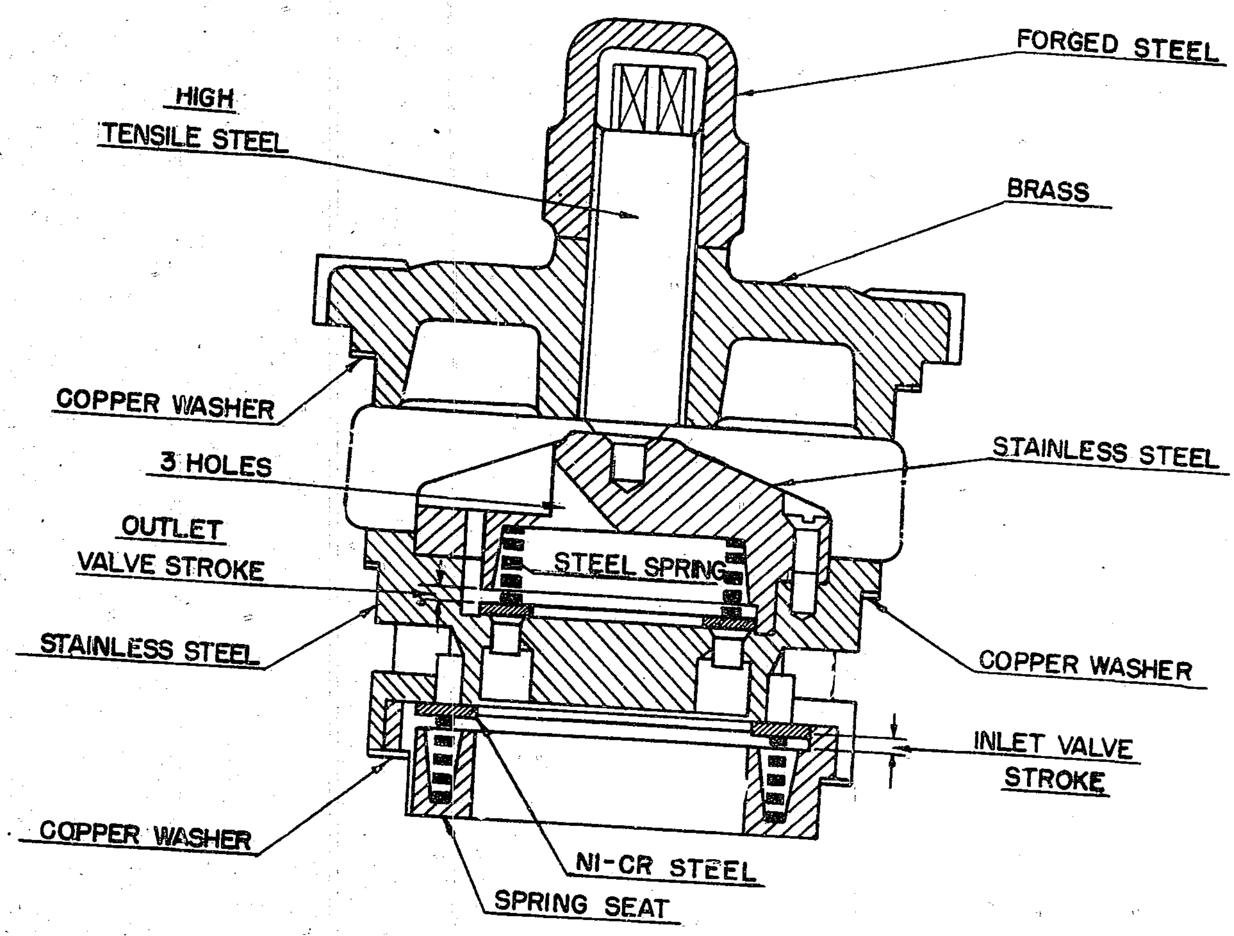


FIGURE 93
A.C. KAMPON 3. COMBINED VALVES, 1ST & 2ND STAGES

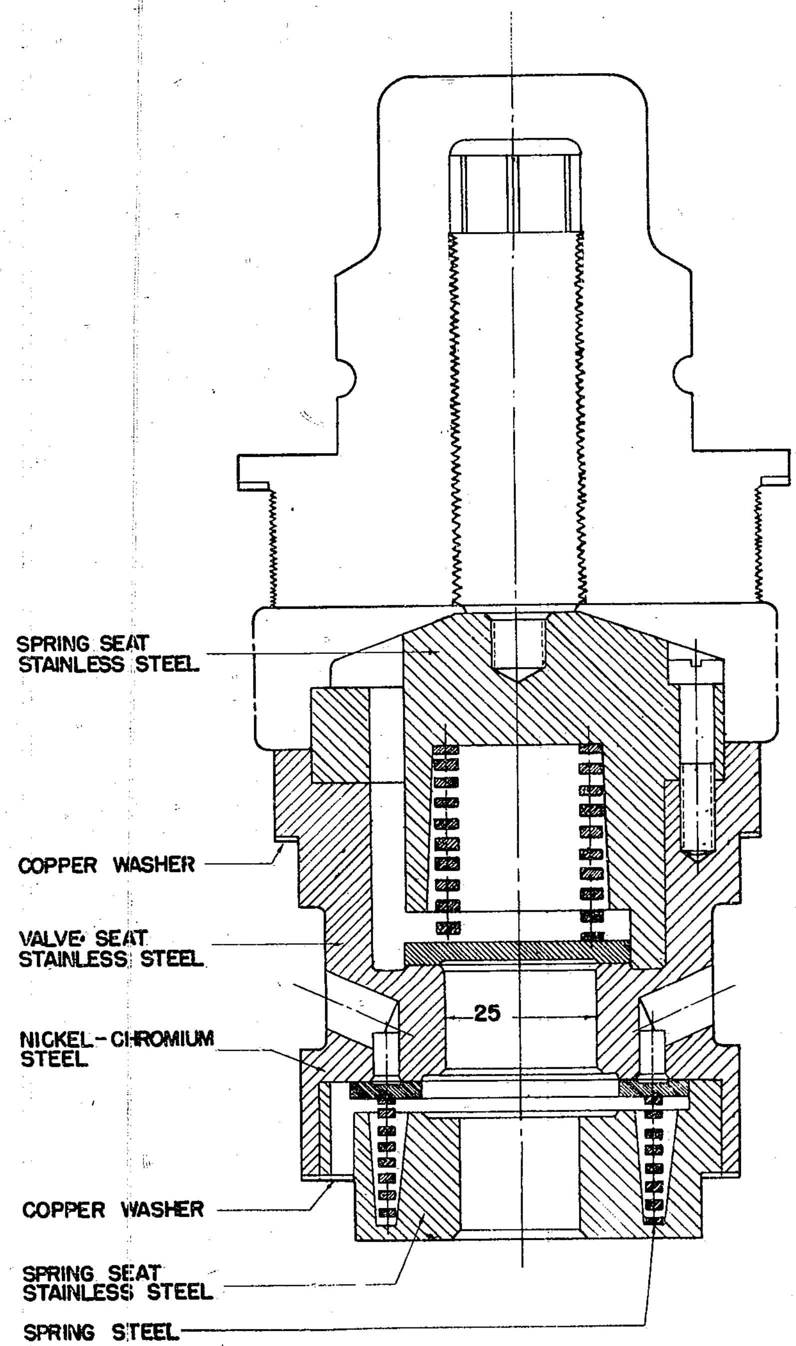


FIGURE 94
A.C. KAMPON 3, COMBINED VALVES, 3RD STAGE

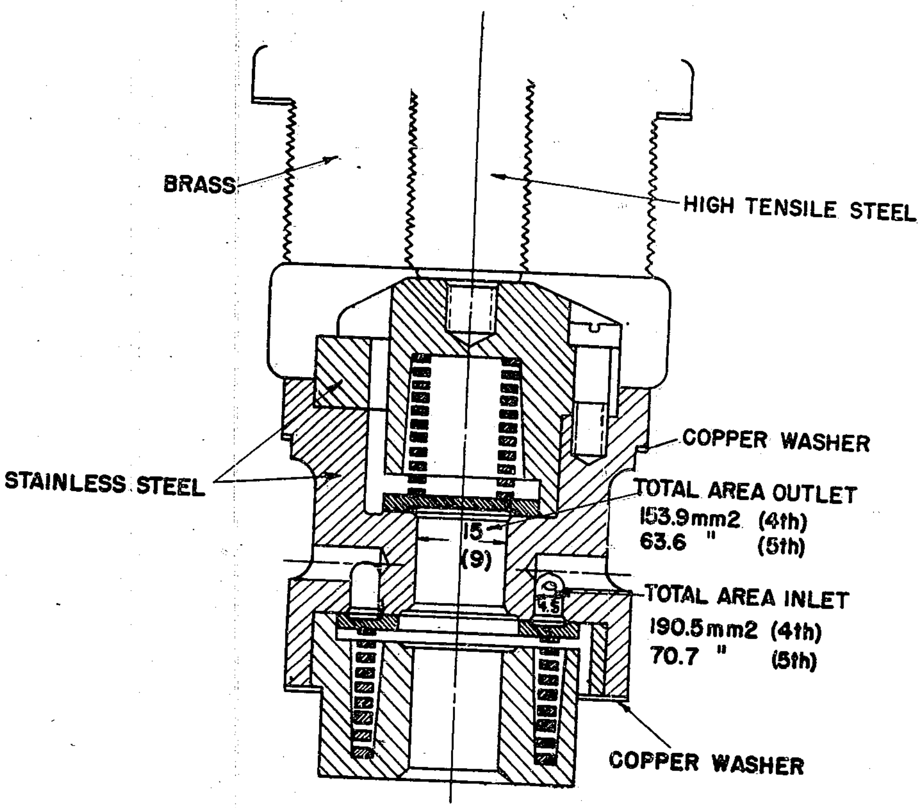


FIGURE 95
A.C. KAMPON 3, COMBINED VALVES, 4TH & 5TH STAGES

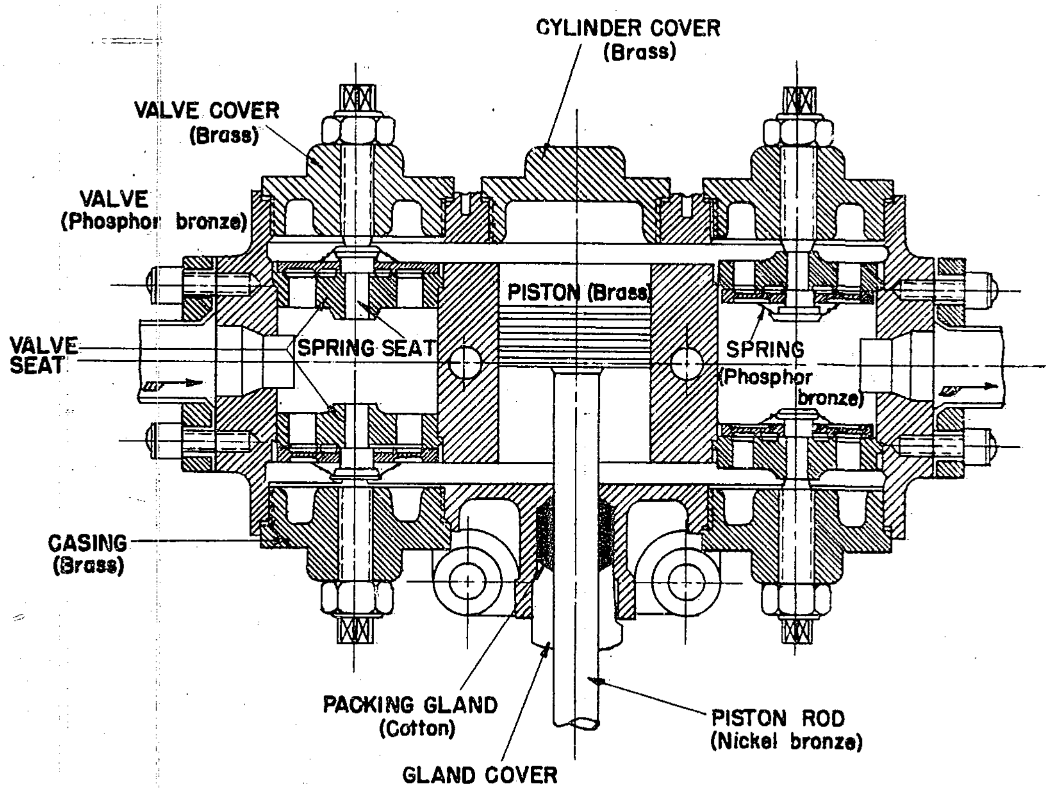


FIGURE 96
A.C. KAMPON 3, COOLING PUMP

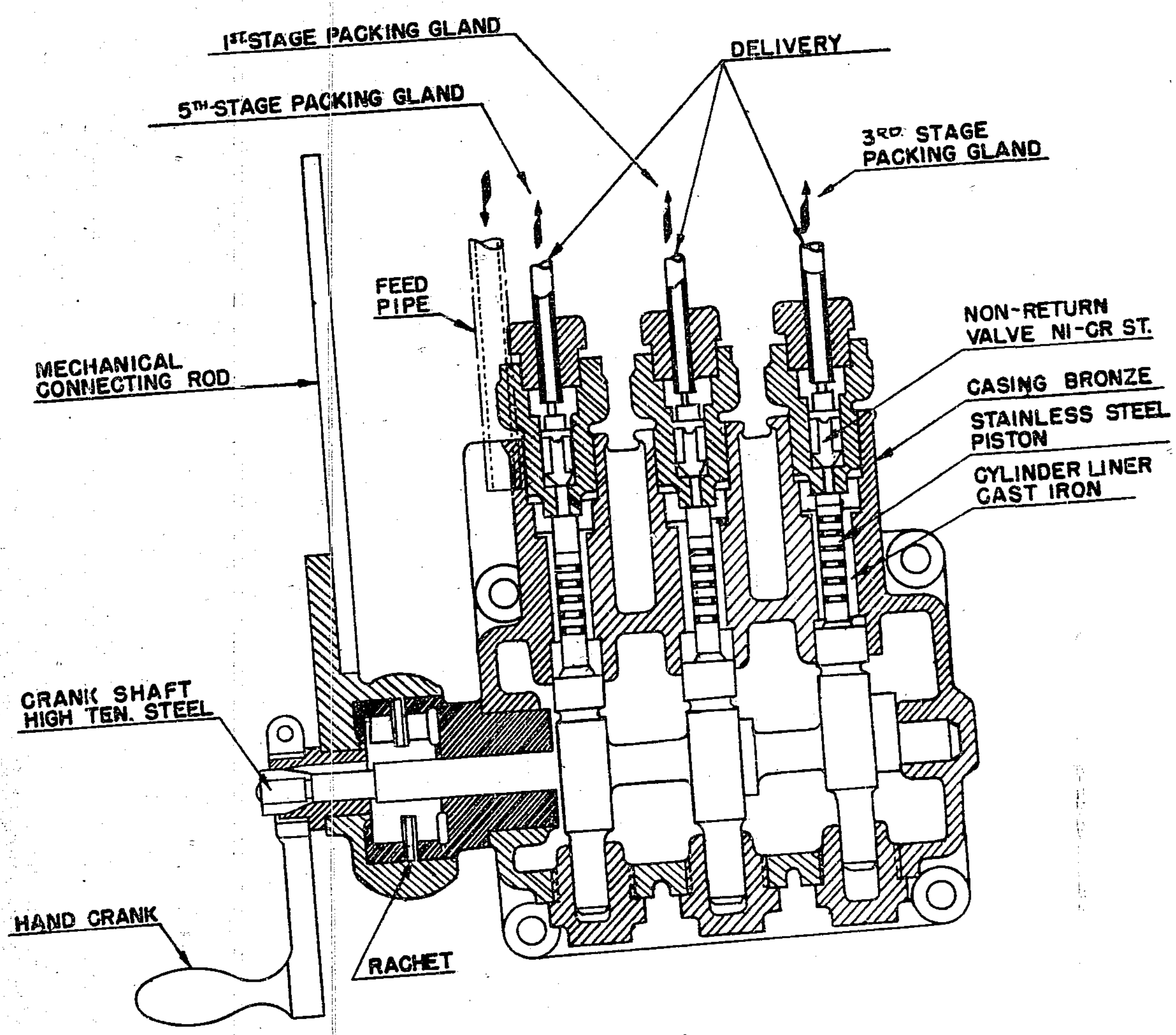


FIGURE 97
A.C. KAMPON 3. OIL PUMP

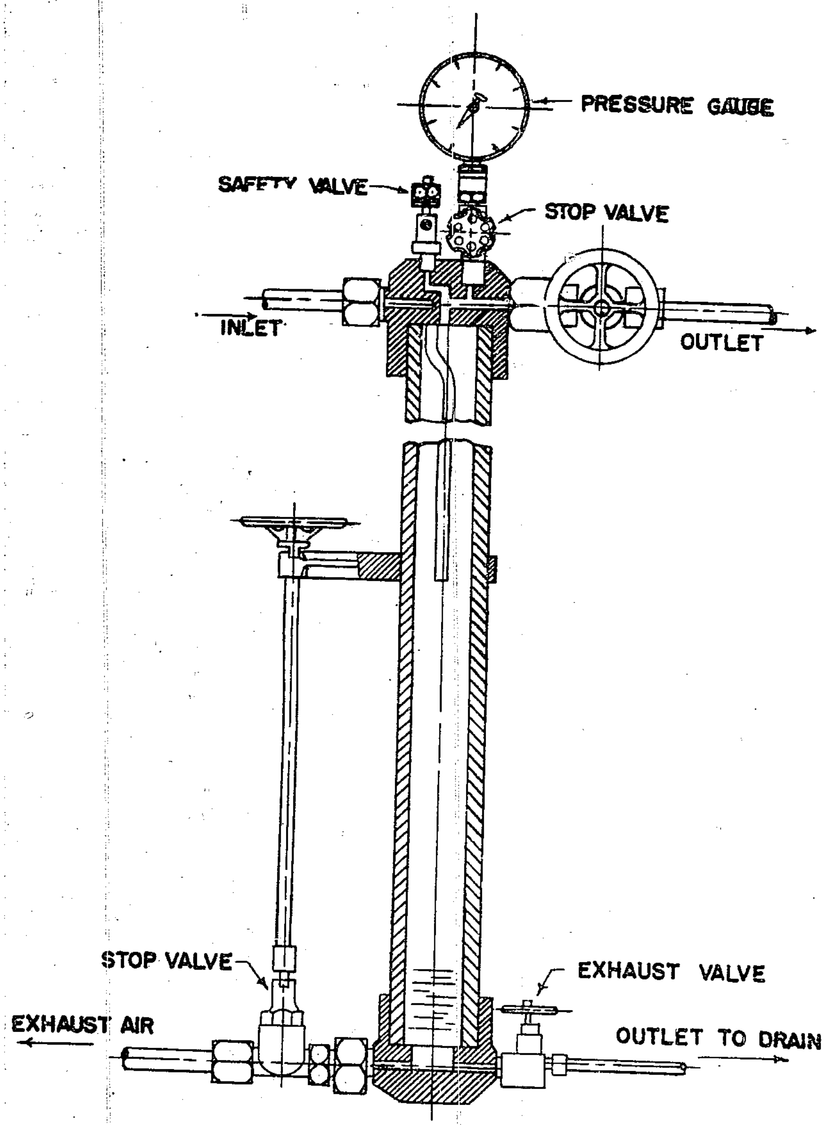


FIGURE 98
A.C. KAMPON 3. WATER AND OIL SEPARATOR

RANGING

JAPANESE EQUIPMENT

For the ranging of a Type 95, Model 2 torpedo, prior to and during the war, the Japanese normally used the following equipment:

- 3 shallow draft open boats, motor-driven
- 2 high-speed motor launches
- 1 steam-driven torpedo carrier
- 3 "acoustic" sets
- 3 target buoys
- 5 radio sets (transmitters and receivers)
- Signal flags
- Stop watches

Speed

The three target buoys were positioned along the range at distances of 1000, 3000 and 5000 meters respectively. The three shallow draft observation boats were moored to each of these buoys. Each was equipped with acoustic gear consisting of a battery of seven (sometimes 14) microphones fitted on a horizontal frame which was submerged to a depth of about 10 feet, and placed parallel to the course. The microphones were connected to a set of earphones in the boat and to a Wheatstone Bridge arrangement with galvanometer. The earphones warned the observer of the torpedo's approach, and the galvanometer needle showed him when the intensity of the signal at each microphone gave a balance. At that instant the torpedo was passing the target buoy, and the observer dropped a signal flag. A watch reading was taken at the firing point.

The same procedure took place at each of the other target buoys. Thus the times for the torpedo to travel 0 to 1000, 1000 to 3000, and 3000 to 5000 meters as well as the time to travel the whole 5000 meters were measured. These times were noted by reading from the watch at each signal; the watch was finally stopped when the torpedo surfaced after its over-run.

Deflection

The deflection was measured by a large pair of binoculars placed on a fixed stand at the firing point. The angle of each torpedo track relative to the true course could be measured by the deflection of these binoculars.

Of the two high-speed launches, one remained at the firing point and was only used in the event of a faulty run, extreme deflection or sudden sinking near firing point. The other launch remained near the end of the range to pick up the torpedo after the run and to pass it to the torpedo carrier. This latter launch was also used to keep the course free from stray craft.

Two radio communications sets were installed at the firing point and also in the torpedo carrier and in each of the launches. These radios were used for general inter-communications.

At the end of each run the torpedo carrier picked up the torpedo and hoisted it aboard. The torpedo was picked up with floats as described in the ranging section, or by slipping a thin steel band over the torpedo and raising it directly with the hoist hooked to this band.

Tides

The tide flow was measured by each of the boats moored at the target buoys. A float with lead ballast was thrown into the sea and a wire attached to it was payed out, as the float drifted with the tide. The time to drift a known distance was measured.

PREPARATION OF TYPE 95, MODEL 2 OXYGEN TORPEDO FOR RANGING

The precautions which must be observed in using pure oxygen for torpedo propulsion render it essential that a lengthy and detailed preparation of the torpedoes should be undertaken, before they are ranged or issued to a ship. After ranging, a similar drill must be observed in stripping the propulsion system, cleaning it of all salt and preserving it with lubricating oil.

Details are set out below of the preparation of Type 95, Model 2 oxygen torpedoes, as carried out by the Japanese prior to running his type on the range at DAINYU near KURE. This preparation is similar for all oxygen torpedoes, and occasional reference is made below to tests carried out for torpedoes, other than Type 95.

Cleaning

The workmen engaged on this task wear rubber boots and rubber aprons (sometimes rubber gloves) provided exclusively for their use. If gloves are not worn, the hands must be kept free from oil.

Oxygen vessel and related components

Valves

(a) Remove charging valve, charging stop valve (including copper connecting pipe) and the oxygen delivery stop valve.

(b) Wash with kerosene.

(c) Dry with dry compressed air.

(d) Wash with hot (circa 100°C) 30% solution of caustic soda to remove last trace of kerosene.

(e) Wash with hot (almost boiling) water to remove soda.

(f) Dry with compressed air.

These components are then protected from contamination with a clean cloth or paper in readiness for final assembly.

Oxygen feed pipe and interior of vessel

(a) Pour kerosene in both directions from oxygen delivery stop valve toward the vessel and the "group", washing out the oxygen feed pipe to vessel and to "group". Where necessary, rust is removed from the interior of the vessel with emery paper or a wire brush. The inside of the vessel is washed with a cloth dipped in kerosene. (If the vessel has recently come from storage, all preservative must be removed). This procedure is repeated several times, finally with fresh kerosene, until the "washing", emerging from the feed pipe and vessel, appear free from contamination.

(b) Dry with dry compressed air.

(c) Remove last traces of hydrocarbon by washing with hot 30% solution of caustic soda. This solution is poured from the oxygen delivery stop valve along the oxygen feed pipe towards the vessel and the group valve. The procedure is repeated several times.

(d) Wash several times with hot water until the outside of the vessel feels hot to the hand. (This will insure rapid drying).

(e) Dry with dry compressed air.

The outer shell, in the vicinity of the charging valve, the charging stop valve and the oxygen delivery stop valve is also cleaned as above.

Vessel end and sealing gasket

(a) As above, this is cleaned with kerosene, caustic soda and hot water.

(b) Dry with dry compressed air.

(c) Before assembling the end of the vessel, the cadmium-plate copper sealing gasket is washed with carbon tetrachloride and painted with water glass (sodium silicate) to make seal.

Sometimes, particularly in the case of small parts, carbon tetrachloride is used as an alternative to caustic soda and water. Carbon tetrachloride is an excellent solvent for oil and will completely remove oily traces. It suffers from the disadvantage, however, that small amounts of hydrochloric acid usually present in the tetrachloride accelerate corrosion of the parts.

Vessel assembly

Assembly is carried out using tools which have been degreased with kerosene, soda and water. These tools are chromium-plated for corrosion protection, since otherwise, in their degreased condition, they would rapidly rust. Bands of thick clean cloth are placed over the outer shell of the vessel covering the charging valve, charging stop valve and the oxygen delivery stop valve to protect them from contamination.

Charging

Close oxygen delivery stop valve and secure oxygen supply pipe to the charging valve. Open the charging stop valve slowly and allow the pressure to increase to 210 kg/cm^2 (3130 lbs/in^2). Charging time is about one hour. The oxygen vessel is normally cooled externally with a water spray. The pressure of oxygen is measured again before launching and should be about 200 kg/cm^2 (2844 lbs/in^2). (The drop from 210 kg/cm^2 is due to cooling). If the pressure has dropped seriously below 200 kg/cm^2 due to leakage, the torpedo usually will not be run.

Once charged, the oxygen vessel is never cleaned internally again, unless the pressure of the oxygen should at any time fall to zero.

Fuel vessel

Clean the fuel non-return valve and strainer with kerosene. (If torpedo is about to be run for first time, the vessel is washed out with kerosene).

Group valve

Strip. Clean with kerosene, hot caustic soda solution and hot water. Dry. Assemble.

Main reducer

Strip. Clean with hot caustic soda solution and hot water; no kerosene is used. Thinly coat the plunger with lubricant. Assemble. If torpedo has come directly from storage, kerosene is used first to remove preservative.

Generator

Clean inside and outside with kerosene, hot caustic soda solution and water. It is important to remove dust from the inside of the unit. Compressed air is blown through the nozzles.

Main engine

General overhaul. Strip. Clean components with kerosene. Lubricate and reassemble.

Buffer chamber

Strip, clean and assemble.

Oil, diluent water and cooling water pumps

Strip, overhaul, assemble.

The following units also are stripped, overhauled, and assembled:

- Depth gear
- Servomotor
- Gyroscope and steering engine

Rear Buoyancy chamber

Remove starting valve for steering air, relief valve and strainer. Clean with kerosene, overhaul and assemble.

Piping

All piping which conveys oxygen gas must be carefully cleaned with caustic soda solution and hot water before assembling.

FUNCTIONAL TESTS

Oxygen delivery stop valve

The gear for automatically opening this valve is assembled without the final bevel wheel on the valve spindle. The engine is slowly rotated with low pressure (60 kg/cm^2; 853 lbs/in^2) compressed air, and the movement of the gear is noted.

Afterbody circuit

A compressed air supply is connected to the group valve, and a pressure of 60 kg/cm^2 (853 lbs/in^2) is applied. The pipe unions in the afterbody gas circuit are smeared with oil and any leakage from the joints can be detected. During this test the propellers are locked.

With compressed air still connected to the group valve, as in the previous test, the ignition delay is set. The hammers are cocked and range setting wheel is adjusted to the minimum figure. The propeller clamp is now removed and the engine rotates slowly.

The fall of the igniters is checked and also the shutting off of the oxygen supply at the end of the set range.

Main reducer

The main reducer is connected to the generator, the outlet from the latter being fitted with a choke which sets up a back pressure equivalent to that occurring during a torpedo run. The diameter of this choke is varied according to the type of reducer which is being tested. For example:

Torpedo type	Speed setting	Diameter of choke
93	high	8mm (0.313 in)
	low	7mm (0.276 in)
95	high	5.5mm (0.215 in)
	low	5.5mm (0.215 in)

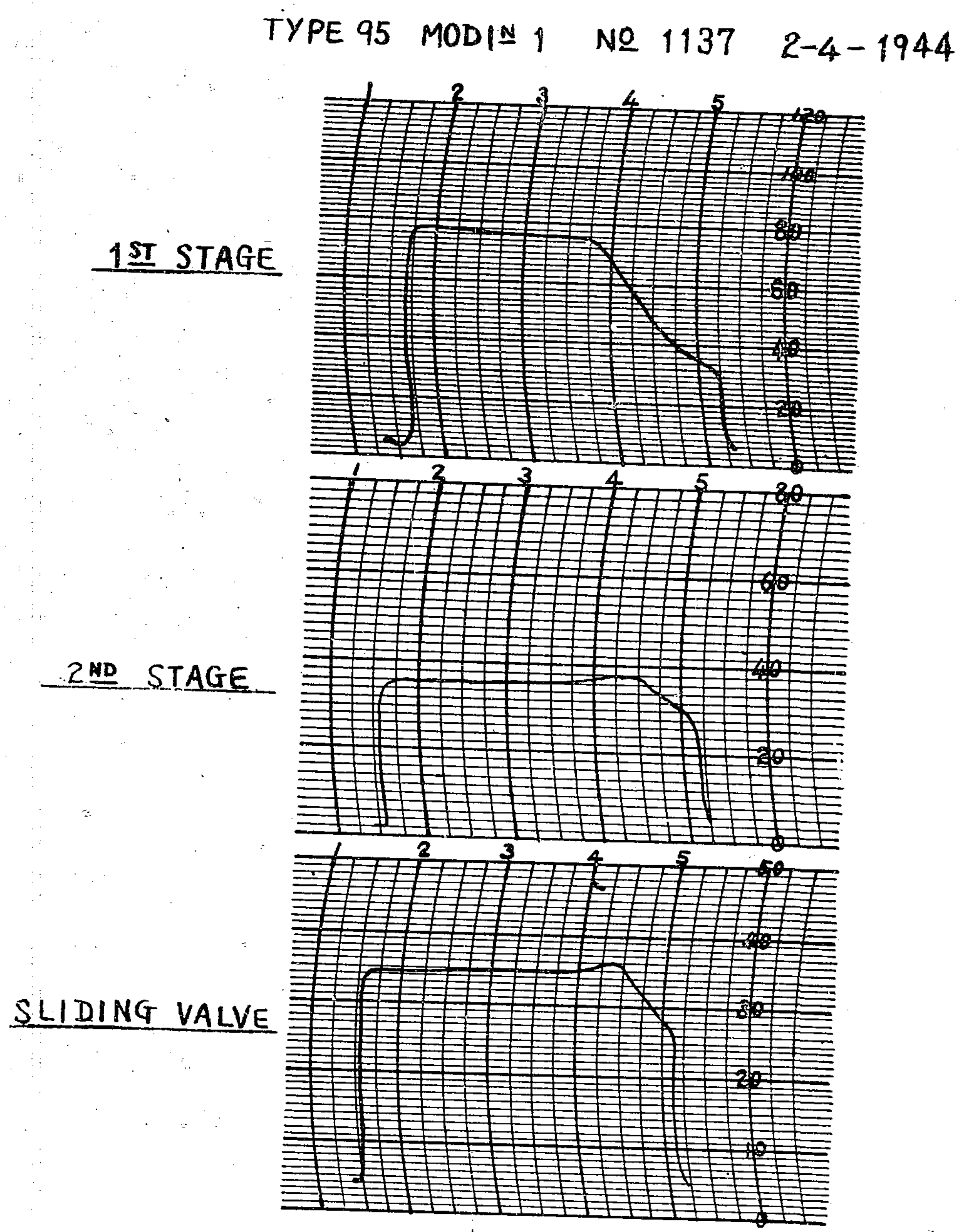
Compressed air at 200 kg/cm^2 is fed into the reducer from standard 250 liter (8.8 ft^3) capacity bottles. The number of bottles used is such that their total capacity approximates or is greater than that of the oxygen vessel of the torpedo, the reducer of which is under test. Thus:

Torpedo type	Volume of oxygen vessel		Number of bottles used for reducer test
	liters	ft^3	
93 Model 1	980	34.6	4
93 Model 3	750	26.5	4
95 Modification 1	386	13.6	2
95 Model 2	220	7.8	2

By means of special caps on the reducer, the pressures of the air in the first and second stages are measured. The pressure of the supply is also measured. A continuous pressure recorder makes a tracing of each pressure. Ideally, the tracings should show a steady decrease in pressure of the supply; a less steep falling off of pressure in the first stage, and a horizontal tracing showing constant pressure in the second stage. In practice, with a good reducer, the second stage tracing, for the greater part is horizontal but generally shows a slight rise towards the end of the test, due to spring characteristics, final tail-off. Reducer test curves are shown in Figure 99.

If the curve of the second stage pressure slopes up or down, the area of the valve seat is altered. This is done in on of two ways. Either the path through which the gas has to pass is shortened by removing part of the shoulder of the seat, or the angle of the valve seat is slightly altered so that the contact area between the valve and the valve seat is reduced.

If the curve is irregular, the plunger is lapped into the barrel and the valve and seat are ground together. The difficulty of this latter operation is caused by any departure of the plunger hole from the cylindrical. In the case of an oval hole, the barrel is lapped cylindrical by means of a standard lap and an oversize plunger is fitted.



READINGS

ORIGN PRESSURE	200	180	160	140	120	100	80	60	50	40
1ST STAGE OF REDUCER	78	77	77	76	75	70	69	51	40	31
2ND " " "	37.0	37.0	37.1	37.1	37.2	37.3	37.4	38.3	36.5	30
SLIDING VALVE "	35.2	35.3	35.4	35.5	35.6	35.7	36.1	37.2	34.0	29.0

FIGURE 99
REDUCER TEST CURVES, TYPE 95 MODIFICATION 1

Generator

Two tests are carried out:

(a) Rating test: A special bench apparatus is used. The generator is mounted in a vertical position on the bench. A water bottle is connected to the water and fuel inlet unions to the generator head in turn.

Using a pressure of 1 kg/cm^2 (14.2 lbs/in^2) water is fed to the nozzle for a period of two minutes. During this period, the nozzle setting for each speed is used and the delivery is measured by volume.

Delivery rate for Type 95 (high speed)	Nozzle	Delivery	Vol. ratio
	Fuel nozzle	4±0.05 liters (242±3.3 in^3)	1
	Water nozzle	35±0.1 liters (2140 6.1 in^3)	8.7

If the deliveries do not fall within these limits, new nozzles are fitted or holes reamed as required.

(b) Flame test: For this test only the combustion nozzle is required. The purpose of the test is to determine the position of the fuel sprayer which gives the optimum shape and dimensions of the flame. The test is described in detail in the section dealing with generator design.

Main engine

After the overhaul, cleaning, checking and the reassembling of the engine the following tests are made:

(a) The combustion manifold of the engine is connected to a compressed air supply and a pressure of 40 kg/cm^2 (568 lbs/in^2) is applied. The propellers are locked in two positions in turn, first in one position and then turned through 180° and locked again. This test will reveal leakages which may occur in the cylinder heads.

(b) The exhaust shaft is blanked off with a disc of oiled paper and a pressure of about 0.5 kg/cm^2 (7.1 lbs/in^2) is applied to the rear buoyancy chamber. Leakage between the latter and the crankcase will be indicated by the oiled paper disc.

Buffer chamber

The following tests are made on this chamber:

(a) Discharging time: The chamber is filled with water and all holes are blanked except the outlet to the generator. An air pressure of 8 kg/cm^2 (114 lbs/in^2) is applied to the oxygen nipple on the top of the chamber. The water in the chamber under this pressure should be discharged through the generator supply vent in five seconds.

(b) Discharging pressure: The generator supply vent is closed with a pressure gauge. All other holes are blanked off. The chamber is filled with water and an air line is connected to the oxygen nipple at the top of the chamber. The air pressure is slowly increased and water should discharge through the regulating valve under a pressure of about 2.7 kg/cm^2 (38.4 lbs/in^2) recorded by pressure gauge. If the pressure required for discharge is greater than this value the spring on the regulating valve is adjusted or replaced.

(c) Piston clearance: Water at 40 kg/cm^2 (568 lbs/in^2) is fed to the oxygen nipple above the regulating valve. The leakage of water past the valve should be from 60 - 300cc (3.66 - 18.3 in^3) in two minutes. Usually the figure is in the region of 120cc (7.32 in^3).

(d) Non-return valve of buffer chamber: This valve is tested for leakage by rotating the engine with the buffer chamber filled with water. In practice, if this valve should leak, water will be introduced into the oxygen line and hence i into generator, where it will seriously affect combustion at the start of the run. This test is made after the buffer chamber has been connected in the torpedo circuit, and, for the purpose of the test, the oxygen feed line to the chamber is broken.

Oil distributor

Oil at a pressure of 5 kg/cm^2 (71 lbs/in^2) is supplied to the distributor and it is ascertained whether each distributing point discharges oil. (See Figure 100). The distributor is rotated at 100 revolutions per minute.

Engine cooling pump

The testing apparatus is shown in Figure 100. The water discharge is measured and should be five liters (0.18 ft^3) per 100 revolutions of the engine,(i.e. 100 revolutions of pump).

Diluent water pump (to buffer chamber) and oil pump

The engine is rotated at about 200 revolutions per minute with compressed air. (See Figure 100). Two chokes in the oil and water delivery side of the pump approximate to a back pressure of 5 kg/cm^2 (71 lbs/in^2).

Deliveries should be:

	Volume	Engine revs	Pump revs
Water	8.0 liters (490 in^3)	100	50
Oil	0.8 liters (49 in^3)	100	50

Depth gear and servomotor

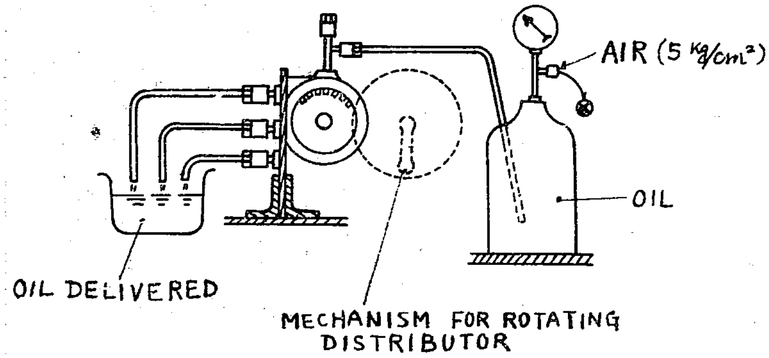
The depth gear is adjusted and calibrated as follows:

(a) A bent wire is attached to the inner crank lever of the depth gear and arranged to move over a scale attached to the stand. The weight alone is swung and should complete six oscillation before coming to rest.

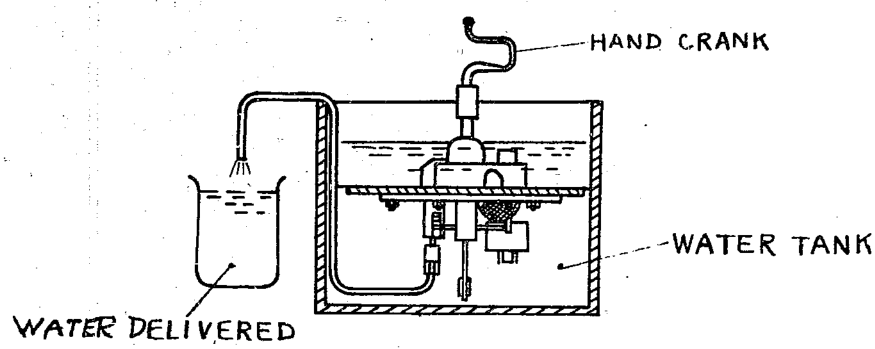
A load equal to five meters (16.5 ft) depth is applied by a lever to the hydrostatic valve. This deflects the weight. The spring is now given a compression equal to five meters (16.5 ft) and the weight should return to zero.

With the loads on, the inclination test is next applied. Table is tipped and then returned to the level. Pointer on depth gear should return to within 20 minutes of original setting.

OIL DISTRIBUTOR TEST



ENGINE COOLING PUMP TEST



DILUENT WATER PUMP AND OIL PUMP TESTS

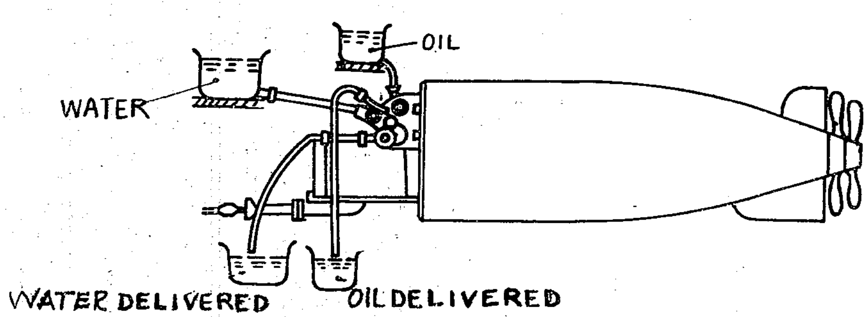


FIGURE 100
TESTS OF ENGINE DETAILS

(b) Adjust rudder travel in servomotor rods to give maximum travel of 5mm (0.197 in) up and 23mm (0.905 in) down.

(c) Lock pendulum in vertical position with screw. The rudders should then be horizontal. If not, adjust connection between depth gear and servomotor.

(d) For inclination test, the torpedo is suspended horizontally and oscillated in a vertical plane about the horizontal lateral axis through the center of gravity. The depth gear should be sufficiently sensitive to operate the rudders when the torpedo is inclined at an angle of 30 minutes to the horizontal. If this is not the case the locking screw in depth gear must be eased.

The travel of the rudders up and down is noted. The limits are:

5mm (0.197 in) up	1^{o} inclination
23mm (0.905 in) down	3^{o} inclination

The horizontal position of the torpedo is determined with a spirit level, and the angle of inclination at which the rudders move is similarly measured. An angled plate gauge is used to measure the rudder travel.

(e) The rudder locking gear is also checked.

First stage (50 revs)	horizontal
Second stage (50 to 110 revs)	Up 5mm (0.197 in) Down 19mm (0.75 in)
Third stage (depth controlled)	Max. (Up 5mm (0.197 in) (Down 23mm (0.905 in)

Gyroscope adjustments

(a) The air circuit is tested for leakage. The turbine wheel is spun up by itself and a leakage test of the air connections made.

(b) For testing rudder travel and gyro sensitivity, spin up gyro wheel, and oscillate the torpedo in a horizontal plane about the vertical lateral axis through the center of gravity. The rudder movement should be 3.8mm (0.15 in) on each side.

Normally this test is made only on a new gyro and is carried out with a pointer from the tail shaft (bent at right angles toward the ground) swinging over a scale on the floor.

For a routine checking test (e.g. Type 95, Model 2 which was run at DAINYU), the torpedo is oscillated for five minutes and the rudder movement is checked for precession. The Japanese always use the same gyroscope in any one torpedo. They are not interchangeable.

Steering air (firing) circuit

In effect, this test determines the ability of the torpedo to start successfully on the steering air.

Forty revolutions are set on gearing for shutting off steering air.

Igniter hammers are cocked.

Water flap is pushed aft.

High pressure air is connected to the inlet side of the operating valves and the engine rotated with steering air. The number of revolutions are counted by observing a piece of rag tied on one blade of the propellers. The two igniter hammers should strike after 5 and 10 revolutions respectively. The oxygen delivery stop valve should be fully open after 60 revolutions. The flap-operated steering air valve should be closed after 40 revolutions.

In order to make this test as exacting as possible, the air used should have a high pressure (200 kg/cm^2; 2844 lbs/in^2) so that maximum resistance to the opening of the oxygen delivery stop valve is encountered.

To facilitate the opening of this valve in practice, a pilot valve is fitted in the main valve; it lifts slightly befor the main valve and partially balances the pressure.

Afterbody/forebody assembly

In assembling the afterbody to the forebody the following connections are made:

Air lead from steering air bottles to steering air starting valve.
Air lead from steering air starting valve to servomotor.
Main oxygen supply pipe to "group".
Fuel supply pipe to generator.
Water supply pipe to fuel chamber.
Servomotor connecting rods.
Rudder locking gear.
Forward end of the engine to the forebody.

Workers engaged at DAINYU

In the preparation of one torpedo for ranging the workers are engaged as follows:

One worker for exercise head and recorder.
One for oxygen valves (i.e. oxygen charging valve, oxygen charging stop valve, oxygen delivery stop valve).
Two for general cleaning of oxygen vessel, oxygen delivery pipe, and vessel end.
One for buffer chamber.
One for depth gear, servomotor and disc reducer.
One for generator.
One for reducer.
One for diluent sea water, cooling and oil pumps.
One for gyroscope and double disc reducer.
Three for stripping, cleaning, adjusting, and reassembling engine; cleaning of fuel vessel; filling with fuel, and lubricating oil. These three are also responsible for the general assembly of the whole torpedo.

Total number of workers engaged - 13.

Time to complete preparation of one torpedo - 30 hours (approx).

TRIALS

With a view to checking the performances which were claimed by the Japanese for their oxygen torpedoes, eight runs were made on the torpedo range at DAINYU, near KURE, between 28 December 1945 and 29 January 1946. For these ranging tests, four submarine oxygen torpedoes of Type 95, Model 2 were used. Owing to the destruction of a considerable part of the torpedo range installations in the KURE area, it was not considered feasible to run the Type 93 torpedo. Under the circumstances, it would not have been possible to make reliable measurements of the performance of this torpedo which possessed such long range characteristics.

Of the four torpedoes which underwent the tests, one was lost at the end of its first run; another successfully completed three runs; the remaining two made two runs each. The performance data obtained from these test are shown in tabular form on the following pages.

Passing conditions

21" Type 95, Model 2 submarine torpedo

Speed	49 ± 1 knots
Range	5500 meters (6000 yards)
Depth keeping	5 ± 0.5 meters (16.4 ± 1.6 ft)
Direction keeping (at maximum range)	± 90 meters (± 98 yards)

DETAILS OF DAINYU RANGE

The position of the range at DAINYU is shown in Figure 101. (See also, Figure 102). The installations at the range consist of one large preparation shop, two smaller ones and an inspection shop. The firing point is situated at the end of a jetty, 100 yards long, and consists of a two-story building. In the second story of this building is the observation room which is equipped with a large pair of binoculars (x30 magnification) and fitted with a cut-away section in the floor through which the discharge of the torpedo can be seen. On the ground floor the torpedo handling and firing apparatus is fitted. This consists of two electrically operated overhead hoists (three and five tons capacity respectively) for transferring torpedoes from the transport trucks to the loading trucks; two electric winches for loading, raising and lowering the two frames from which the torpedoes are fired (Figures 103 and 110); and a hand-operated drum on which the firing cable is wound. This cable passes around pulley wheels to the frame where it is attached to a lever which, when pulled, raises the stop from the T-piece guide on the torpedo and operates the starting lever. The cable is taut immediately before firing, and one sharp half-turn of the drum fires the torpedo. Thus, firing takes place from a standing start and the water flap is not used, being aft when the torpedo is loaded.

The frames can be used for 24", 21" or 18" torpedoes by using guide liners to suit.

Beneath the two frames is a depth of water of 6 fathoms M.L.W.S. and the torpedoes normally are fired from a depth of three meters (10 ft). The direction of firing is 135° (T).

ACOUSTIC GEAR

During and prior to the war, the range was equipped with target buoys. Observer boats, equipped with acoustic gear and radio, were moored alongside these buoys. The instant at which a torpedo passed the

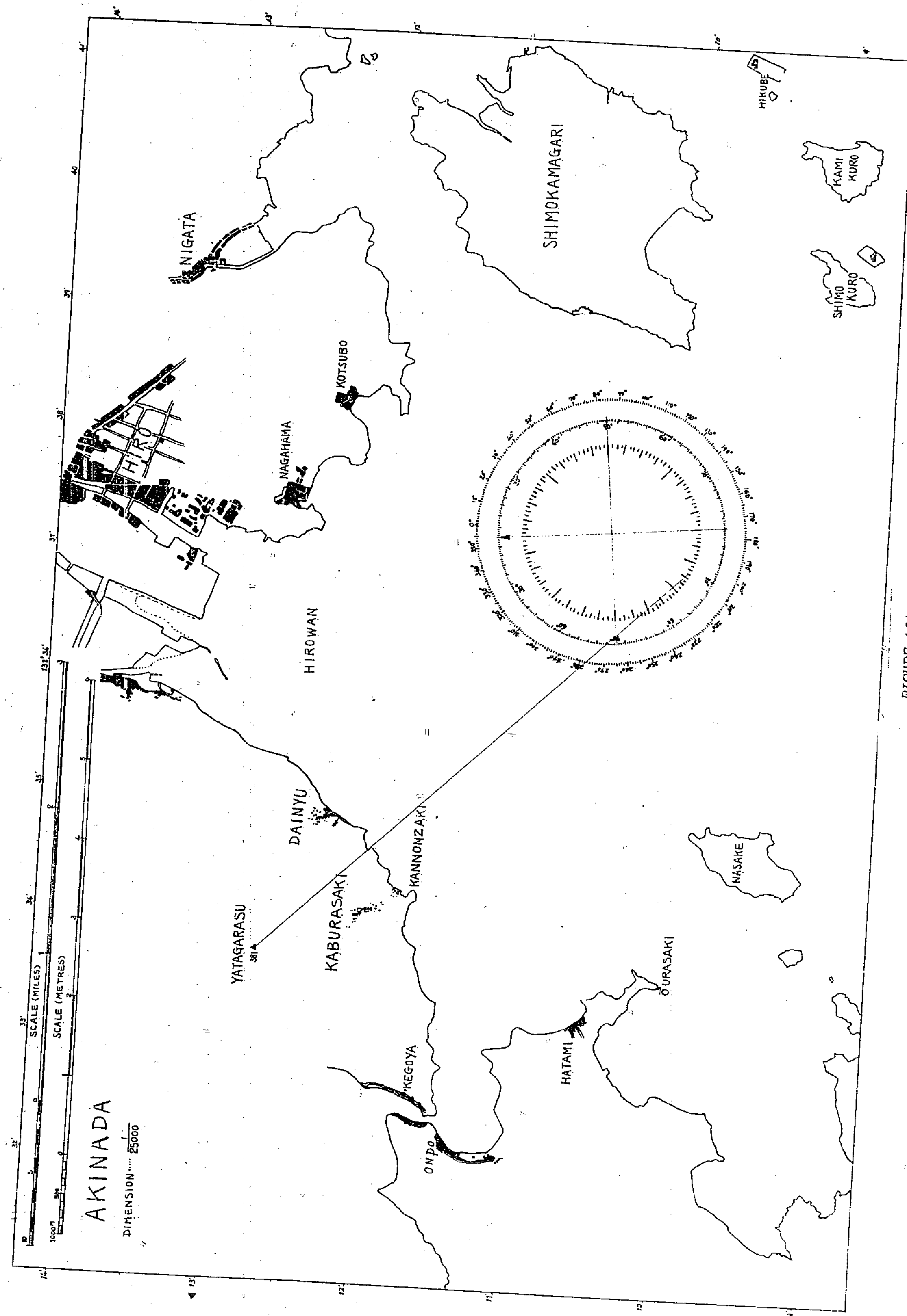


FIGURE 101
CHART OF DAINYU RANGE

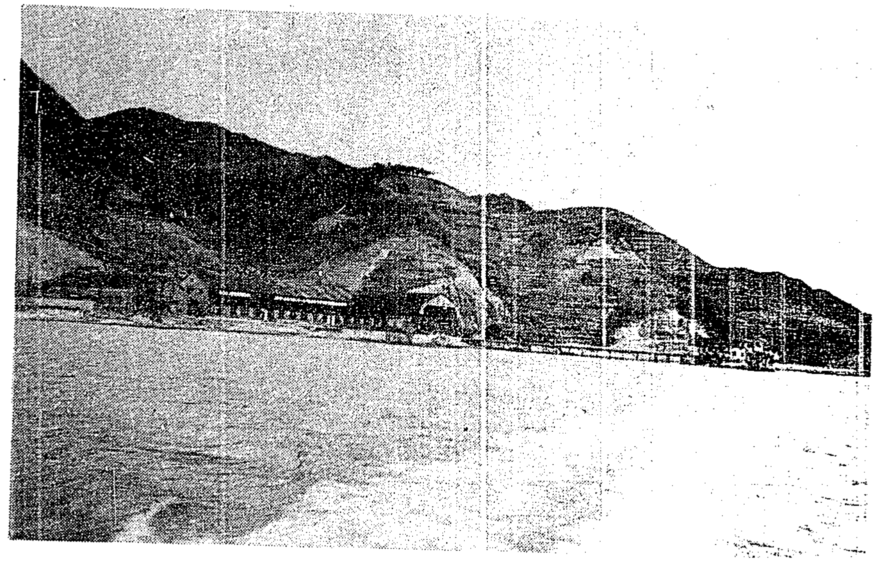


FIGURE 102
VIEW OF DAINYU RANGE FROM THE SEA

buoy was detected by the intensity of sound in the pick-up microphone and a signal was flagged to the firing point, where the time of run was measured with stop watches. By this means the average speed over sections of the run, as well as the average speed over the whole run, could be calculated.

At the end of the war, the acoustic gear and target buoys were destroyed; thus the normal measuring equipment was not available for the trial runs made with Type 95, Model 2, in December 1945 and January 1946. This situation presented many difficulties which were overcome when USS BALTIMORE agreed to furnish equipment and personnel to assist in the trials.

MEASUREMENTS AT THE TRIALS

EQUIPMENT

1 400-ton tug boat (Japanese crew)
1 aircraft ("Kingfisher")
3 LCM's
1 whaleboat
3 radio sets
4 stop watches
6 pairs of binoculars
Miscellaneous signalling equipment

The three radio sets were fitted in the tug, aircraft, and firing point, respectively. Allied personnel in the tug consisted of a navigation officer, a communications officer and 10 men. Two stop watches were used aboard.

At the firing point were three abservers (two Allied, one Japanese), a communications officer and four signalmen. Two stop watches were used at the firing point.

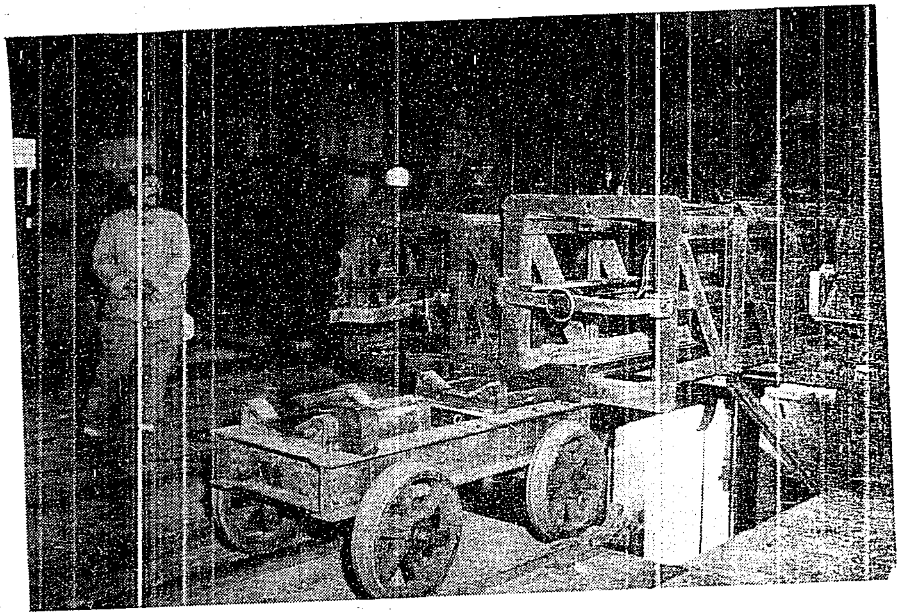


FIGURE 103
TORPEDO FRAMES

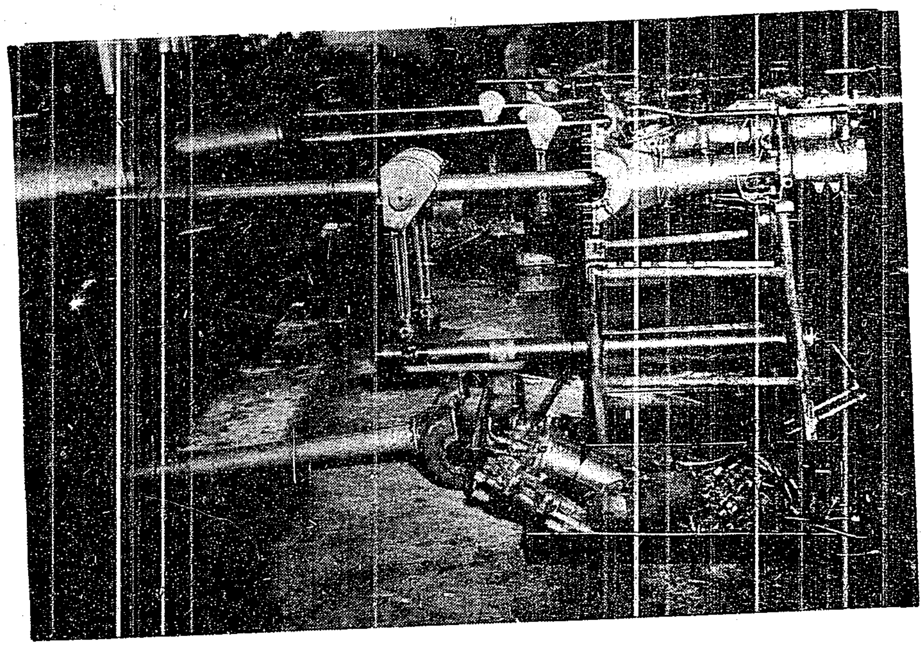


FIGURE 104 (a)
ENGINE OVERHAUL

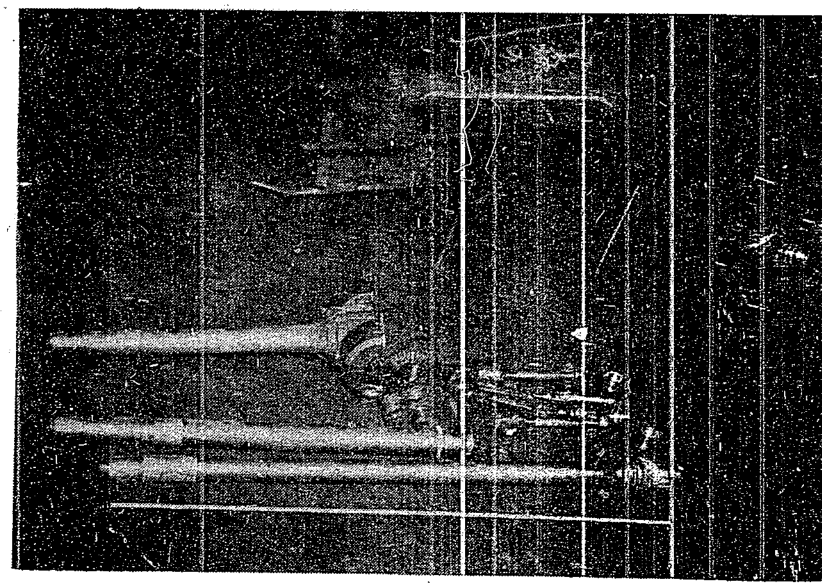


FIGURE 104 (b)
ENGINE OVERHAUL

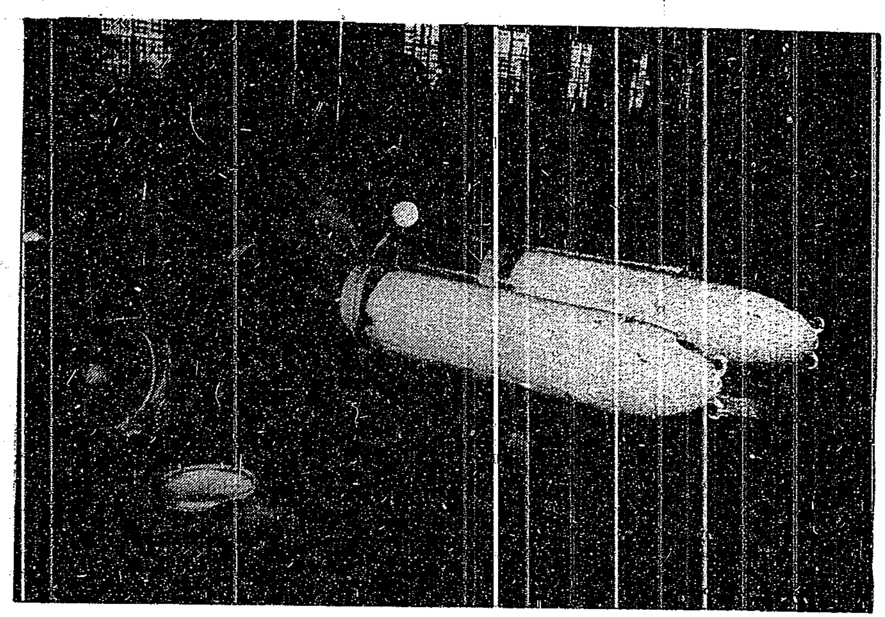


FIGURE 105
PREPARATION OF TORPEDOES

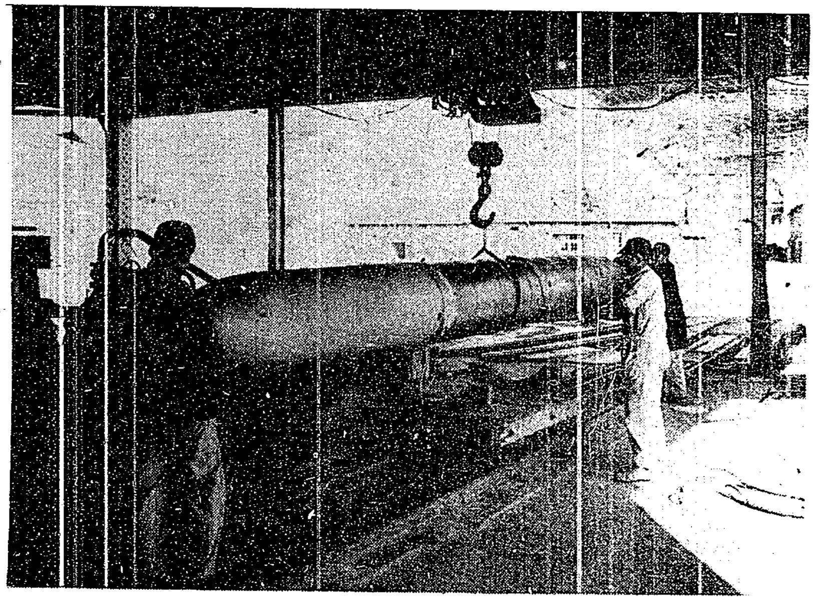


FIGURE 106
TORPEDO BEING TRANSFERRED TO LAUNCHING TRUCK

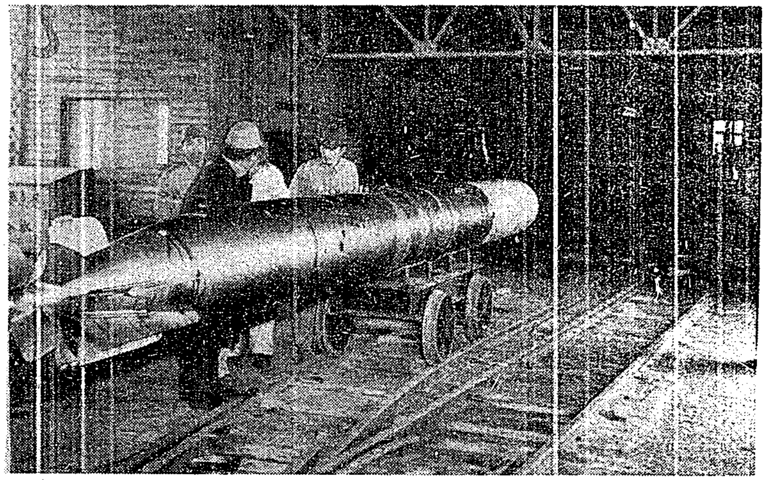


FIGURE 107
TORPEDO ON LAUNCHING TRUCK

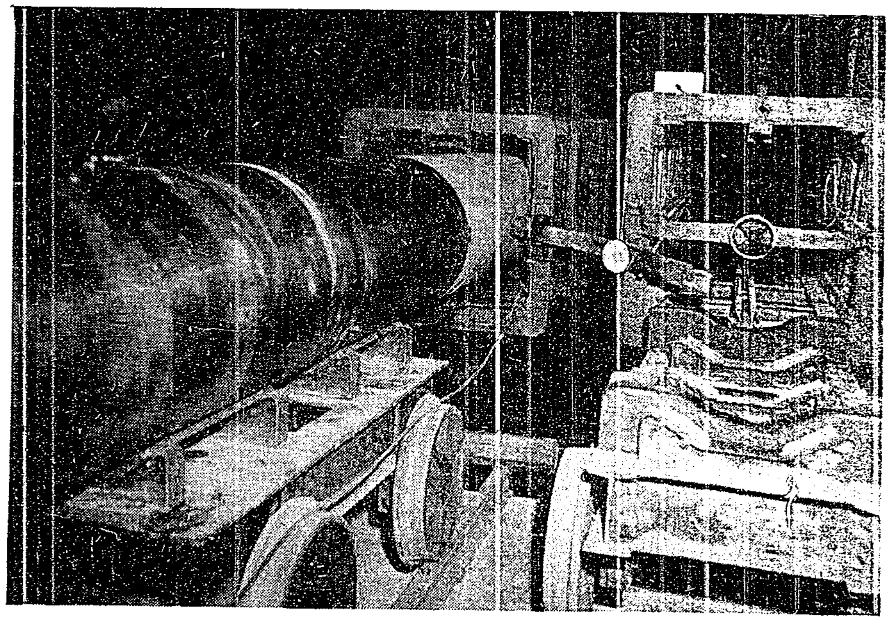


FIGURE 108
TORPEDO BEING LOADED INTO FRAME

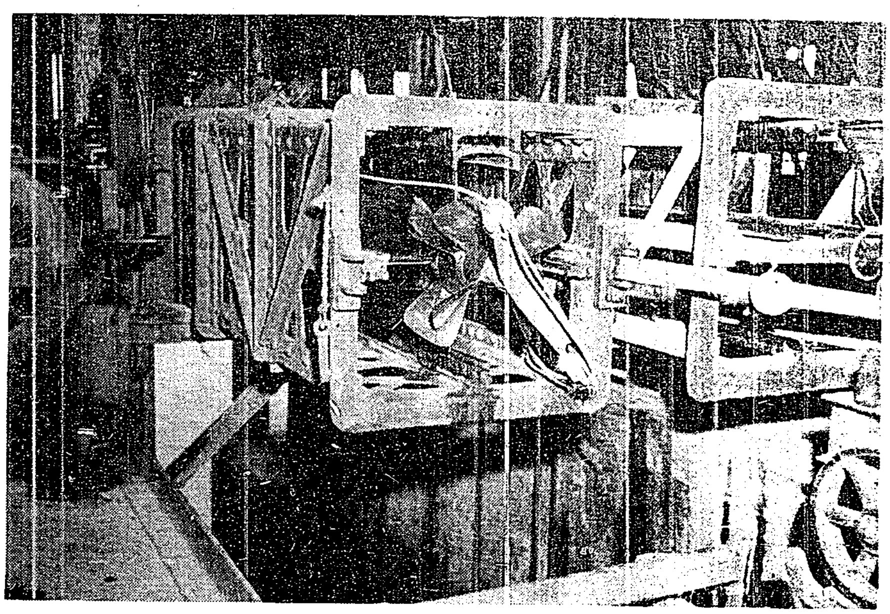


FIGURE 109
TORPEDO IN FRAME

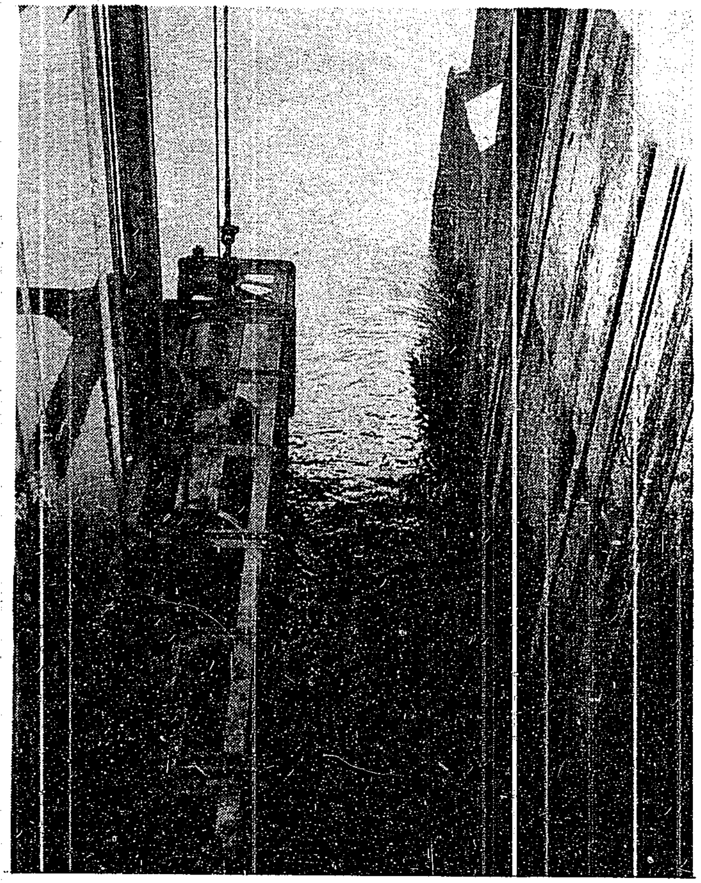


FIGURE 110
FRAME BEING LOWERED

The aircraft carried a pilot, wireless operator and, on some runs, a photographer.

The whaleboat was manned by an American crew from USS BALTIMORE and also carried three Japanese workers who assisted in picking up the torpedo at the end of the run.

ROUTINE

On the morning of the run, the following final checks were made on the torpedo which was to be ranged. (See Figure 104-110):

In preparation shop

(1) Check pressure in oxygen vessel.
(2) Charge steering air and check pressure.
(3) Check quantity of fuel in the fuel vessel.
(4) Check water in buffer chamber
(5) Check water and oil in the reducer.
(6) Remove drain screw plugs from valve chest; drain engine and replace plugs. (To drain, the propellers were given one turn by hand, while the plugs were out).

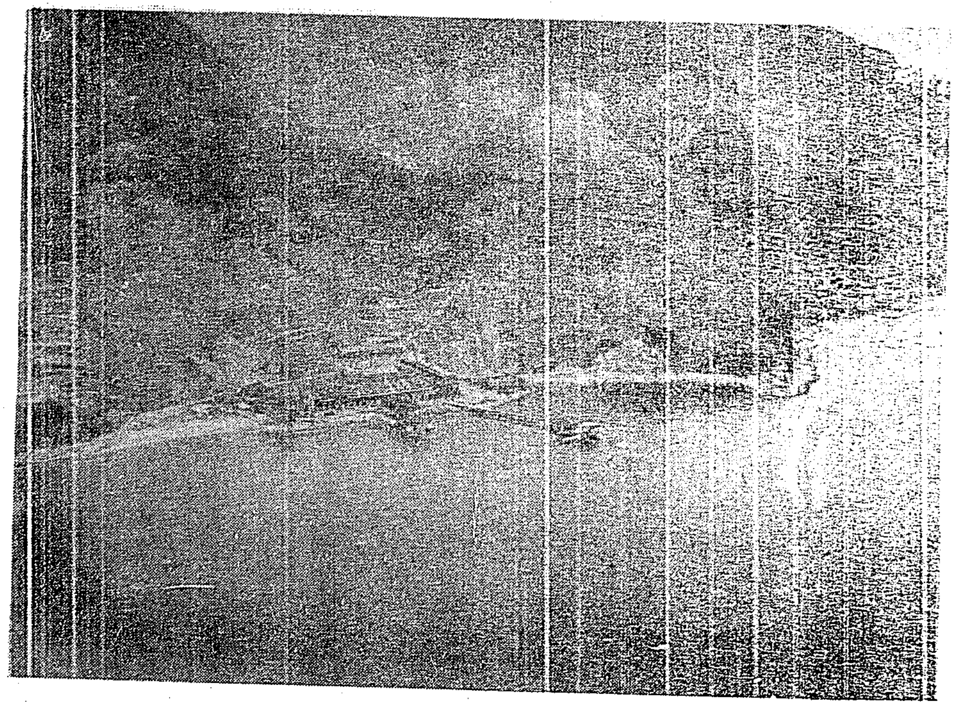


FIGURE 111
INSTALLATIONS AT FIRING POINT
ON TORPEDO RANGE AT DAINYU

(7) Check functioning of recorder in exercise head.
(8) Check range and speed setting.
(9) Check steering air shut-off gear.
(10) Inspect starting valve in the "group". For this check, remove the "group" cover, and then the pilot and main valves. Inspect the seats and freedom of movement of these valves. (This is an important check).
(11) Check horizontal rudder locking gear.

At firing point

(12) Check setting of igniter hammers and insert igniters.
(13) Open steering air stop valve and then open gyro door and listen for air leaks. (This test also was made on the previous day).
(14) Pour 30cc of carbon tetrachloride into the non-return valve of the oxygen delivery valve. (Sometimes in submarines tetrachloride is not used due to corrosion troubles which arise).
(15) After (14), insert bevel gear wheel to operate oxygen delivery stop valve. (The gear wheel is not assembled until immediately before loading the torpedo into the frame, for safety reasons).
(16) Load torpedo into frame.

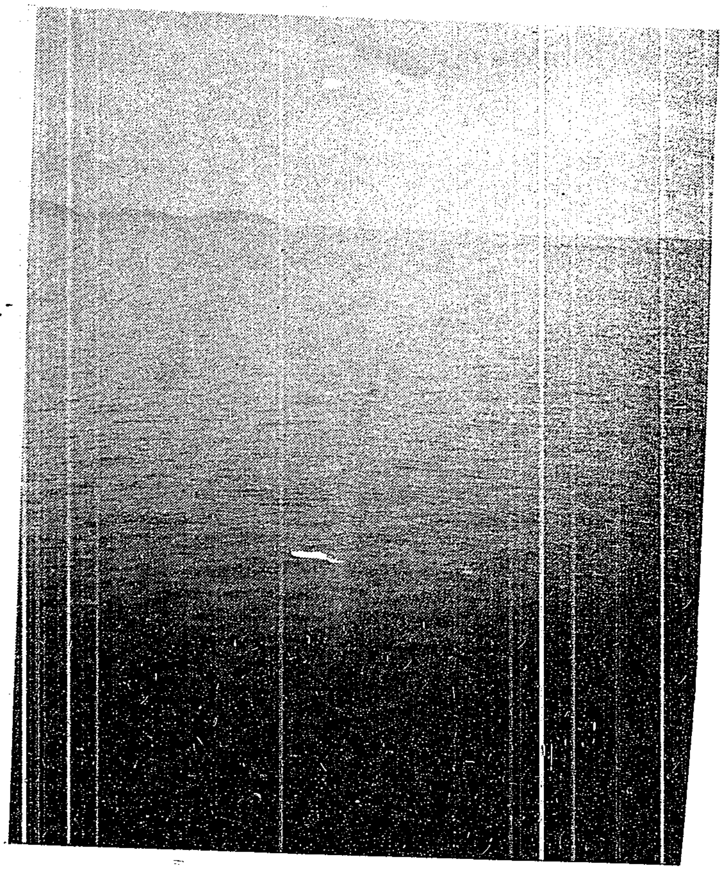


FIGURE 112
TRACK OF START OF RUN OF TORPEDO NO.5053 FROM FIRING POINT. (29 JANUARY 1946)

The check tests in the preparation shop occupied the time of three men for one hour. If speed is necessary the tests could be completed in 30 minutes.

The operations at the firing point occupied the time of two men for 30 minutes.

About half an hour before the scheduled time of running, the tug left the firing point and took up a position about 6000 yards off shore and about 400 yards off the expected course of the torpedo. The radio on the tug was not sufficiently powerful to reach the shore, and messages from ship to shore were relayed by the aircraft which patrolled the area. (Visual signals were not generally satisfactory due to the smoke made by the tug). Messages from the shore to the tug were received in the wheelhouse of the latter over a loud speaker.

Two LCM's patrolled, to the port and starboard sides of the range, to keep the danger area free from vessels.

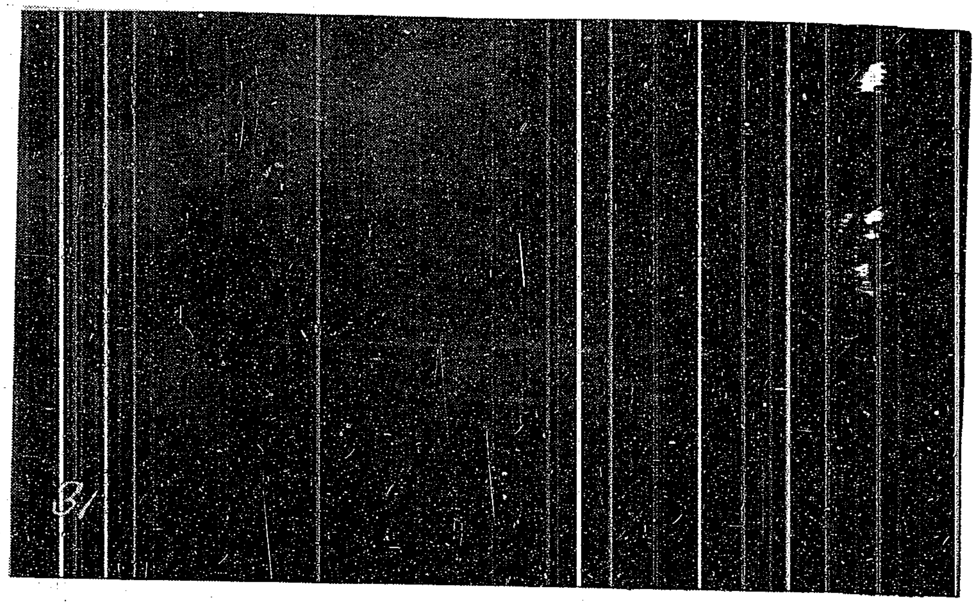


FIGURE 113
TRACK OF NO.5053 (29 JANUARY 1946)

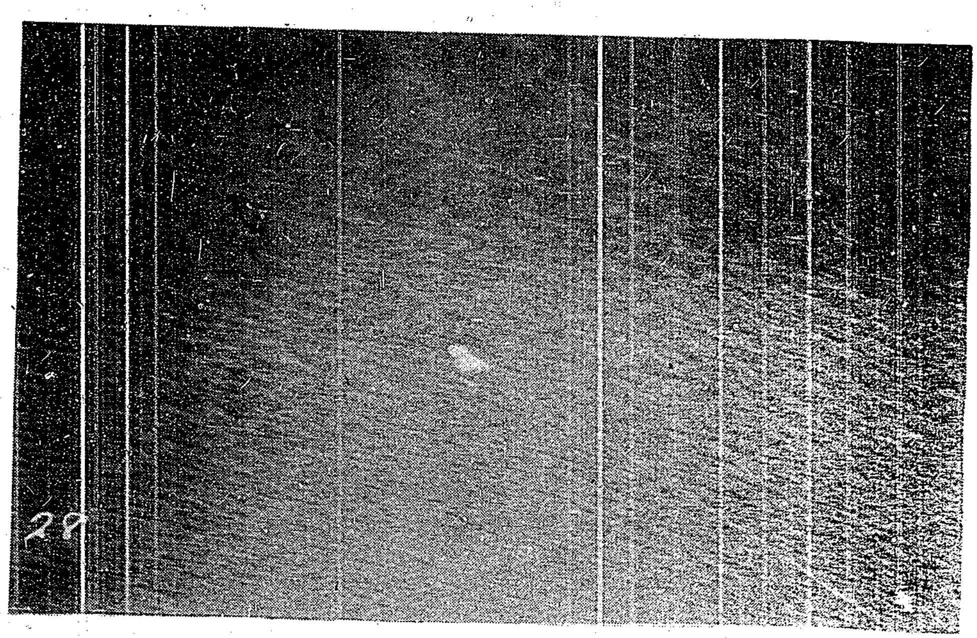


FIGURE 114
SURFACING OF NO.5053 (29 JANUARY 1946)

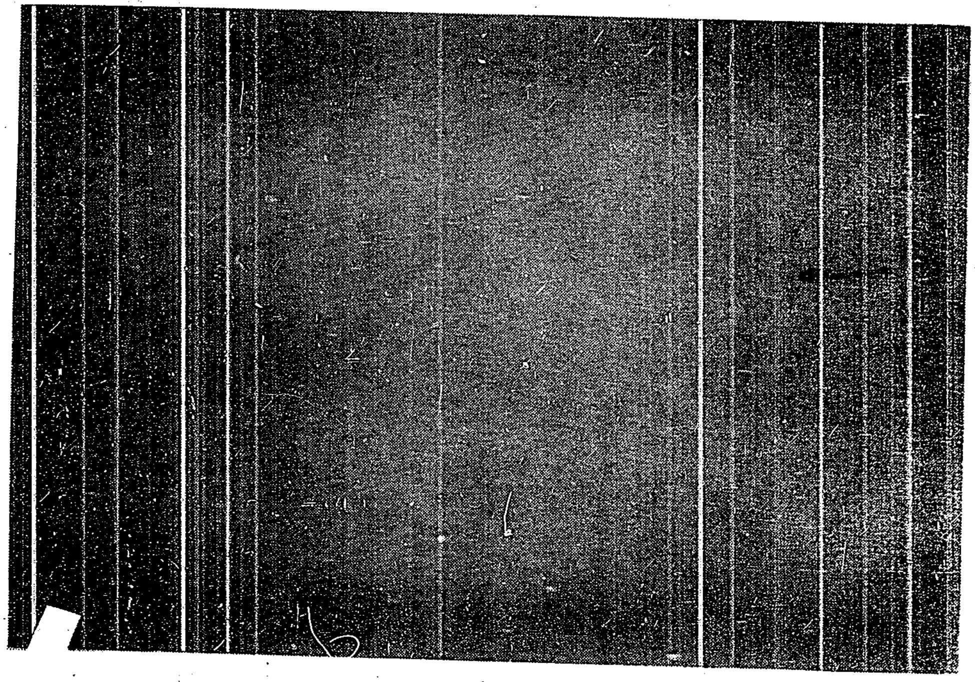


FIGURE 115(a)
TRACK OF NO.2737 (29 JANUARY 1946)

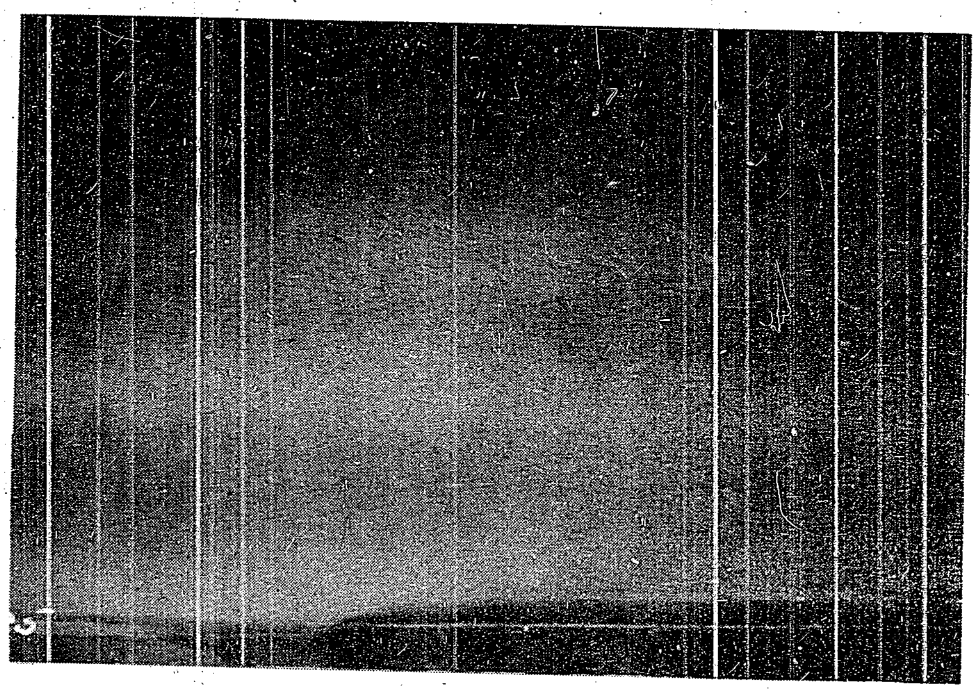


FIGURE 115(b)
TRACK OF NO.2737 (29 JANUARY 1946)

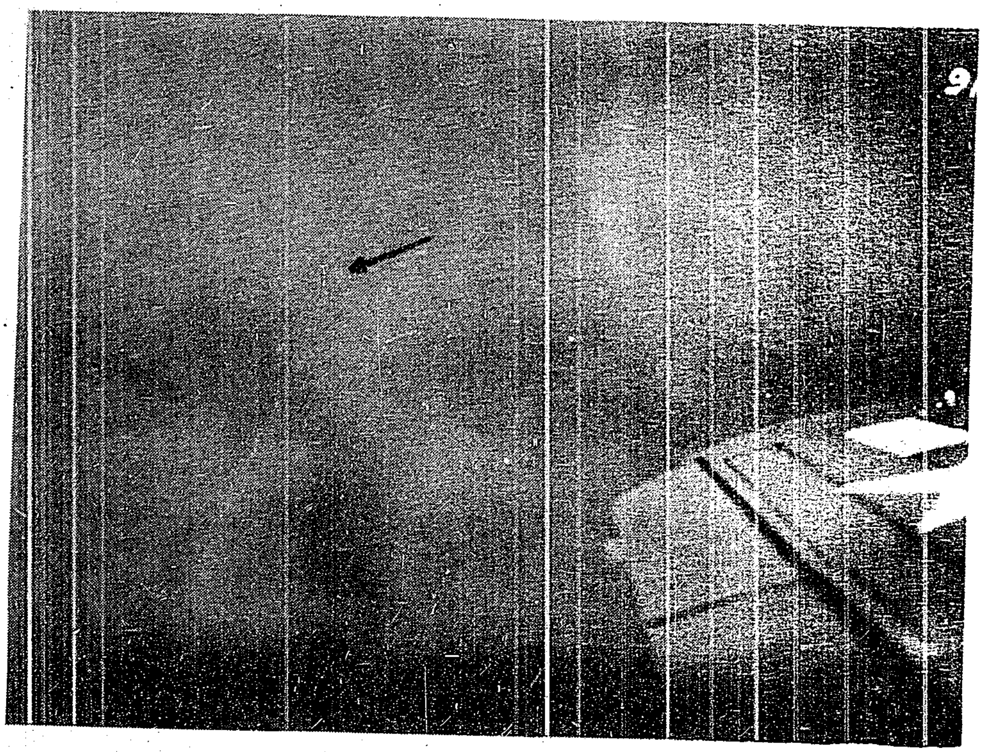


FIGURE 116
TRACK OF NO.2725 (29 JANUARY 1946)

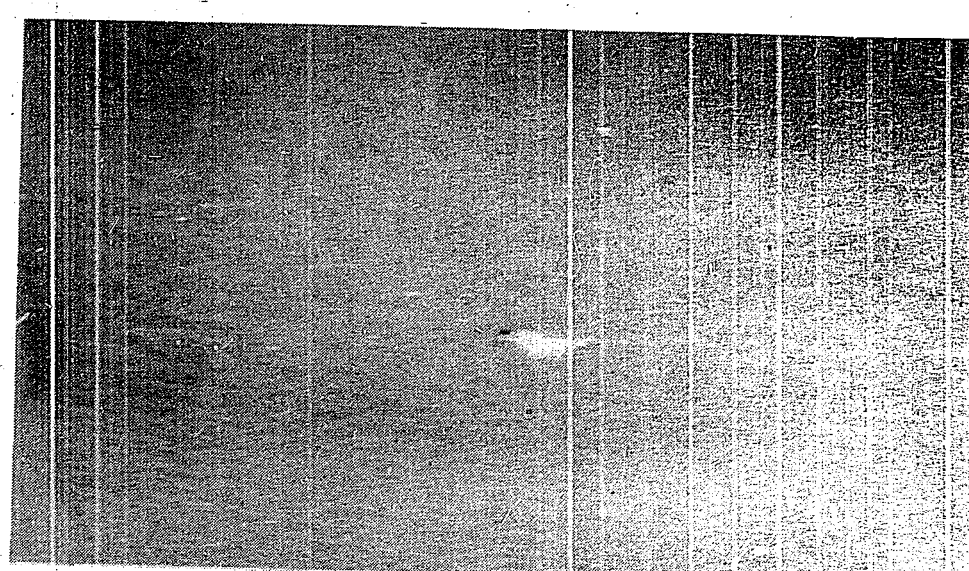


FIGURE 117
SURFACING OF NO.2725 (29 JANUARY 1946)

About 10 minutes before firing, the frame with the torpedo was lowered to the surface of the water (See Figure 110). Immediately before firing, the shore transmitted the following warning signals:

5 minutes preparation warning.
90 seconds warning.
30 seconds warning.
"Stand-by".
FIRE.

In the five minute preparation warning the torpedo was lowered into the water to a depth of about 10 feet (depth of discharge). The signal "fire" was given to the Japanese operator (who stood by the firing pulley) by means of an electric bell, which was rung by an observer on the second story of the firing point.

Instant of firing

This was seen by the observers at the firing point through the cut-away section in the floor and two stop watches were started when the tail of the torpedo left the frame; at that moment, the communications officer looking down from the window in the observer's room was able to see the head (painted yellow) emerging from the firing point and gave the radio firing signal which was received by the aircraft and the tug. By this means, the instant of starting of the watches on the tug depended only on the signal from the communications officer who gave his signal independently of the starting of watches at the firing point.

The course of the torpedo was followed from the firing point with binoculars, and the tug was informed by radio whether the track was to port or starboard of the true course. Observers in the aircraft were able to see the torpedo running in the water. When the aircraft was directly above the torpedo, a signal to this effect was given, and therefore the observers on the tug and on the firing point were kept informed of the position of the torpedo throughout the run.

TRACK

The tracks of the torpedoes, as seen from the firing point, were extremely slight. Except for the start of the run (about 50 yards), when some bubbles were formed by the air used in starting(Figure 112) there is no visible gaseous discharge in the wake of the torpedo. The track could be detected only by the lubricating oil left in the wake. This appeared as a smooth strip upon the surface of the water, probably due to the surface tension effect of the oil. At a distance of 2000 to 3000 yards, the track could no longer be seen from the firing point. It was noticed that the track was slightly more easily followed when the sun was shining. All the runs were made in good weather and it is thought that the track would be very difficult to detect under less favorable conditions.

In no instance during the trials was the track visible to observers on the tug.

From the air, the torpedo could be seen during the run and, from certain positions, the track could be seen. The pilot's observations, and those of the Navigating Officer aboard the tug, of the run of torpedo No. 2473 on 28 December 1945 (this torpedo was lost) are as follows:

"The track of the torpedo was extremely straight. Torpedo appeared black during run, (yellow nose did not show under water). The torpedo left a clearly visible yellow streak which remained visible for about three minutes, (this could only be seen 20 degrees on either side of the vertical, probably due to refraction). From an altitude of 500 feet looking back along the track, an oil slick was observed from firing point to the point of surfacing. No exhaust appeared except for the above mentioned yellow streak. The plane did not see the torpedo itself when it broke the surface, but observed two splashes. The second splash was about 150 yards further along the track. However, there was neither a yellow streak nor an oil slick between the two splashes".

Observations from the tug:

"No track was seen. The torpedo (yellow nose) was observed to break the surface. It appeared to leap about a foot into the air, then disappear. There was no sign of the torpedo after it surfaced. It appeared to porpoise at the end of run, then sink. Plane confirmed plotted position of surfacing".

"Plotted position of surfacing":

Latitude 34° 09' 58"
Longitude 132° 37' 15"

"Track of torpedo: 133.3° (True)"

Aerial photographs of some of the runs were taken (Figures 112-117). For these photographs, a K20 aerial camera of focal length 6-3/8 inches was used. The altitude was 300-500 feet.

MEASUREMENT OF RANGE

When the torpedo broke surface at the end of the run, it normally dived again and appeared about 20 yards further on with the head bobbing up and down, its nose first about six feet above the surface, and then setting down until two feet of the blowing head showed above water. The whaleboat proceeded to the point of surfacing as fast as possible and secured the torpedo. Next, the tug arrived at the point and plotted the exact position by three point bearings (using a sextant horizontally). By this means, the range run by the torpedo was calculated. The tug then took the torpedo in tow, and proceeded back to its former position to await the next run. This procedure was repeated for each run.

In all the runs, except the first one, 1 kilogram (2.2 lbs) of fluorescein was dissolved in the water with which the exercise head was filled. This colored a large patch of water on the surface of the sea, where the torpedo surfaced. (During the war, a continuous leak of fluorescein from the head was sometimes used during a run to mark the track).

PICKING UP OF TORPEDOES

At the end of the trial the tug towed the torpedoes back to the firing point, where they were picked up, one by one, by an LCM. When near the jetty, two pear-shaped iron floats (about 40" long and 18" diameter) joined by a three foot rope were dropped into the sea. The torpedo was towed slowly over the rope between these floats. As the speed of towing increased, the torpedo slowly became horizontal and the floats slipped back towards the tail where the rope caught in the tail structure. The torpedo was now brought along side the jetty in an almost horizontal position. Two steel wire loops were passed around the body and the torpedo finally was raised by a crane. It was then returned to the preparation shop on a truck (running on rails).

In general, two hours elapsed after the firing of the torpedo before it was back again in the preparation shop, when the following procedures were carried out.

AFTER RUNNING

Return torpedo to the preparation shop. Close oxygen delivery stop valve. Pull up the starting lever and close the steering air stop valve. Check condition of the propulsion system by turning the propellers by hand. (This also helps to remove water from the engine).

CONSUMPTIONS

(1) Measure pressure of oxygen and steering air. The pressure of the latter is often-zero, due to leakage from the flap-operated steering air starting valve during and after the run.

(2) Measure fuel consumption. The volume of sea water in the fuel chamber is drained out and measured. If some fuel also drains out, it is easy to discern the line of separation between the fuel and the water.

(3) Measure consumption of lubricating oil.

(4) Take the water flow meter readings and calculate the volume of diluent water used during the run.

EXERCISE HEAD

Remove the exercise head, take out the recorder and read the speed, depth, and rolling from the tracing.

Strip the discharge valve in the head and the piston of the hydraulic cylinder. Clean, assemble and test the functioning of the blowing mechanism by raising a water bottle which is connected by a pipe to the hydro-dynamic valve in the nose of the head. As the pressure of the water increases the functioning of the blowing mechanism is noted.

Check the recorder. Strip, clean, and assemble, if required for another run.

FOREBODY

(1) Disconnect the five pipes (oxygen, two steering air, water and fuel) and separate the afterbody from the forebody.

(2) Remove depth gear. Strip, clean, assemble and adjust.

(3) Remove bevel gear wheel from the oxygen delivery stop valve and clean. Pour carbon tetrachloride from the non-return valve into the pipe to clean it.

ENGINE ROOM

(1) Remove the buffer chamber, servomotor and disc reducer.

Clean, assemble and adjust.

(2) Remove the generator, reducer, group, diluent sea water pump (including oil pump), and the cooling pump for engine. Strip, clean, assemble and test.

(3) If the speed obtained during the run is within the passing conditions, the engine is not stripped for the next running, but the water in the cylinders is drained through the screw plugs of the valve chest, by hand rotating the propellers. If the performance is not within the passing conditions (or if the next run is the third run), the engine is stripped, cleaned, all parts checked and reassembled. The slide valve clearances are measured and the valves are replaced as necessary.

(4) Remove gyroscope from the rear buoyancy chamber. Test on the bench. Then strip, clean, assemble and adjust.

RANGING DATA SHEETS

RANGING DATA SHEET FOR TYPE 95, MODEL 2 TORPEDO NO. 2473

(Due to the loss of this torpedo at the end of the run, complete data were not obtainable).

Number of Run	1
Date of Run	28 December 1945

DATA BY DIRECT MEASUREMENT

Time of Run (Seconds)	
(1) Firing Point	
No. 1 watch	230*
No. 2 watch	226.9
(2) Tug	
No. 1 watch	226.5
No. 2 watch	226.7
(3) Average of three watches	226.7
Range Run	
(1) Meters	5466
(2) Yards	5980
Average Speed	
(1) Knots	46.85
(2) Meters/second	24.1
(3) Yards/second	26.4
Course of Torpedo (true)	133.3°
Direction	
Wander left (1) meters	162
(2) yards	178
Wander right (1) meters	-
(2) yards	-

*Discount

Period of time elapsed between end of run and measurement of consumptions (hours)	Torpedo lost at end of run
Oxygen Pressures	
Before Run (1) kg/cm^2	200
(2) lbs/in^2	2844
After Run (1) kg/cm^2	-
(2) lbs/in^2	-
Total Drop (1) kg/cm^2	-
(2) lbs/in^2	-
Oxygen Consumption	
Pressure Drop Rate (1) kg/cm^2/1000m	-
(2) lbs/in^2/1000 yd	-
Steering Air Pressures	
Before Run (1) kg/cm^2	225
(2) lbs/in^2	-
After Run (1) kg/cm^2	-
(2) lbs/in^2	-
Fuel Consumption	
(1) Liters	-
(2) Cubic Feet	-
Diluent Water Consumption	
Meter Readings (1) Before Run	-
(2) After Run	-
Consumption (1) Liters	-
(2) Cubic Feet	-
Lubricating Oil Consumption	
(1) Liters	-
(2) Cubic Inches	-
Slide Valve Clearances	
(1) Before Run (a) Port	-
(2) After Run (b) Starboard	-
(a) Port	-
(b) Starboard	-

DATA FROM RECORDER

Speed	
Average (knots)	-
Maximum (knots)	-
Tail-Off	
Depth	
Setting (1) Meters	5
(2) Feet	16.4
Average depth of run (1) Meters	-
(2) Feet	-
Initial Dive (1) Meters	-
(2) Feet	-
Roll	-

GENERAL DATA

Photographs taken	None

Weather	
Sea	Short, choppy, white caps.
Wind (Beaufort)	4
Sun	Bright
Clouds	4/10
Tide	NE, 0.06 knot

DATA BY CALCULATION

Water/Fuel Ratio	
(1) By Volume	-
(2) By Weight	-
Approx. total oxygen consumption (No allowance for temperature changes).	
(1) kg	-
(2) lbs	-
Oxygen/Fuel Ratio By Weight	-

RANGING DATA SHEET FOR TYPE 95, MODEL 2 TORPEDO NO. 5053

Number of Run	1	2	3
Date of Run	5 Jan. 1946	19 Jan. 1946	29 Jan. 1946
DATA BY DIRECT MEASUREMENT			
Time of Run (Seconds)			
(1) Firing Point			
No. 1 watch	215.2	210.0*	214.2
No. 2 watch	215.8	208.0	214.5
(2) Tug			
No. 1 watch	214.7	208.8	213.3
No. 2 watch	215.0	208.6	213.5
(3) Average of watches	215.2	208.5	213.9
Range Run			
(1) Meters	5220	5360	5260
(2) Yards	5711	5864	5754
Average Speed			
(1) Knots	47.1	49.9	47.7
(2) Meters/Second	24.3	25.7	24.6
(3) Yards/Second	26.5	28.2	26.9
Course of Torpedo (true)	135.2°	133°	136°
Direction			
Wander Left (1) Meters	18	187	-
Wander Left (2) Yards	19.7	205	-
Wander Right (1) Meters	-	-	92
Wander Right (2) Yards	-	-	101

*Discount

NUMBER OF RUN	1	2	3
Period of time elapsed between end of run and measurement of consumptions (hours)	2	2	3
Oxygen Pressures			
Before Run (1) kg/cm^2	188	205	186
(2) lbs/in^2	2673	2915	2645
After Run (1) kg/cm^2	62	68	33
(2) lbs/in^2	882	967	469
Total Pressure Drop (1) kg/cm^2	126	137	153
(2) lbs/in^2	1791	1943	2173
Oxygen Consumption			
Pressure Drop Rate			
(1) kg/cm^2/1000m	24.1	25.6	29.1
(2) lbs/in^2/1000 yd	313.6	331.3	377.6
Steering Air Pressures			
Before Run (1) kg/cm^2	225	230	236
(2) lbs/in^2	3200	3271	3356
After Run (1) kg/cm^2	12	0	0
(2) lbs/in^2	171	0	0
Fuel Consumption			
(1) Liters	20	19.25	20.4
(2) Kilograms	10.4	15.8	16.7
(3) Cubic Feet	0.71	0.68	0.72
(4) Pounds	36.1	34.8	36.7
Diluent Water Consumption			
Meter Readings			
(1) Before Run	005518.2	005642.0	005764.8
(2) After Run	005636.5	005763.4	005893.5
Consumption			
(1) Liters	118.3	121.4	128.7
(2) Cubic Feet	4.2	4.3	4.5
Lubricating Oil			
(1) Liters	2.28	3.6	3.9
(2) Cubic Inches	139.1	219.7	238.0
Slide Valve Clearance (mm)			
(1) Before run (a) Port	-	0.15	0.25
(b) Starboard	-	0.15	0.25
(2) After run (a) Port	0.15	0.25	0.30
(b) Starboard	0.15	0.20	0.30
<u>DATA FROM RECORDER</u>			
Speed			
Average (knots)	45.0	46.0	45.8*
Maximum (knots)	45.0	46.1	46.0
Tail-off	No	No	Yes
Depth			
Setting (1) Meters	5.0	5.0	5.0
(2) Feet	16.4	16.4	16.4

*Excluding tail-off

TORPEDO NO.5053, (con't)

NUMBER OF RUN	1	2	3
Average Depth of Run			
(1) Meters	6.0	5.8	4.9
(2) Feet	19.7	19.0	16.1
Initial Dive			
(1) Meters	13	15.0	12
(2) Feet	43	49	39.4
Roll	5°P 15°P	12°P 3°S	15°P 3°S

GENERAL DATA

Photographs of Run	Yes	No	Yes
Weather			
Sea (Small surface chop)	Calm	Calm	Calm
Wind (Beaufort)	2	1-2	1-2
Sun	Bright	Bright	Nil
Clouds	4/10	1/10	10/10
Tide (knots)	SW 0.5	SW 0.7	SW 0.6

DATA BY CALCULATION

Water/Fuel Ratio			
(1) By Volume	5.9	6.3	6.3
(2) By Weight	7.2	7.7	7.7
Total Oxygen Consumption (10° C) (No allowance for temperature changes).			
(1) kg	37.0	40.3	45.0
(2) lbs	81.4	88.7	99.0
Oxygen/Fuel Ratio By Weight	2.25	2.55	2.69

RANGING DATA SHEET FOR TYPE 95, MODEL 2 TORPEDO NO. 2737

Number of Run	1	2
Date of Run	19 Jan. 1946	29 Jan. 1946

DATA BY DIRECT MEASUREMENT

Time of Run (Seconds)		
(1) Firing Point		
No. 1 watch	207.0	207.8
No. 2 watch	209.0*	207.8
(2) Tug		
No. 1 watch	206.2	207.0
No. 2 watch	206.0	206.8
(3) Average of watches	206.3	207.3
Range Run		
(1) Meters	5210	5265
(2) Yards	5700	5760
Average Speed		
(1) Knots	49.0	49.3
(2) Meters/Second	25.2	25.4
(3) Yards/Second	27.6	27.8

*Discount

NUMBER OF RUN	1	2
Course of Torpedo (true)	134°	138°
Direction		
Wander left (1) Meters	91	-
(2) Yards	99.6	-
Wander right (1) Meters	-	275
(2) Yards	-	301
Period of time elapsed between end of run and measurement of consumptions (hours)	2	2.5
Oxygen Pressures		
Before Run (1) kg/cm²	195	195
(2) lbs/in²	2773	2773
After Run (1) kg/cm²	62	50
(2) lbs/in²	881	710
Total Drop (1) kg/cm²	133	145
(2) lbs/in²	1891	2059
Oxygen Consumption		
Pressure drop rate		
(1) kg/cm²/1000m	25.5	27.5
(2) lbs/in²/1000 yd	331.7	357.5
Steering Air Pressures		
Before Run (1) kg/cm²	230	237
(2) lbs/in²	3271	3365
After Run (1) kg/cm²	0	5
(2) lbs/in²	0	71
Fuel Consumption		
(1) Liters	19.5	20.5
(2) Kilograms	16.0	16.8
(3) Cubic Feet	0.69	0.72
(4) Pounds	35.2	37.0
Diluent Water Consumption		
Meter Readings		
(1) Before Run	000013.9	000143.0
(2) After Run	000132.7	000262.0
Consumption		
(1) Liters	118.8	119.0
(2) Cubic Feet	4.2	4.2
Lubricating Oil Consumption		
(1) Liters	3.6	5.4
(2) Cubic inches	219.6	329.4
Slide Valve Clearances (mm)		
(1) Before Run (a) Port	0.05	0.10
(b) Starboard	0.05	0.10
(2) After Run (a) Port	0.10	0.20
(b) Starboard	0.10	0.20

<u>DATA FROM RECORDER</u>

	1	2
Speed		
Average (knots)	49.3	47.1
Maximum (knots)	49.7	48.0
Tail-off	No	No

NUMBER OF RUN	1	2
Depth		
Setting (1) Meters	5	5
(2) Feet	16.4	16.4
Average Depth of Run		
(1) Meters	5.3	4.0
(2) Feet	17.4	13.1
Initial Dive		
(1) Meters	9	9
(2) Feet	29.5	29.5
Roll	12°P 10°S	35°P 5°S

GENERAL DATA

Photographs taken	No	Yes
Weather		
Sea	Calm	Calm
Wind (Beaufort)	1-2	1
Sun	Bright	Nil
Clouds	1/10	10/10
Tide (knots)	SW 0.7	SW 0.6

DATA BY CALCULATION

Water/Fuel Ratio		
(1) By Volume	6.1	5.8
(2) By Weight	7.4	7.1
Approx. total oxygen consumption (10°C) (No allowance for temperature changes)		
(1) kg	39.1	42.6
(2) lbs	86.0	93.7
Oxygen/Fuel Ratio		
By weight	2.44	2.53

RANGING DATA SHEET FOR TYPE 95, MODEL 2 TORPEDO NO. 2725

Number of Run	1	2
Date of Run	19 Jan. 1946	29 Jan. 1946

DATA BY DIRECT MEASUREMENT

Time of Run (Seconds)		
(1) Firing Point		
No. 1 watch	200	200
No. 2 watch	200.5	200
(2) Tug		
No. 1 watch	200	199.5
No. 2 watch	200.5	199.5
(3) Average of watches	200.25	199.75
Range Run		
(1) Meters	5365	5105
(2) Yards	5869	5585

NUMBER OF RUN	1	2
Average Speed		
(1) Knots	52.0	49.6
(2) Meters/Second	26.8	25.6
(3) Yards/Second	29.3	28.0
Course of Torpedo (true)	135°	135°
Direction		
Wander Left (1) Meters	Nil	Nil
Wander Left (2) Yards	Nil	Nil
Wander Right (1) Meters	-	-
Wander Right (2) Yards	-	-
Period of time elapsed between end of run and measurement of consumption (hours)	2	2
Oxygen Pressures		
Before Run (1) kg/cm^2	197	195
Before Run (2) lbs/in^2	2797	2773
After Run (1) kg/cm^2	70	63
After Run (2) lbs/in^2	994	895
Total Pressure Drop (1) kg/cm^2	127	132
Total Pressure Drop (2) lbs/in^2	1803	1874
Oxygen Consumption		
Pressure Drop Rate		
(1) $kg/cm^2/1000m$	23.7	25.9
(2) $lbs/in^2/1000$ yds	307.2	335.5
Steering Air Pressures		
Before Run (1) kg/cm^2	230	232
Before Run (2) lbs/in^2	3271	3294
After Run (1) kg/cm^2	0	0
After Run (2) lbs/in^2	0	0
Fuel Consumption		
(1) Liters	21.25	20.5
(2) Kilograms	17.4	16.8
(3) Cubic Feet	0.75	0.72
(4) Pounds	38.3	37.0
Diluent Water Consumption		
Meter Readings		
(1) Before Run	000013.7	000145.0
(2) After Run	000126.0	000263.6
Consumption		
(1) Liters	112.3	118.6
(2) Cubic Feet	4.0	4.2
Lubricating Oil		
(1) Liters	4.2	5.2
(2) Cubic inches	256.2	317.2
Slide Valve Clearance (mm)		
(1) Before Run (a) Port	0.07	0.10
(1) Before Run (b) Starboard	0.07	0.10
(2) After Run (a) Port	0.10	0.15
(2) After Run (b) Starboard	0.10	0.15

NUMBER OF RUN	1	2
DATA FROM RECORDER		
Speed		
Average (knots)	53.0	52.3
Maximum (knots)	53.5	53.5
Tail-off	No	No
Depth		
Setting (1) Meters	5.0	5.0
(2) Feet	16.4	16.4
Average Depth of Run (1) Meters	5.0	4.9
(2) Feet	16.4	16.1
Initial Dive (1) Meters	12.0	10.0
(2) Feet	39.4	32.8
Roll	5°P 15°S	0°P 15°S
GENERAL DATA		
Photographs of Run	No	Yes
Weather		
Sea	Calm	Calm
Wind (Beaufort)	1-2	1
Sun	Bright	Nil
Clouds	1/10	10/10
Tide (knots)	SW 0.7	SW 0.6
DATA BY CALCULATION		
Water/Fuel Ratio		
(1) By Volume	5.3	5.8
(2) By Weight	6.5	7.1
Total Oxygen Consumption (10°C) (No allowance for temperature changes)		
(1) kg	37.3	38.8
(2) lbs	82.1	85.4
Oxygen/Fuel Ratio By Weight	2.14	2.31

ANALYSIS OF RESULTS

ESTIMATED ERRORS IN MEASUREMENTS

From an observer's point of view, the weather conditions under which all the torpedoes were run, were good. Visibility was good, and the surfacing of the torpedo was always seen by observers on the tug, and by at least one observer at the firing point. (Usually, all the observers at the firing point saw the torpedo surface).

TIMING ERRORS

Start of run: At the firing point, the tendency of the two observers was to start their watches before the torpedo was actually clear of the frame. This is an important point, since at that moment the torpedo was moving slowly and as much as one second after start of motion could elapse before the tail of the torpedo emerged from the frame. The head, which was painted yellow could be seen, but in 10 feet of water, it was very difficult to know the instant at which the tail left the frame. The maximum error here was probably about 0.5 seconds.

The signal of the start of the run was given to the tug by the Communications Officer over the radio. This officer gave the "fire" signal, when he saw the torpedo nose emerging from under the firing point. At that instant, the tail was almost clear of the frame. Therefore, the error in starting the watches on the tug depended solely on the personal errors of the Communications Officer and the two observers with stop watches on the tug. This total error had a probable maximum of 0.5 seconds.

Finish of run: Where the observers with stop watches (both on tug and at firing point) saw the torpedo break surface the maximum error in stopping the watches was unlikely to exceed 0.5 seconds.

Total maximum error is timing: From the above, total maximum timing error is:

At Firing Point	1 second
On Tug	1 second

Over a run of duration of 200 seconds this contributes a maximum percentage error of 0.5% which always tends to make the measured average speed less than the actual average speed.

In certain cases, one watch of the four differed considerably from the readings of the other three. This was due to the fact that the observer using this watch did not see the torpedo surface, but stopped his watch on a signal from another observer. In three instances, therefore, the reading of one watch was discounted because it differed by more than one second from the average of the other three; (one second being taken as the total maximum error likely, under the conditions of observation stated previously).

Range errors: The navigator of the USS BALTIMORE, who measured the range of each run, stated that his measurements may give a figure which is larger or smaller than the actual range run.

If the range run is taken as 5700 yards then the maximum percentage error in range measurement will be:

$$\frac{100}{5700} \times 100\%$$

$$= 1.75\%$$

Total maximum error: The calculation of the average speed of the run involves the division of the range by the time; therefore the total maximum percentage error will be obtained by adding the percentage error in time to the percentage error in range.

Therefore total maximum error in speed:

$$=(\pm 1.75+0.5)\%$$

$$= 2.25\% \text{ or } -1.25\%$$

Therefore, in a measured average speed of 50 knots the error will be:

1.1 knots or -0.6 knots

or a measured speed of 50 knots will be within the limits 49.4 to 51.1 knots.

Remarks: From the foregoing, it will be seen the largest contributing factor to the final error in speed, is the error occurring in the measurement of range. Under the conditions of the trials (no target buoys), it was not possible to measure the range with a greater degree of accuracy.

TIDES

These were estimated from charts which showed the speed and direction of the tide for the DAINYU area. The maximum speed of tide occurring on any day was 0.7 knots. The direction was always SW or NE which is across the range and therefore did not effect the speed of the torpedo.

A tide of 0.7 knots NE will, however, cause a drift of 80 yards to the left in the course of the torpedo.

The following figures show the measured "wander" after correction for tides.

TORPEDO NO.	RUN NO.	TIDE (KNOTS)	DRIFT (YARDS) Left or Right	MEASURED WANDER (YARDS)	CORRECTED WANDER (YARDS)
2473	1	NE 0.06	8 L	178 L	170 L
5053	1	SW 0.5	61 R	20 L	81 L
	2	SW 0.7	82 R	205 L	287 L
	3	SW 0.6	73 R	101 R	28 R
2737	1	SW 0.7	81 R	100 L	181 L
	2	SW 0.6	78 R	300 R	222 R
2725	1	SW 0.7	79 R	Nil	79 L
	2	SW 0.6	68 R	Nil	68 L

From the above corrected "wanders"

	Wander (yds)
4 runs	not more than 81
2 runs	less than 200
2 runs	less than 300
Passing condition	not more than 100 yds at 6000 yards range.

SUMMARY OF RESULTS

In the following table the results of the eight runs are summarized:

SUMMARY OF MEASUREMENTS

Type 95 Model 2 Torpedo

TORPEDO NO	RUN NO	RANGE (YARDS) ±100	SPEED (KNOTS) +1.1, -0.6	CORRECTED WANDER	OXYGEN RESIDUE (kg/cm²)	RECORDED AVERAGE DEPTH (FEET)	REDUCER PRESSURE (kg/cm²)	SLIDE VALVE CLEARANCES (MM) BEFORE RUN PORT	BEFORE RUN STBD	AFTER RUN PORT	AFTER RUN STBD
2473	1	5980	46.85	170 L							
5053	1	5711	47.1	81 L	62	19.7	38.0*	0.15	0.15	0.15	0.15
	2	5864	49.9	287 L	68	19.0	38.0	0.25	0.20	0.25	0.20
	3	5754	47.7	28 L	33	16.1				0.3	0.3
2737	1	5700	49.0	181 L	62	17.4	37.0	0.05	0.05	0.1	0.1
	2	5760	49.3	222 L	50	13.1	37.6	0.1	0.1	0.2	0.2
2725	1	5869	52.0	79 L	70	16.4	37.6	0.07	0.07	0.1	0.1
	2	5585	49.6	68 L	68	16.1	37.6	0.1	0.1	0.15	0.15

PASSING CONDITIONS

Speed	49 ± 1 knots
Range	6000 yards
Depth Keeping	16.4 ± 1.6 ft
Direction Keeping	100 yards (at 6000 yards range)

*Increased to this figure after the first run.

REMARKS

Torpedo No. 2473 made only one run in which it attained a speed of 46.85 knots. No reducer test was made before the run, and it is not known whether any tail-off occurred due to large slide valve clearances (these were not measured before the run).

Torpedo No. 5053 made three runs. Before the first run the reducer was not tested and the speed realized was 47.1 knots. Before the second run the reducer was screwed down to 38 kg/cm^2 (540 lbs/in^2), and in this run an average speed of 49.9 knots was attained. In the third run, the slide valve clearances were large and a definite tail-off occurred, as shown by the recorder tracing and the residual oxygen pressure. No change in reducer was made before the run. The low speed of 47.7 knots attained is, therefore, readily explicable.

Torpedoes No. 2737 and 2725 made two runs each. In all of the four runs the average speeds attained were above the passing speed laid down by the Japanese. (No explanation can be offered for the drop in speed in the second run of No. 2725).

The mean results for the three torpedoes are as undernoted:

(No. 2473 has been neglected because it was lost and complete data were not obtained. The first run of No. 5053 has been included, although it was slightly slow, to increase the number of runs to obtain a better average).

Speed: The mean value for seven runs was 49.2 knots.

It will be noticed that no account is taken of "tail-off" in the passing conditions; the torpedoes are expected to complete the run at the speed without "tail-off".

The aim in passing the torpedoes is to work on the top limit. In some types the limits in speed are given as -0+2 knots. This was also said to have a good psychological effect on the inspectors.

Range: The average range run was shorter by 268 yards than that specified; i.e. 5749 instead of 6017. This was not considered serious since the oxygen remaining averaged 58.3 kg/cm^2 (827 lbs/in^2) for a reducer pressure of 37.6 (534 lbs/in^2) i.e., a margin of practically 300 lbs/in^2. In addition there was no sign of "tail-off" in recorder diagrams.

Depth: The torpedoes were run at a depth setting of 5 meters (16.4 ft). The average depth was 16.7 ft.

The initial dive varied from 9.0 - 15 meters (29.5 - 49.1 ft) with an average of 11.4 meters (37.4 ft). From measurement of the recorder diagram the initial dive occurs at 220 meters from the firing point; i.e., after the rudder locking has been removed and coincides with the torpedoes reaching its set speed.

The depth keeping during the run was best in No. 2725 although it was the fastest torpedo. There was not much to choose between the other two, one No. 2737 on 29 January running shallow by 1.5 meters (4.9 ft) and the other, No. 5053, running one meter (3.78 ft) deep.

List: The torpedoes rolled heavily to port at the start of the run, the maximum being 55° with a mean figure 42°. During the run the torpedoes were upright.

<u>Direction keeping</u>: The method of measuring the course of the torpedo with a sextant is not sufficiently accurate to obtain reliable figures for the wander. The error occurring in the measurement is too great.

The spread of the W/F ratios is fairly wide, from 5.3 - 6.3; i.e., 19%, with a mean figure of 5.9. This is considerably less than the ratios of 8.7 obtained in the bench test and is comparable with the figure used for a standard air-paraffin wet heater torpedo. There does not seem to be a close relation between the bench and the range, the former must therefore be a purely artificial test.

The start of the run in each case was perfectly smooth; there was no sign of an incipient explosion as is obtained with a semi-internal combustion cycle.

From an examination of the list record, it would appear that the combustion was steady in all runs except that of torpedo No. 5053 on 5 January 1946 and at the start of the run of No. 2737 on 28 January 1946. In the former the combustion was unsteady throughout the run.

Of the three torpedoes it is considered that the worst was No. 2737, there being considerable variation in speed during the run. The best was No. 2725 which was also the fastest. The depth line on the latter also was consistently good throughout the run.

The results indicate that the slide valve clearances become too large (0.3mm, 0.0118") after three or four runs and must be renewed.

<u>Igniters</u>: The igniters used in the trials were 18 months old. Under normal conditions an igniter is not used more than one year after manufacture. No failures occurred.

SPEED FROM RECORDERS

Japanese recorders have been designed to record speed as well as depth and roll. The speed is recorded by means of a differential pressure head set up by the kinematic pressure on the nose and the hydrostatic pressure on the underside of the head. This differential pressure will be dependent on the pressure distribution on the surface of the head and therefore on the shape of the latter. The Japanese only claim reliable functioning of the recorder when placed in the so-called "trial head" for which the recorder was designed. In the trials, only one of these heads was used, the other three being "ship training heads" for torpedo trials carried out from ship. On this account, considerable discrepancy will be noted in the results between the measured speed and recorded speed.

In the case of No. 2725 which was fitted with a "trial head" the results were:

	Measured Average Speed	Recorded Average Speed
Run 1	52.0	53.0
Run 2	49.6	52.3

Some of this discrepancy can be accounted for by the fact that no allowance has been made for the "standing start" and the time required for the torpedo to surface after "shutting-off". It usually takes the torpedo about five seconds to accelerate from the frame to its maximum speed.

In the case of the torpedoes (Nos. 5053, 2737) fitted with the "ship heads" the recorded speed tended to be low. No consistent deviation in the recorded speed from the measured speed could be determined.

The recorder speed tracings are, nevertheless, of value since they show variation of speed during the run, and where a "tail-off" occurred in No. 5053, it was clearly indicated.

Copies of the recorder diagrams are given in Figures 118-124.

CONCLUSIONS

The four torpedoes which underwent the trials were both old and new and were selected at random from storage by Allied personnel. They were not in any way "tuned up" for the tests.

It is regretted that further runs could not have been made, but, in the time available, and owing to the departure of USS BALTIMORE from KURE it was not considered feasible to carry out further trials.

Although the scope of the trials was not sufficient to make an accurate statistical survey of the performance of the Type 95 Model 2 torpedo, the claims of the Japanese for this torpedo are considered to be justified, particularly since no allowance has been made for the frame discharge.

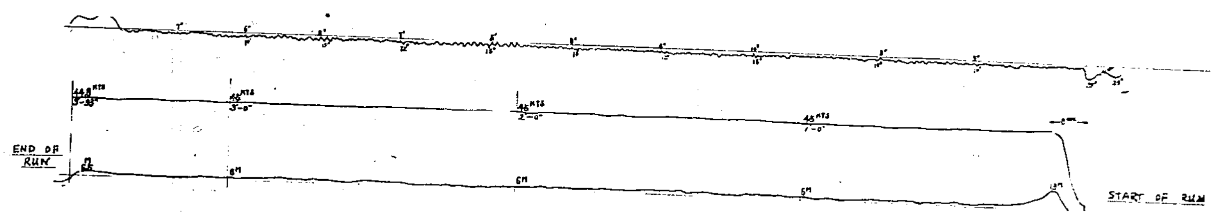


FIGURE 118
RECORDER DIAGRAM, TORPEDO NO.5053 (5 JANUARY 1946)

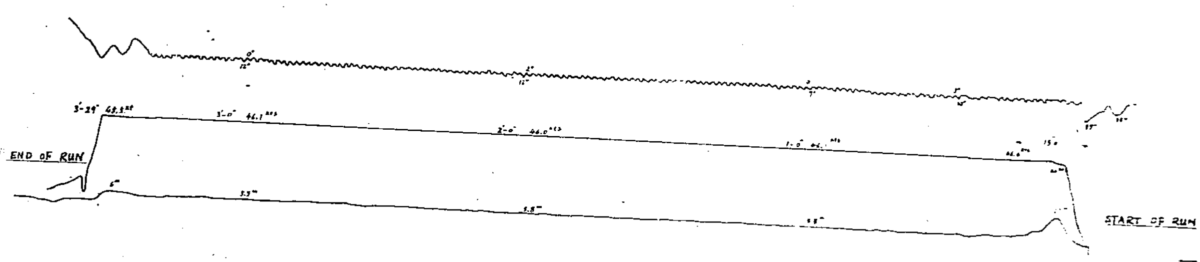


FIGURE 119
RECORDER DIAGRAM TORPEDO, NO.5053 (19 JANUARY 1946)

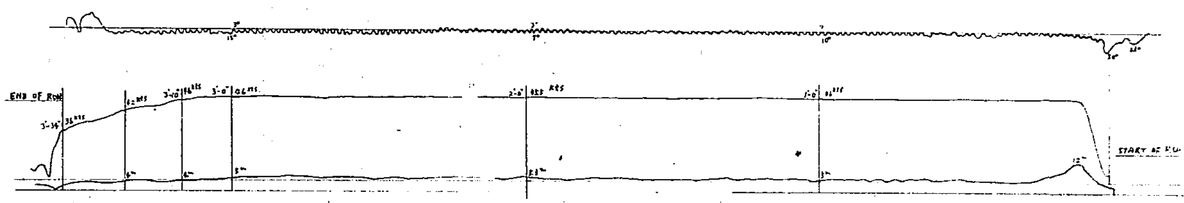


FIGURE 120
RECORDER DIAGRAM. TORPEDO NO.5063 (29 JANUARY 1946)

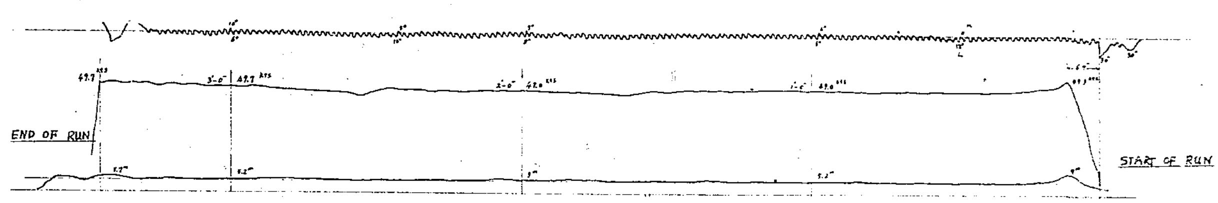


FIGURE 121
RECORDER DIAGRAM. TORPEDO NO.2737 (19 JANUARY 1946)

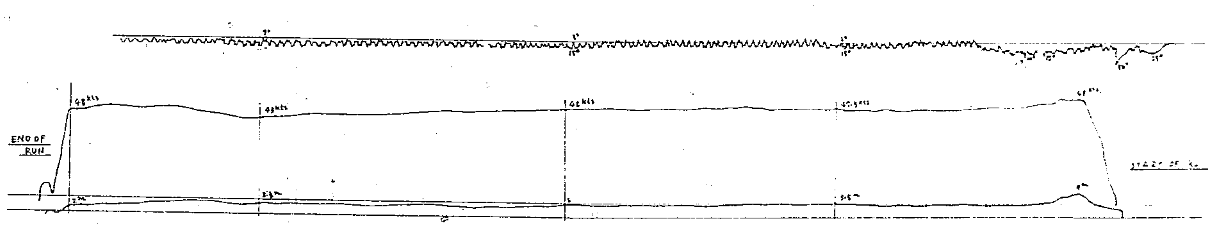


FIGURE 122
RECORDER DIAGRAM. TORPEDO NO.2737 (29 JANUARY 1946)

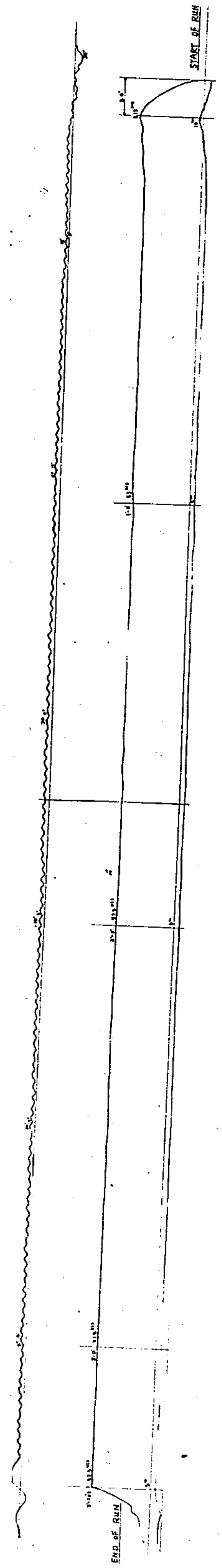


FIGURE 123
RECORDER DIAGRAM, TORPEDO NO.2725 (19 JANUARY 1946)

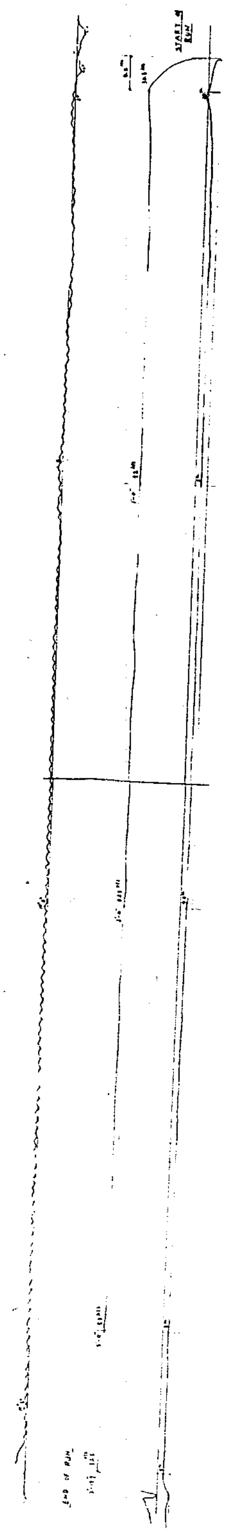


FIGURE 124
RECORDER DIAGRAM, TORPEDO NO.2725 (29 JANUARY 1946)

COMPONENTS

HEADS

Exercise Head

The working principle of all Japanese exercise heads is the same. The heads differ from one another only in the characteristics which render them suitable for fitting to a specific type and model of torpedo and for use in ranging trials or in ship training.

Thus, they can be divided into two main classes:

(1) Trial head.
(2) Ship training head.

The first is used for ranging the torpedo and for general trials. The ship training head is for use in training exercises carried out from aboard ship. Their characteristics are as follows:

Trial Head (Figure 125)

This head is fitted with:

Recorder (Speed, depth and roll) & Standard blowing mechanism

Ship Training Head (Figures 126 and 127)

This is fitted with:

Recorder (same type as for trial head)
Phosphorescent illuminator
Electric illuminator (with battery)
Standard blowing mechanism

In addition to these two main classes, exercise heads differ in length and diameter according to the type and model of torpedo to which they are to be fitted.

Blowing Mechanism

In the nose of the torpedo are two water inlets, one for the speed recorder and one for the blowing mechanism. The inlet for the recorder is exactly on the longitudinal axis of the torpedo through the nose, and the one for blowing is slightly below it. Illustrations of the two main components of the blowing mechanism (hydraulic cylinder and the blowing valve) are shown in Figures 128 and 129 respectively.

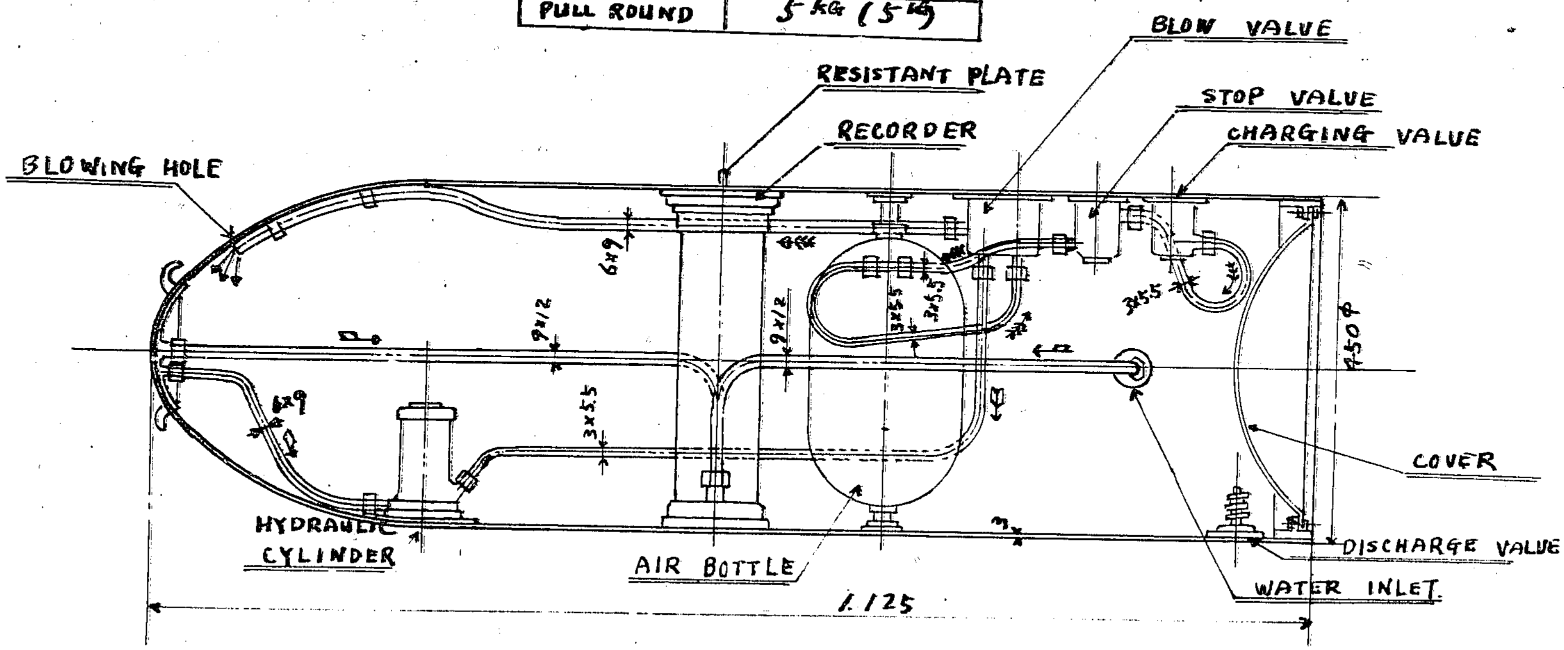
Operation: Before loading into the tube, the air bottle stop valve is opened. Air is then admitted to the blowing valve casting which contains an oil reservoir as well as a spring-loaded valve. It passes through a small drilling onto the top of the valve and into the oil reservoir. Pressure is applied therefore to both the oil circuit and to the valve to keep it shut.

The hydraulic cylinder contains a spring-loaded piston which is connected to the nose of the head. When the torpedo is running, the piston is forced back into the cylinder by both the dynamic and static pressure of water. At the start of the run, when it moves, it slides over the control spindle and cocks the blowing lever pawl. At the end of the run, when the speed falls to 14 knots, the spring forces the piston down, carrying with it the

KEY
- ⇛ AIR
- ⇨ OIL
- ▭> SEA-WATER

ESSENTIAL		DIMENSIONS
WEIGHT (EMPTY)		130 KG (138 KG)
WEIGHT (FULL)		410 KG (360 KG)
VOLUME		280 L (222 KG)
INNER PRESSURE (WHEN UP)		4 KG/CM²
AIR BOTTLE	VOLUME	7 L
	CHARGING PRESSURE	160 KG/CM²
PULL ROUND		5 KG (5 KG)

REMARKS: ( ) SHOW TORPEDO TYPE-02.

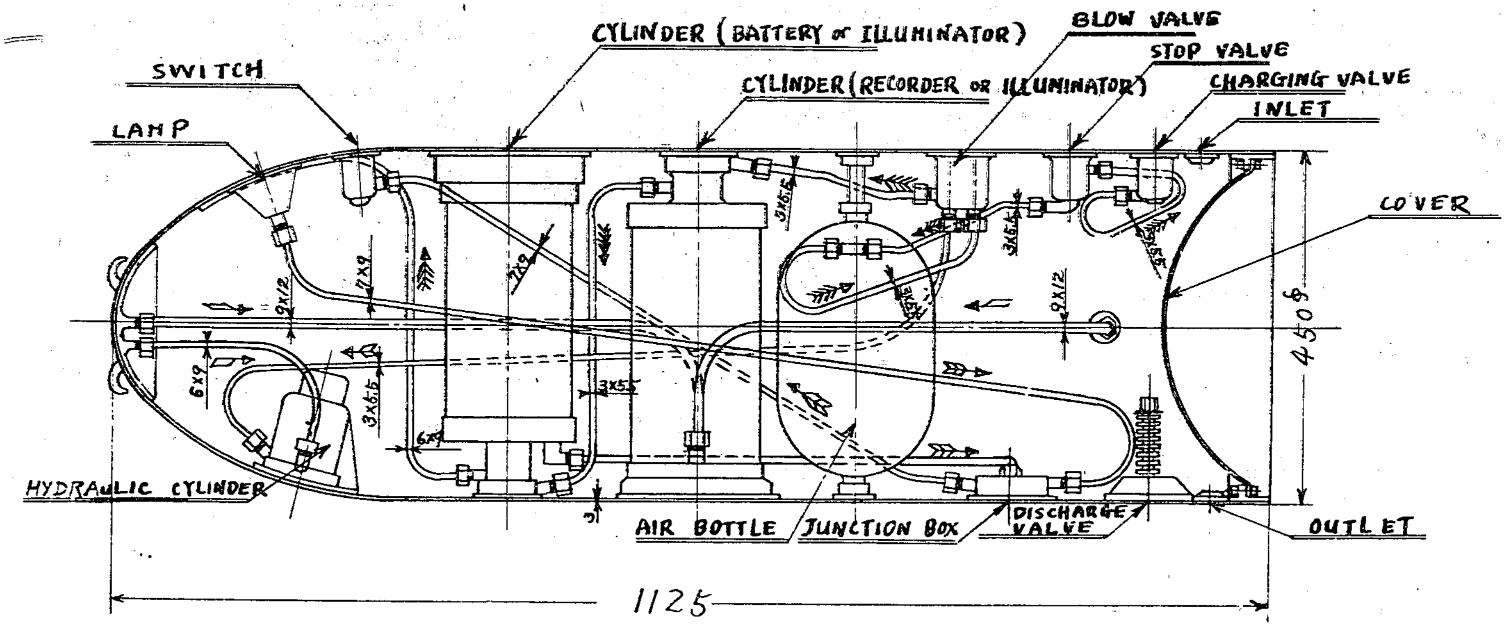


ALL DIMENSIONS IN mm

FIGURE 125
TRIAL HEAD, TYPE 97 & 02

KEY
- AIR
- OIL
- SEA-WATER
- ELECTRIC CIRCUIT

ESSENTIAL		DIMENSIONS
WEIGHT (EMPTY)		142 KG
WEIGHT (FULL)		360 KG
VOLUME		218 L
INNER PRESSURE (WHEN UP)		5 KG/CM²
AIR BOTTLE	VOLUME	7 L
	CHARGING PRESSURE	160 KG/CM²
PULL ROUND		5 KG



DIMENSION IN mm

FIGURE 126
EXERCISE HEAD, TYPE C2

ESSENTIAL		DIMENSIONS
WEIGHT (EMPTY)		136 kg
WEIGHT (FULL)		410 kg
VOLUME		274 L
INNER PRESSURE (WHEN UP)		4 kg
AIR BOTTLE	VOLUME	7 L
AIR BOTTLE	CHARGING PRESSURE	160 kg
PULL ROUND		5 kg

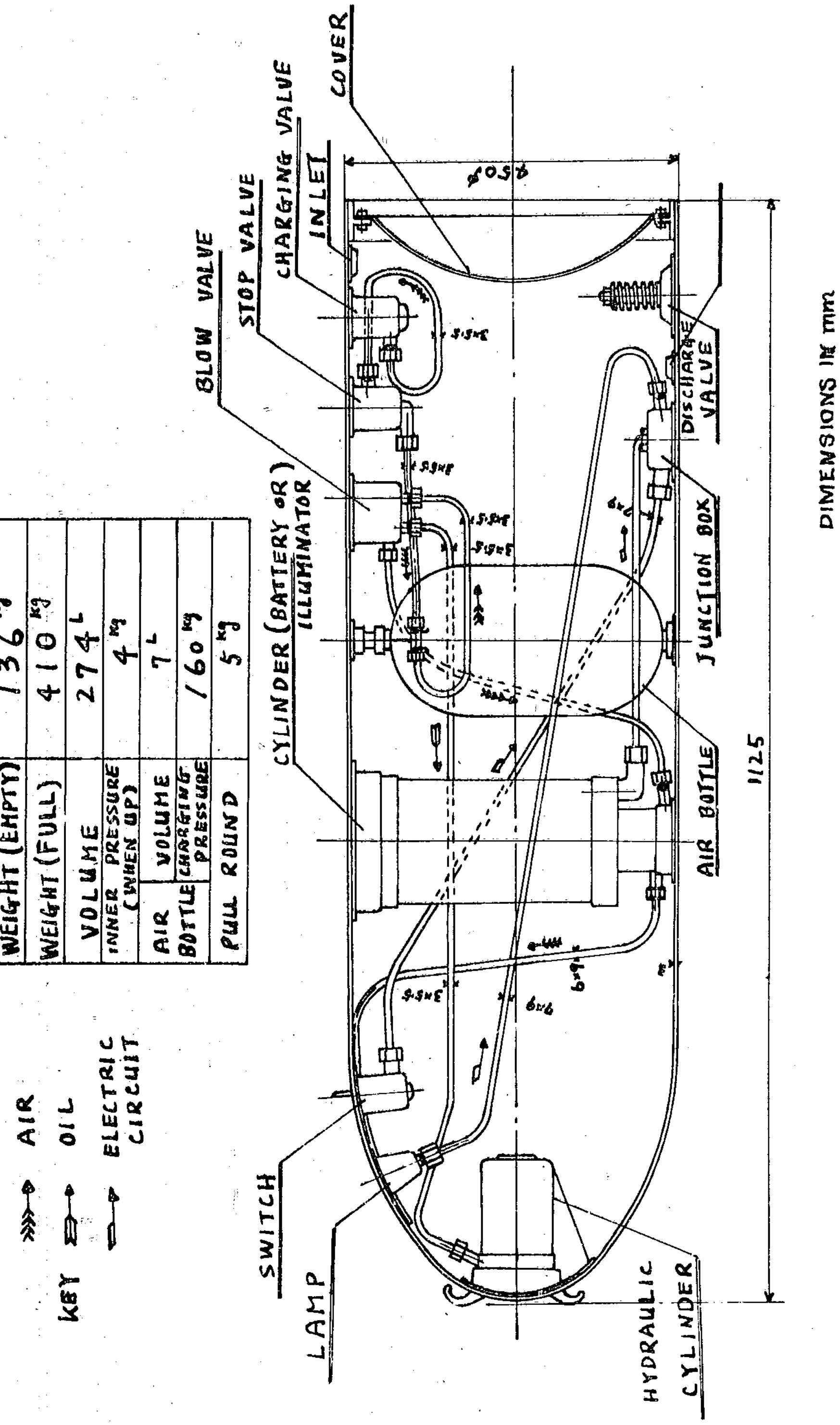


FIGURE 127
EXERCISE HEAD TYPE 97

REMARKS:
Piston begins to move when torpedo speed is 17kts., returns when it decreases to 14kts.

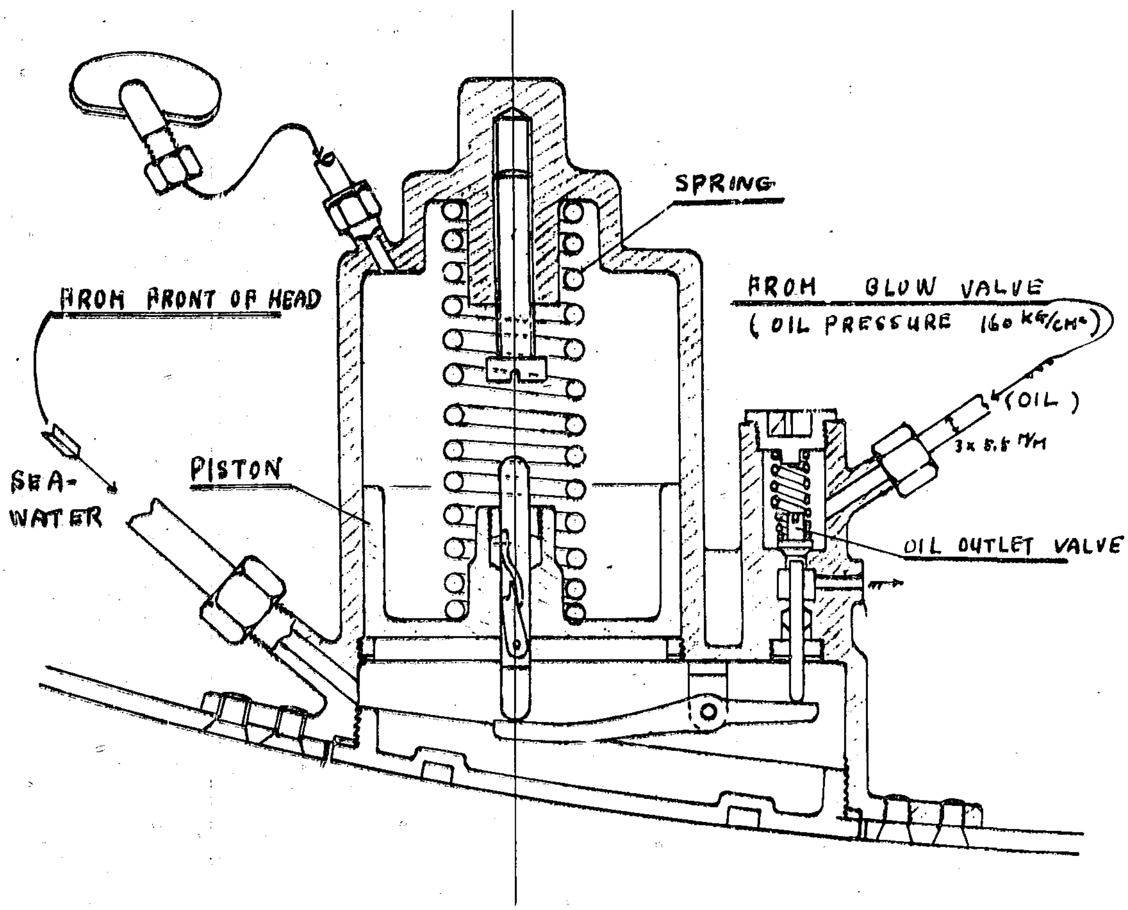


FIGURE 128
HYDRAULIC CYLINDER

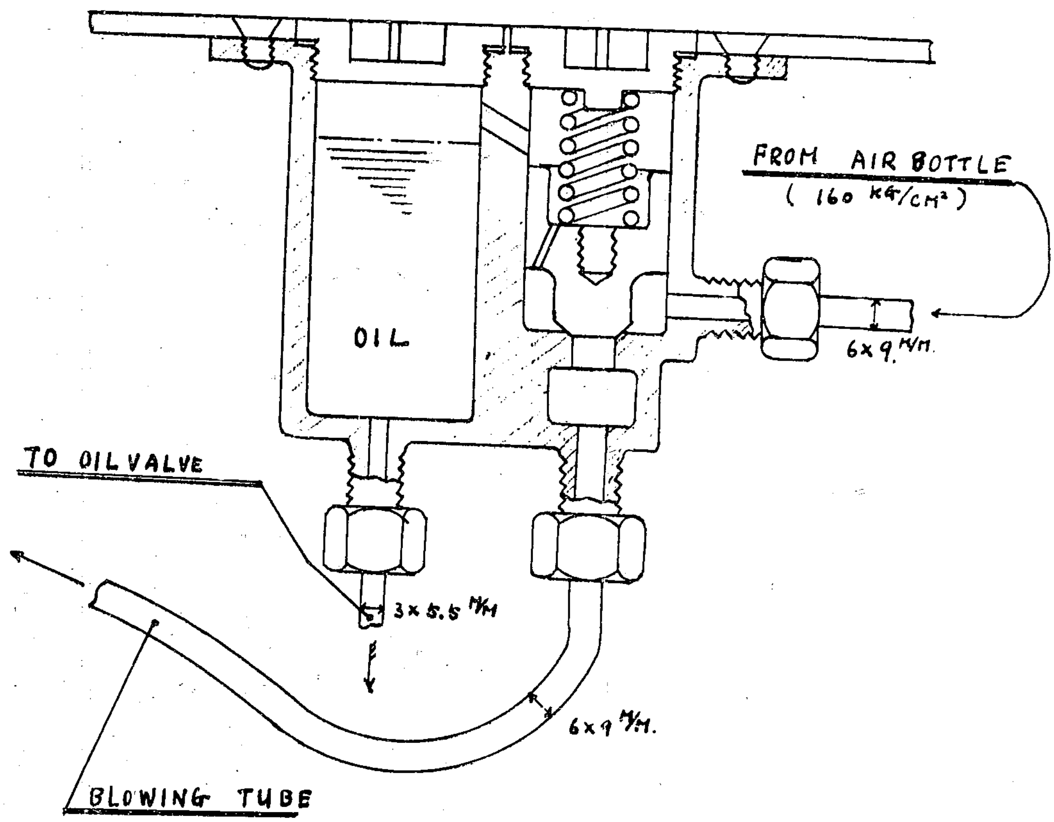


FIGURE 129
BLOWING VALVE

control spindle which operates a lever opening the oil outlet valve.

The pressure on the oil reservoir and on the upper side of the air valve falls so that the pressure around the valve is sufficient to open it. The air in the bottle is then discharged into the top of the head and blows the filling liquid through the discharge valve.

Discharge valve: This is shown in Figure 130 and consists of a non-return valve of large area whose spring is designed to open under a pressure of 0.5 kg/cm^2 (7.21 lbs/in^2). This valve is situated on the underside of the head at the after end.

Air vessel: The blowing air bottle in the head is always charged to about 160 kg/cm^2 (2272 lbs/in^2) but varies in volume according to the volume of the head. This bottle was first made of a "Silzin" bronze casting (Cu 80.5; Zn 15; Si 4.5) but later was made of steel because of the shortage of copper. The vessel is placed slightly aft of the middle of the head, and charging and stop valves are fitted on the topside. (See Figure 131.)

Recorder

This records speed by virtue of the differential pressure head set up by the dynamic pressure on the nose and the hydrostatic pressure on the side of the head.

Two valves, sensitive to small pressure changes, are fitted in the recorder. The springs of the valves are of the bellows type (similar to an aneroid barometer) and are made of German silver. Through the middle of each spring passes a spindle to the top of which is attached a multiplying lever with a pencil at the end. The bottom of the spindle is fixed to the bottom of the spring. To one valve is connected a pipe leading to the nose of the head; to the other valve is connected a pipe leading to the side of the head. Small increases of sea water pressure on these valves compress the spring, push up the lever and move the pencil in a vertical direction. A recorder paper is rolled on two drums which are placed on each side of the pencils; the latter then make a tracing on the paper. One drum revolves, driven by a clockwork mechanism on top of the recorder. The speed of revolution depends on the design of the recorder, of which there are two types; one has a speed of 150mm/min, the other a speed of 300mm/min. The working principle of each of these designs is the same.

The roll is recorded by a roll pendulum damped in oil (to prevent damage in severe rolling). The pendulum is coupled to a pencil which makes a tracing on the same paper as the speed and depth tracings.

Operation: The recorder is placed in a pocket on the upper side or underside of the head. The pressure pipe connections are taken into the recorder through the washer on the mouth of the recorder pocket, and the joints sealed by this washer.

Two tracings are obtained for depth and speed. The latter is traced as a result of the sum of the dynamic and hydrostatic pressure. Thus, the speed is measured by taking the depth tracing as the base. By means of calibrated scales the depth, speed and roll can be directly read from the tracings.

This method is dependent on the pressure distribution around the head and therefore the recorder will function effectively only in a head for which it was designed. The Japanese recorder was designed for the streamlined trial heads for Types 93 and 95. It will not function satisfactorily in round heads or in ship training heads. The streamlined form of the latter is broken by electric light, etc. In these cases a correction must be made to the recorded speed.

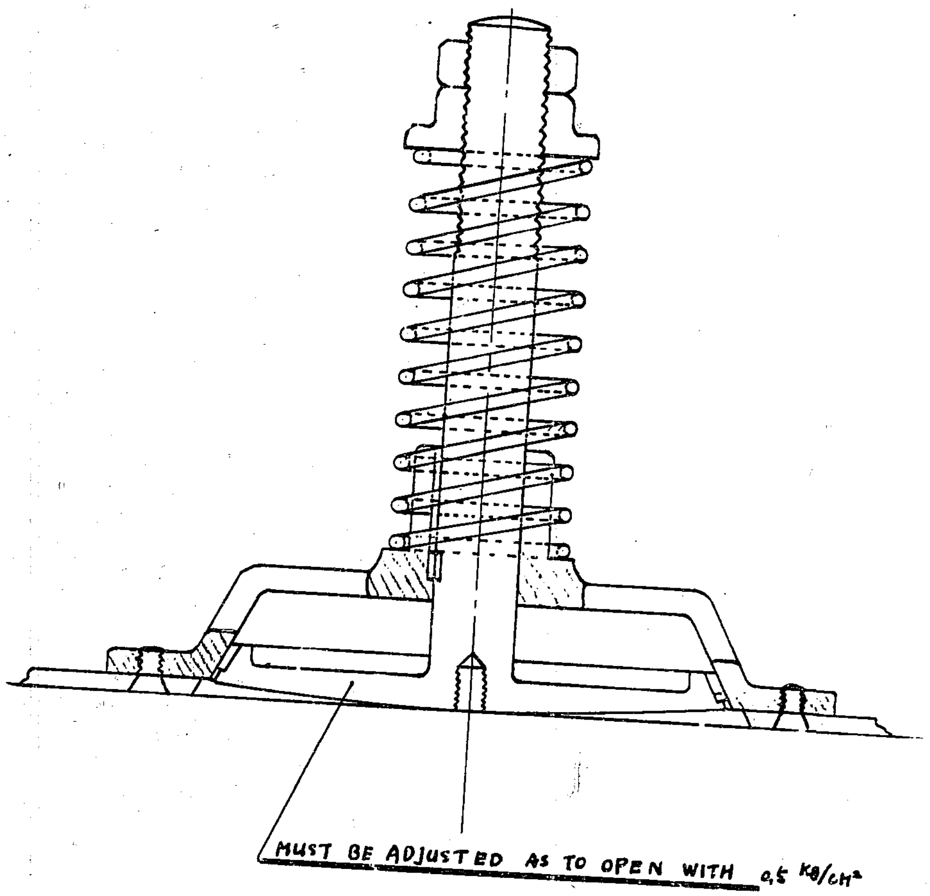


FIGURE 130
DISCHARGE VALVE

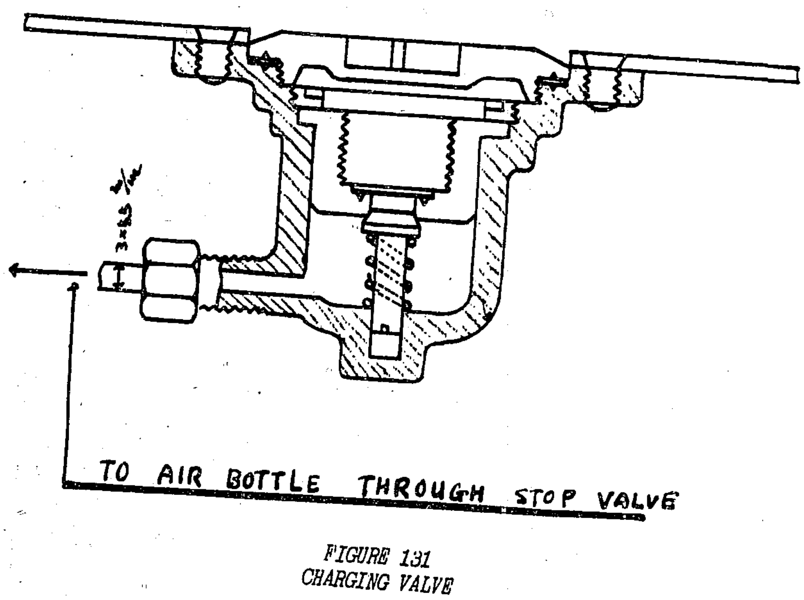


FIGURE 131
CHARGING VALVE

The starting mechanism of the recorder is held down by the tube, and, when the torpedo is fired, it is pushed into a vertical position by a spring and starts the recorder clockwork mechanism.

Ship Training Head

This is fitted with a recorder as in the previous case. It also has a pocket filled with calcium phosphide (Ca_3P_2) for use in night trials. The mouth of this pocket is covered with a rubber diaphragm. When the head blows it pushes up a spindle through the rubber cover and allows the water to come in contact with the phosphide. Phosphine gas is generated as a result and, since this is spontaneously inflammable, the position of the torpedo is effectively marked.

$$Ca_3P_2 + 6H_2O = 3\ Ca(OH)_2 + 2PH_3 \text{ (phosphine)}$$

About 5 kg (10 lbs) of calcium phosphide is carried and this burns for about three hours.

Around the ship training head are placed three electric lamps which mark the course of the torpedo at night. These lamps are illuminated by a 12 volt battery.

Filling of Head

Usually sea water is used; but in special cases, where accurate experimental measurements must be made, a liquid of higher density, more closely approximating the explosive, is used. Either concentrated solutions of common salt or zinc chloride in water are used. Sometimes fluorescein is included in the filling solution to mark the spot where the head blows. Sometimes lead ballast is included.

Shape of Head

Prior to 1940 the Japanese used the round-shaped head. In 1940 the Italian streamlined head was introduced into Japan. It was found that on fixing these Italian heads to a Type 95 torpedo, the speed increased from 48 to 50 knots. Subsequently, all high-speed torpedoes (i.e. Types 93 and 95) were fitted with streamlined warheads and exercise heads. The curve of the Italian head was slightly modified by the Japanese. The details are shown in Figure 132.

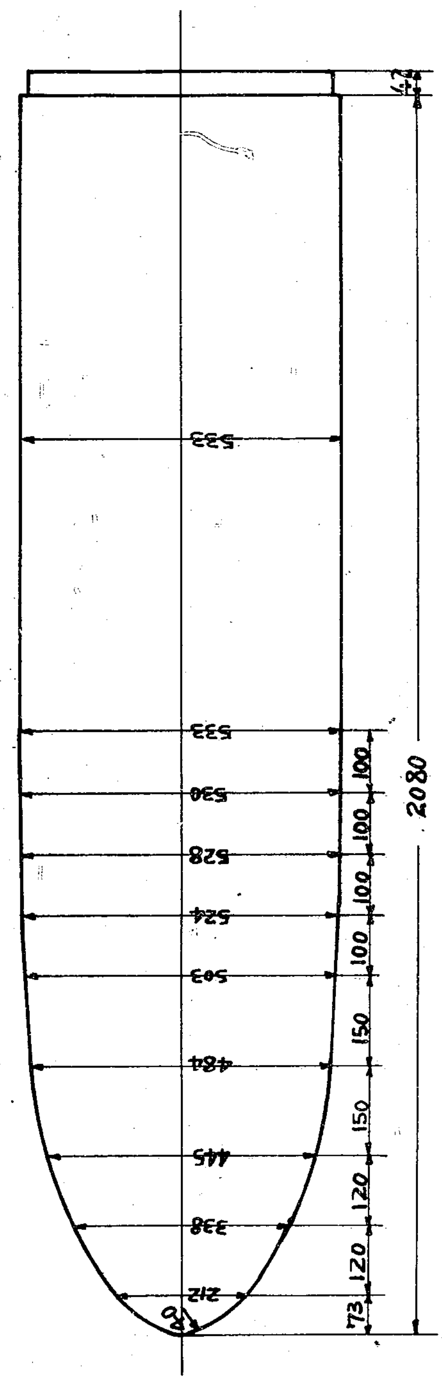
Warhead

For ship torpedoes there are two types of warheads, called Model 1 and Model 2, regardless of diameter, so that each model is made in a number of groups having diameters and weights suitable for the type of torpedo to which it is to be fitted.

Model 1: This is round-nosed and is used on Types 6th and 8th year; 89; 90; 92; 93 Model 1, Modifications 1 and 2; 95 Modification 1; 96; 97; and 02. (See Figure 133.)

Model 2: This is streamlined and was produced after the tests of the Italian streamlined head. It is fitted to Types 93, Model 1, Modifications 1 and 2; Type 93, Model 3; Type 95, Modification 1 and Type 95, Model 2.

The standard design consists of welded steel plate about 3mm thick with the bayonet-type joint, except in the case of those for the Types 6th and 8th year and Type 92. The inside of the head is tin plated electrically and then a coating of black lacquer is added. Originally the head was filled with blocks of explosive; latterly the explosive was cast, the cover being finally bolted on. In the 6th and 8th year types "whisker"

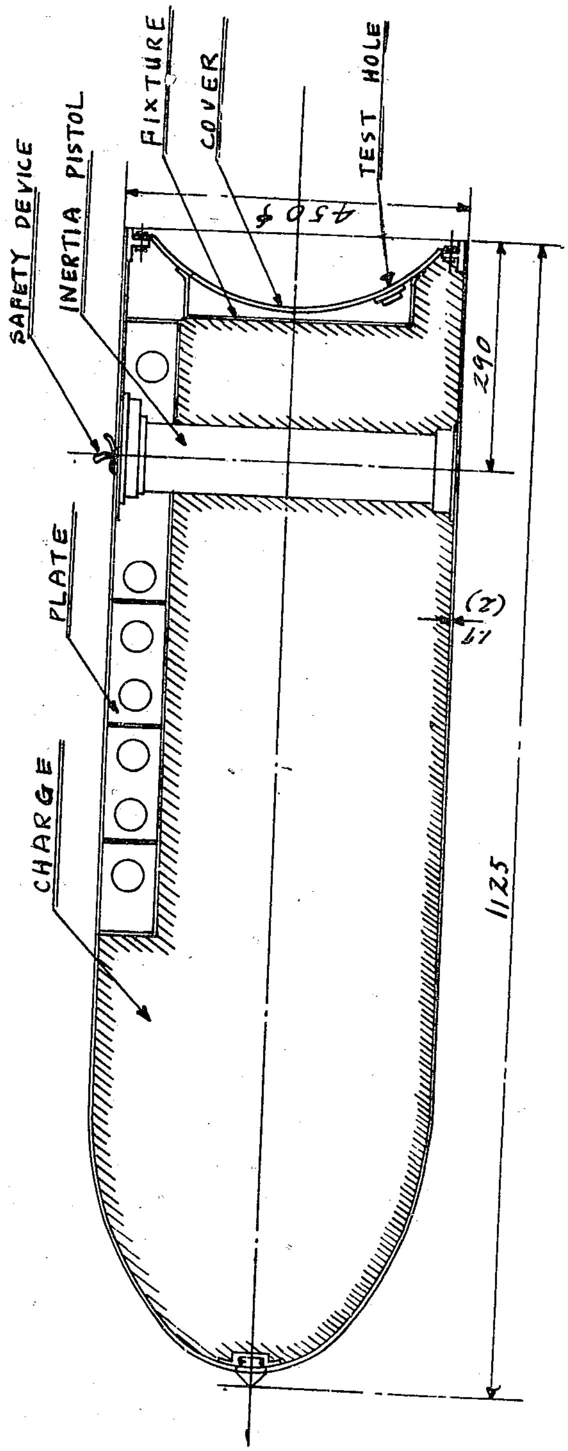


DIMENSIONS IN MILLIMETRES

FIGURE 132
STREAMLINED HEAD

REMARKS: ( ) SHOW TORPEDO TYPE 02

ESSENTIAL	DATA
WEIGHT (EMPTY)	52 KG (54 KG)
WEIGHT (FULL)	410 KG (362 KG)
PISTOL	8 KG (8 KG)
CHARGE	350 KG (300 KG)
PULL ROUND	5 KG (5 KG)



DIMENSIONS IN mm

FIGURE 133
WARHEAD, TYPE 97 & 02

pistol was used, and in the remainder the inertia pistol was fitted. Lead weights were fitted in some torpedoes to modify the trim.

Special Heads

A number of special heads were also made; they are enumerated below:

Model 3: This was a head with a specially shaped block of steel fitted in the nose to pierce armor plating. It was never used in service.

Model 4: This was a head with a kite attachment. It has been fully described in NavTechJap Report "Japanese Torpedoes and Tubes, Article 2 - Aircraft Torpedoes", Index No. 0-01-2. It was fitted to Types 91 and 92.

Model 5: This is the magnetic head and is described in another section of this report.

Model 6: This is the "V" head. It is described in NavTechJap Report "Japanese Torpedoes and Tubes, Article 2 - Aircraft Torpedoes", Index No. 0-01-2.

Explosive

All Japanese torpedoes use Type 97 explosive which has the following composition:

60%	Trinitrotoluene
40%	Hexanitrodiphenylamine

No stabilizers are added.

Exploders

No radically new designs nor any new principles of operation for torpedo exploders have been revealed by this investigation. Several exploders new to Allied technical intelligence have been found, notable certain inertia pistols of the Type 2 series, and the "M" and "OR" magnetic influence exploders.

Exploders already known to Allied technical intelligence and sufficiently described in existing publications have not been described in this report.

Undernoted is a list of all known Japanese Torpedo Exploders:

1. Type 90
2. Type 90, Model 2
3. Type 90, Model 2 (Strong)
4. Type 4
5. Type 91, Model 1
6. Type 91, Model 2
7. Type 91, Model 3
8. Type 2
9. Type 2, Modification 1
10. Type 2, Model 2
11. Type 2, Model 2, Modification 1
12. Type 2 (Special)
13. Type 3 (Hydroplane Exploder)
14. "M" Model 3 Magnetic Exploder
15. "OR" Magnetic Exploder (experimental)

Of the items in the list above, Nos. 1,2,5,6,8, and 13 are fully described in the MINE DISPOSAL HANDBOOK, Part XXVI, Chapter II, published by the U.S. Navy Mine Disposal School, Washington, D.C. Numbers 2, 3, and 4 are described in NavTecnJap Report "Japanese Torpedoes and Tubes, Article 2, Aircraft Torpedoes", Index No. 0-01-2. Additional information is given below.

Type 90 Model 2 (Strong): This exploder differs from the Type 90, Model 2 in that most of the moving parts have been strengthened either by the use of a different alloy or by an increase in dimensions. The purpose of these changes was to enable the exploder better to withstand the shock of launching from aircraft.

Type 91 Model 3: This exploder is similar in design and operation to the Type 91, Models 1 and 2, except that the whisker span is reduced to 17". This alteration was made to allow the use of the exploder in the 18" (45cm) aircraft torpedo.

Type 2: This is described in the Mine Disposal Handbook. This exploder and some of its modifications were designed by Technical Lt. Tadao KIMOTO of the Japanese Navy. According to Lt. KIMOTO, the Type 2 exploder and its modifications were designed to replace the Type 90 and its modifications. The latter exploder was found to fire prematurely due to the high sensitivity of the inertia mechanism, which was frequently activated by the vibrations of the torpedo engine. The Type 2 and all its modifications have an arming range selection screw, which gives the exploders an arming run of from 400 to 2000 meters of water travel when the torpedo is launched from surface craft and from 300 to 1600 meters when launched from submarines.

Type 2 Modification 1: This exploder is identical in every respect to the Type 2 exploder except that the bail and its safety lock connected to the firing device have been omitted. This exploder is kept in an unarmed state by a brass key which fits through the impeller and into the impeller hub, preventing revolutions of the impeller and the arming of the firing device.

Type 2 Model 2: This exploder also is identical with the Type 2 exploder, having a bail, but without the counter-mining device. A simply constructed mechanism, it was designed for use in torpedoes launched from motor torpedo boats.

Type 2 Model 2 Modification 1: This exploder is identical in design and in use to Type 2, Model 2 except that the bail and its connected mechanisms are omitted.

Type 2 (Special): This exploder is used in the KAITEN suicide torpedoes and midget submarines. Its diameter is the same as that of Type 2, but its length is increased to throw the booster nearer the center of the charge. The impeller, bail, and counter-mining device are omitted. The firing device, identical in design to that of Type 2, is armed by a system of shafts and gears operated by the pilot.

Type 3 (Hydroplane Exploder): This is fully described in the Mine Disposal Handbook.

"M" Model 3 and "OR" Magnetic Exploder: This is dealt with in a subsequent section of the report.

Depth Control

Theory

The undernoted is the formula used by the Japanese for calculating the relation between the running angle of the torpedo, the angle of deviation of the pendulum from the neutral position, and the deviation of the torpedo from the set depth. (See Figure 134)

Let

- r = running angle
- h = deviation from set depth
- L = distance between the hydrovalve and the center of gravity of the torpedo
- a = length of connecting link
- b = length of the pendulum
- w = weight of the pendulum
- A = area of hydrovalve
- c = rate of the depth spring
- d = angle of deviation of pendulum from the neutral position
- s = density of sea water

The relation between the pendulum and the hydrovalve plate is first obtained.

The turing moments about the pivot of the pendulum are:

Clockwise-

$$A \cos d \,(s\,h\,A + LsA \sin r + c\,a \sin d)$$

Counter-Clockwise-

$$W\,b \sin(r - d)$$

Now the angles r and d are very small, so approximately

$$\sin r = r$$
$$\sin d = d$$
$$\cos d = 1$$
$$\sin(r-d) = r-d$$

Equating the two moments and simplifying, the formula becomes:

$$d = \frac{\left\{\frac{b}{a} W - L\,s\,A\right\} r - shA}{\frac{b}{a} W + ca}$$

Type 93 Torpedo

To find the relation for the depth gear of Type 93 torpedo, assuming that the torpedo is running with up nose and below its set depth:

- L = 1800mm
- a = 13mm
- b = 206mm
- W = 8kg
- A = $2376 mm^2$
- S = $1025\ kg/m^3$ $1.025 \times 10^{-6}\ kg/mm^3$
- c = $1.52\ kg/mm^3$

(diameter of wire-4.5mm, diameter of coil-10.25mm, number of turns-33, material-phosphor-bronze)

Then:

$$d = \frac{\left(\frac{206}{13} \times 8.0 - 1800 \times 1.025 \times 10^{-6} \times 2376\right) r - 1.025 \times 10^{-6} \times 2376 \times h}{\frac{206}{13} \times 8.0 + 1.52 \times 13}$$

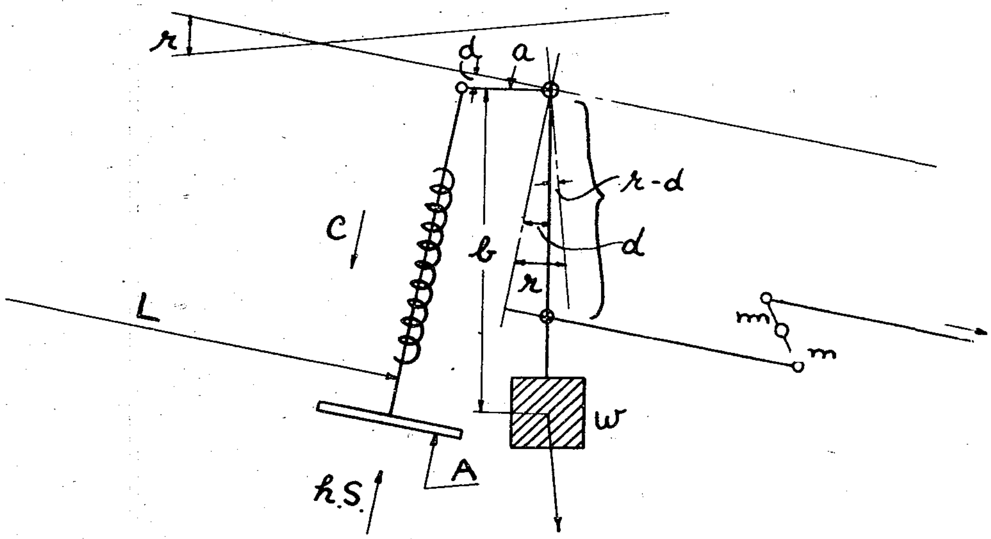


FIGURE 134
DIAGRAM OF DEPTH GEAR, TYPE 93

$$= \frac{(126.4 - 4.44)r - 2.43 \times 10^{-3}\ h}{126 + 19.8}$$

$$= \frac{1.22\ r - 2.43 \times 10^{-3}\ h}{145.8}$$

$$= 0.836\ r - 1.67 \times 10^{-5}\ h$$

Since meters are used as the unit the formula becomes.

$$d = 0.836r - 0.0167\ h$$

As it is more convenient to use degrees, the formula is altered to degrees by dividing the last term by 0.0175 ($1^o = 0.0175$ radians)

$$d^o = 0.836^o r^o - 0.954\ h$$

Substituting $h = 0$, $r = 1^o$

$$d^o = 0.835^o = 50 \text{ minutes}$$

This gives the sensitivity to change in depth.

If $d^o = 0$, $h = 1$ meter, $r = 1^o\text{-}9'$

At this angle the horizontal rudders are in the mid-position.

When the angle d is 1^o, the movement of the slide valve in the servomotor is equal to:

$$e \sin d \times \frac{n}{m} \quad \text{where } e = \text{distance from pivot to depth gear rod}$$

$$= \frac{186 \times 0.0175 \times 43}{43} = 3.25\text{mm}$$

(m & n are the lengths of the operating lever and are taken as equal).

Mechanism in the Torpedo

The depth gear mechanism is similar to that of the Whitehead torpedo. There are no "types" of depth gears as there are for pistols, gyroscopes, etc. The depth gear is designed for each torpedo depending upon the diameter, weight, length, and general design.

The standard design is shown in Figure 135. The water pressure on the hydrovalve is balanced by the extension of the depth spring. The pendulum is pivoted at the top of the frame and is connected to the spindle of the hydrovalve. The spring is fixed at the top to the head of the spindle by screwing the spindle into it. At the bottom it is screwed into a sleeve serrated to form a rack on the outside. A worm wheel meshes with the rack; by the rotation of this the tension of the spring is adjusted and the depth set.

The movement of the hydraulic valve plate is transmitted by a bell crank to the servomotor. A special fitment has been added which enables the torpedo to be run at a much greater depth for any desired distance. The normal depth setting is from 2-16 meters (6.56 ft. - 52.5 ft.); to this can be added a further 4-6 meters (13.12 ft. - 19.7 ft.) making a maximum of 72 ft. The fitment consists of an auxiliary compression spring which applies additional load to the hydrovalve spindle at the top (Figure 136). An engine-driven cam controls it and throws it out of action after the torpedo has run off the required range, when the main depth spring takes control and the torpedo returns to its normal depth. The distance can be varied by rotation of the cam on the spindle.

The servomotor is of the standard design with only oil grooves and no packing rings. The rudder locking device consists of an arm attached to the depth gear rod which is prevented from moving by a cam having two steps on it. The cam is gear-driven from the engine and releases the rudders in two steps. In addition there is an index plate which permits the rudders to be locked in any desired position. (See Figure 137).

Gyroscopes

General

Before the development of the Type 4th year torpedo (1915), gyroscopes Type 38 and Type 41 were used. Spring starting was employed, but the RPM of the wheel were low, and the performance of the gyroscopes was poor.

General particulars of gyroscopes developed subsequently are given in tabular form at the end of the Section.

Type 4th Year

In this type air-blast starting was employed for the first time. A turbine wheel was mounted outside the gimbal system. Air-blast was used to start and maintain the wheel speed. The weight of the wheel was increased and the performance improved considerably. Since only one relay valve was used the power of the steering engine was low, and for this reason, the direction keeping of the torpedo was poor.

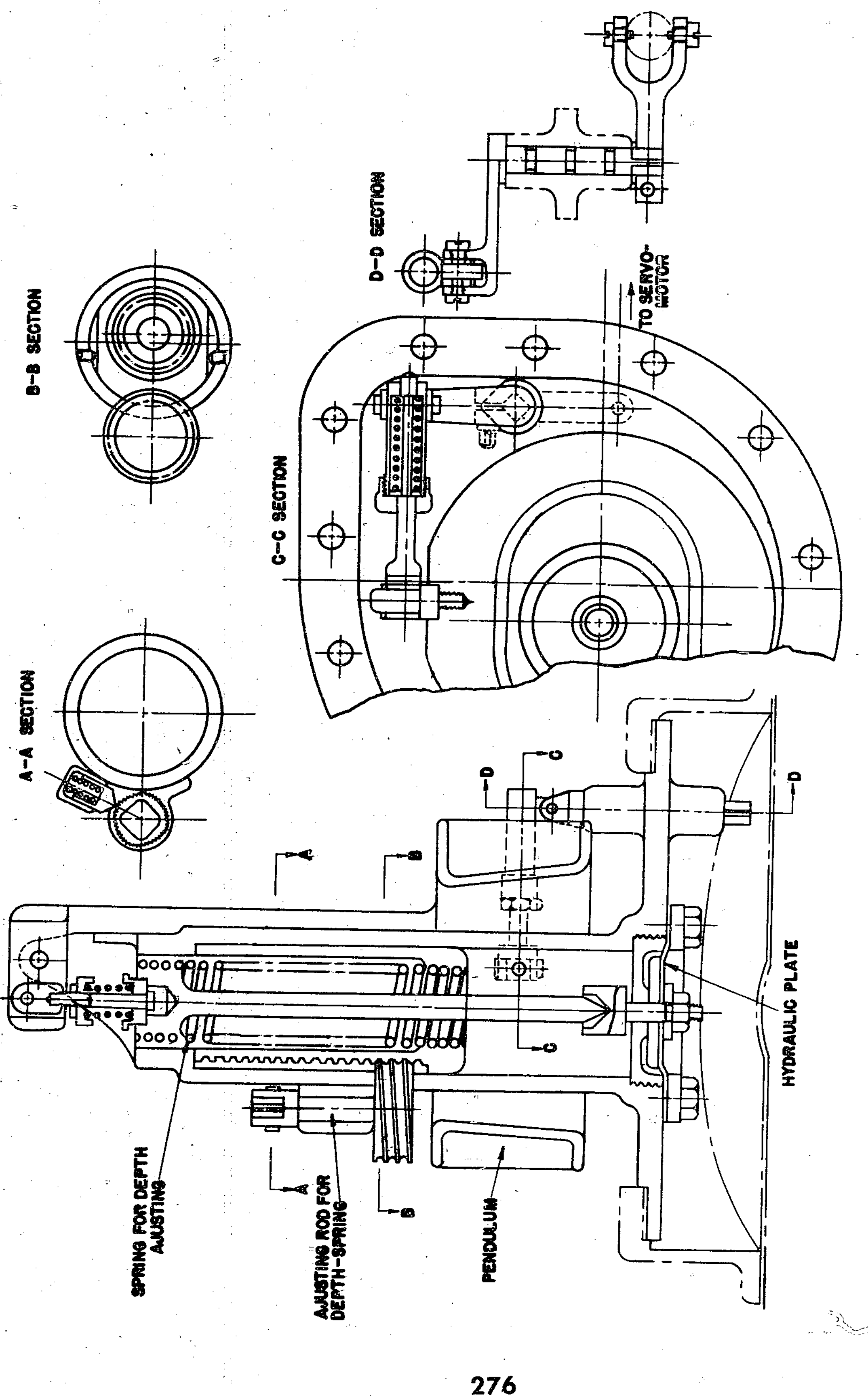


FIGURE 135
STANDARD DESIGN OF DEPTH GEAR

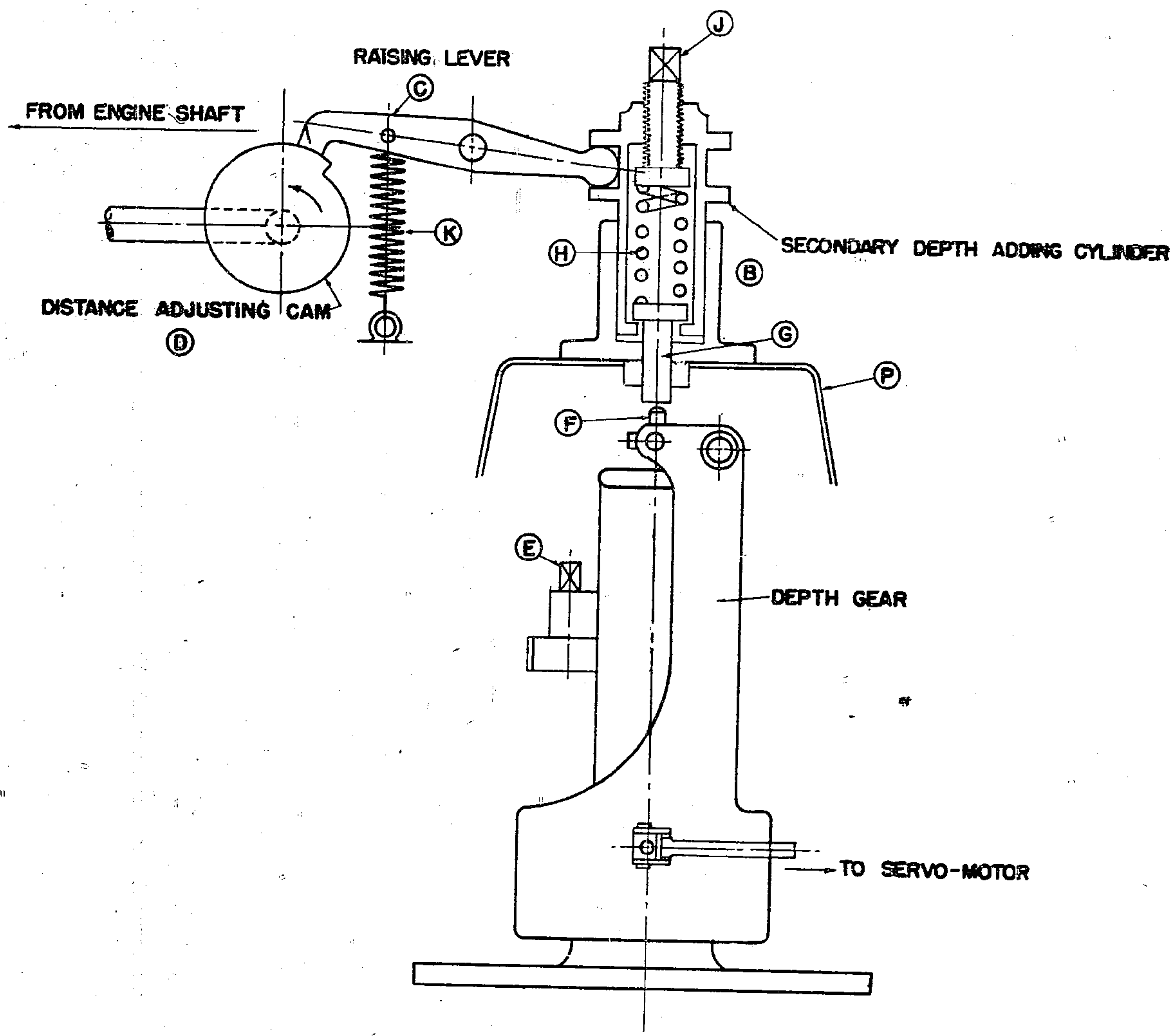


FIGURE 136
SECONDARY DEPTH CONTROL

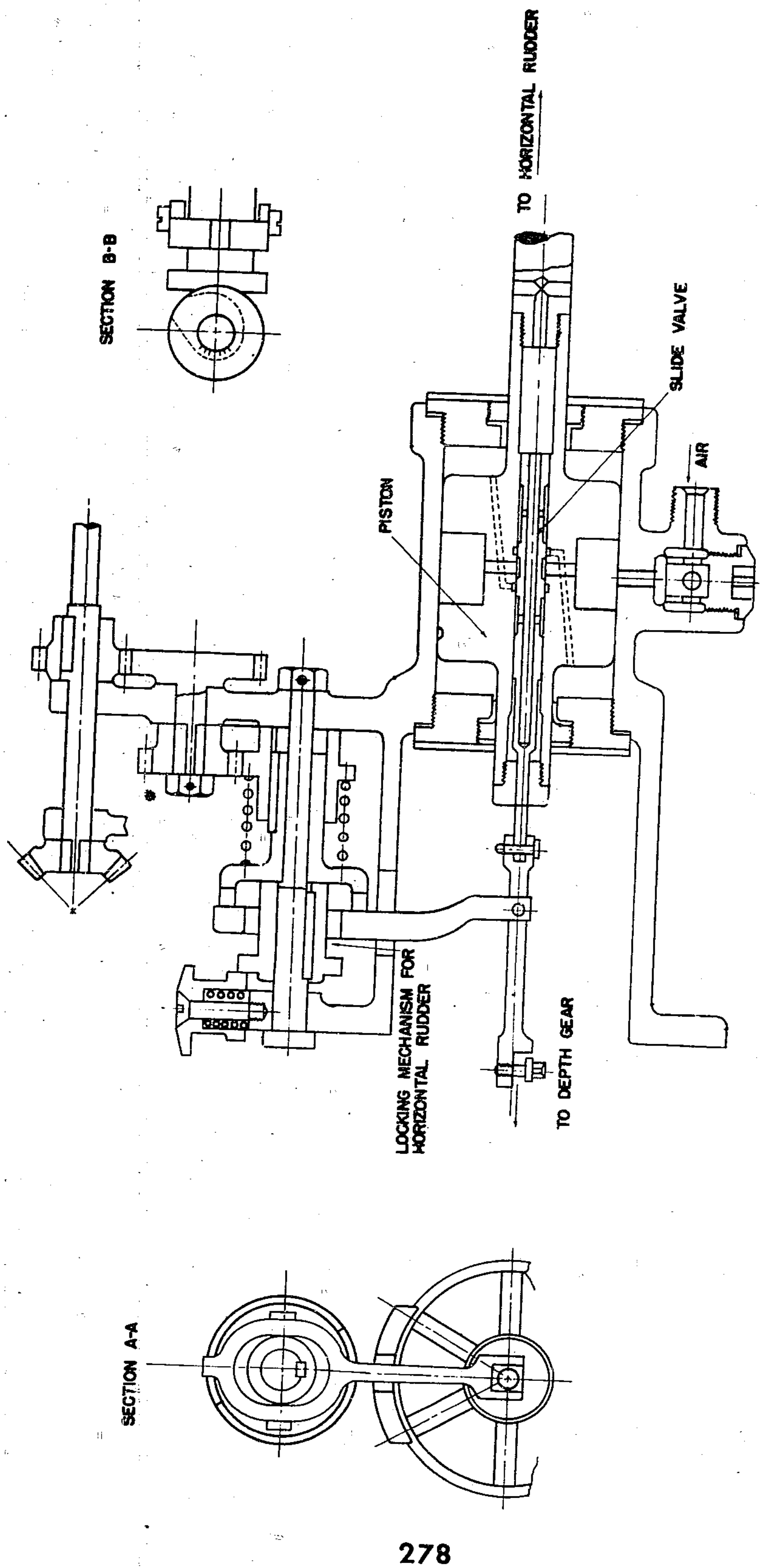


FIGURE 137
SERVOMOTOR

Type 4th Year Modification 2

To improve the steering of the 4th year type a second slide valve was added between the main slide valve and the steering engine. Improvements were also made to the operating mechanism. (See Figure 138 a and b)

Type 92

The mechanism is the same as that of the 4th year, Modification 2 except that the parts were strengthened.

Type 98

The wheel mechanism, i.e. turbine wheel and gyro wheel, is the same as in the Type 92 except that ball bearings are used in the gimbals. The most important addition to the mechanism was the introduction of the balanced diaphragm in place of the link mechanism between the wheel and the slide valve.

The air control system is shown in Figure 139. On the outer gimbal frame is a semi-circular seal to the rotary valve having a clearance of 0.03mm. The rotary valve has two discharge orifices at 180° which are connected to each side of a balancing diaphragm. Air pressure at 1.5 kg/cm^2 is supplied to each side of the disc. When the gimbal rotates, one or the other of the discharge orifices in the valve is uncovered and the pressure falls on the appropriate side of the diaphragm resulting in a lateral movement of the spindle carrying the disc. The spindle is connected to a slide valve which moves, admitting air to the end of the main slide valve, and operates the servomotor controlling the steering engine.

Type 98 was adopted as the standard gyroscope for Types 93 and 95 torpedoes. In the case of the former the torpedo was equipped with a special steering mechanism which permitted the torpedo to circle at the end of the straight run. The gyroscope was also mounted on a rubber vibration damper. It was stated that the deflection from the course was very small and that this helped to render the track invisible.

Type 02

This type was made for short range torpedoes only, i.e. the Type 02 torpedo, and with a view to easy manufacture. The starting was by air-blast. The mechanism was simple and easy to produce but the performance was poor. (See Figure 140.)

Electric Gyroscope for KAITEN Torpedo

Historical

About 10 years ago an electrically driven gyro wheel was satisfactorily produced, but further development work was stopped because of the difficulty in assembling it in the torpedo and the long time required to get it up to speed. At that time small submarines were being manufactured and since their gyroscopes were unsatisfactory the electric gyroscope was adopted and gave satisfactory results. Later, when the KAITEN torpedo was produced, this gyroscope was used in conjuction with the air circuit of Type 98.

Dynamo

The dynamo is a three-phase alternating current unit having an input voltage of 24 volts and an output of 120. (Figure 141). It is supplied from a wet battery of 12 cells.

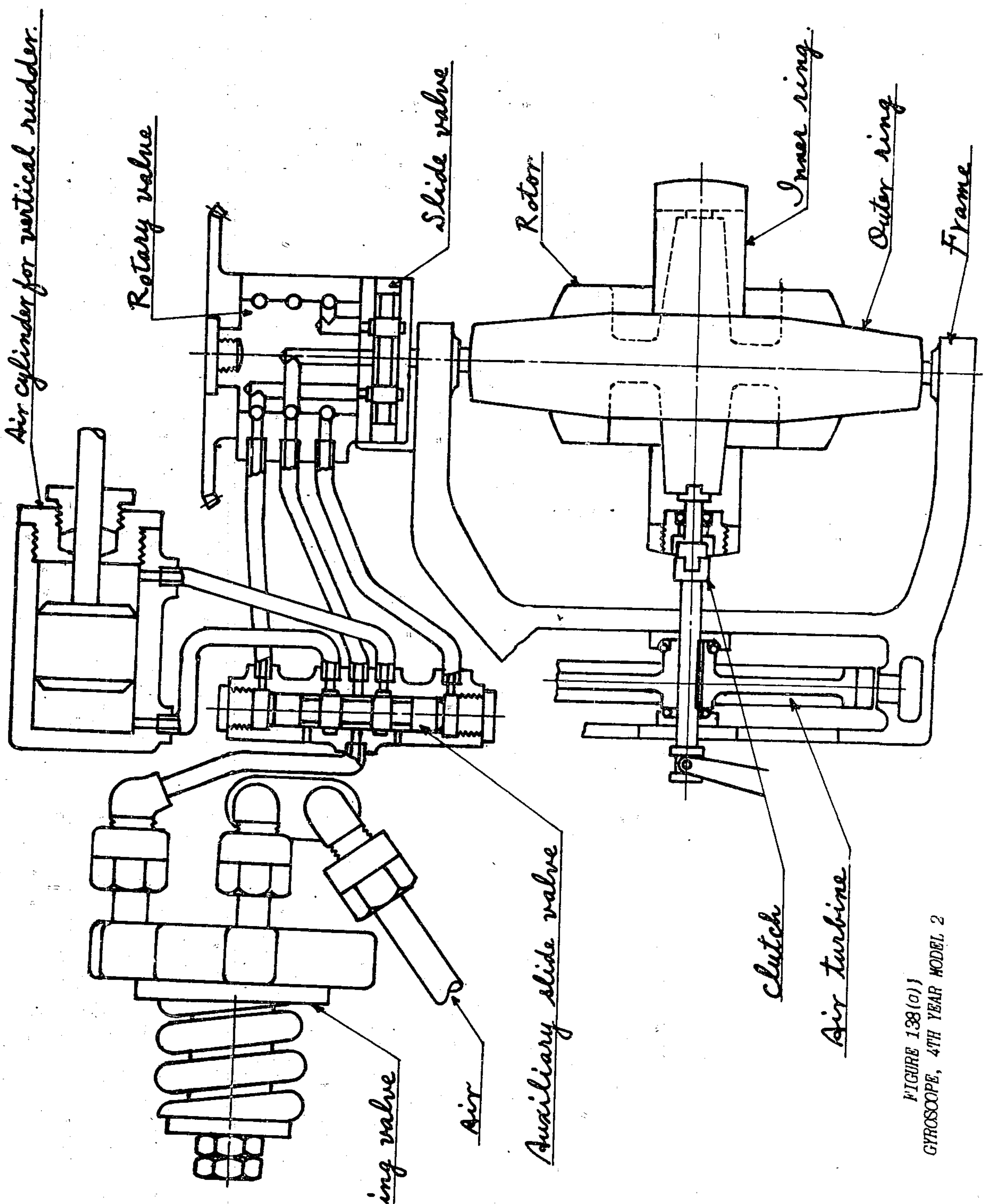


FIGURE 138(a)
GYROSCOPE, 4TH YEAR MODEL 2

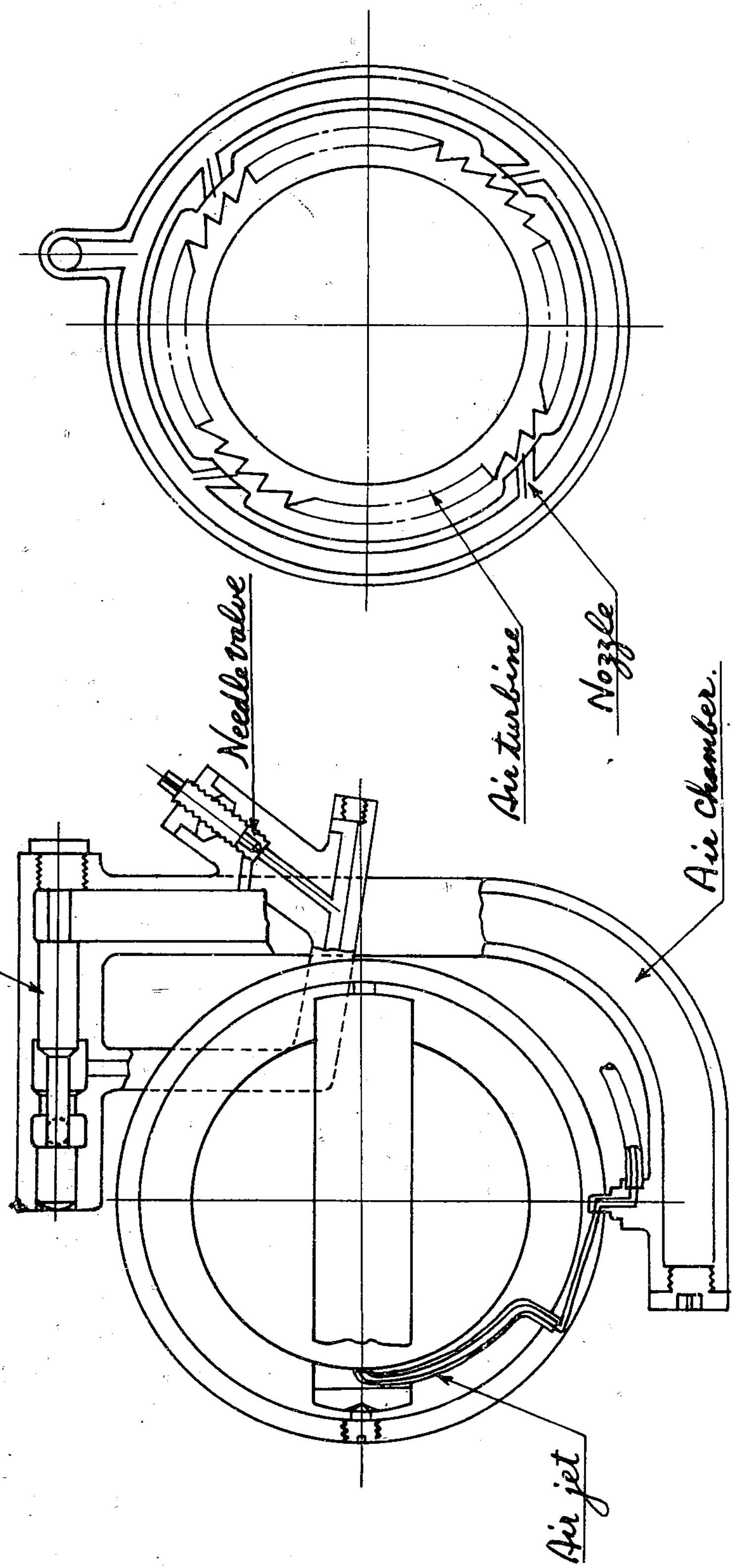


FIGURE 138(b)
GYROSCOPE, 4TH YEAR MODEL 2

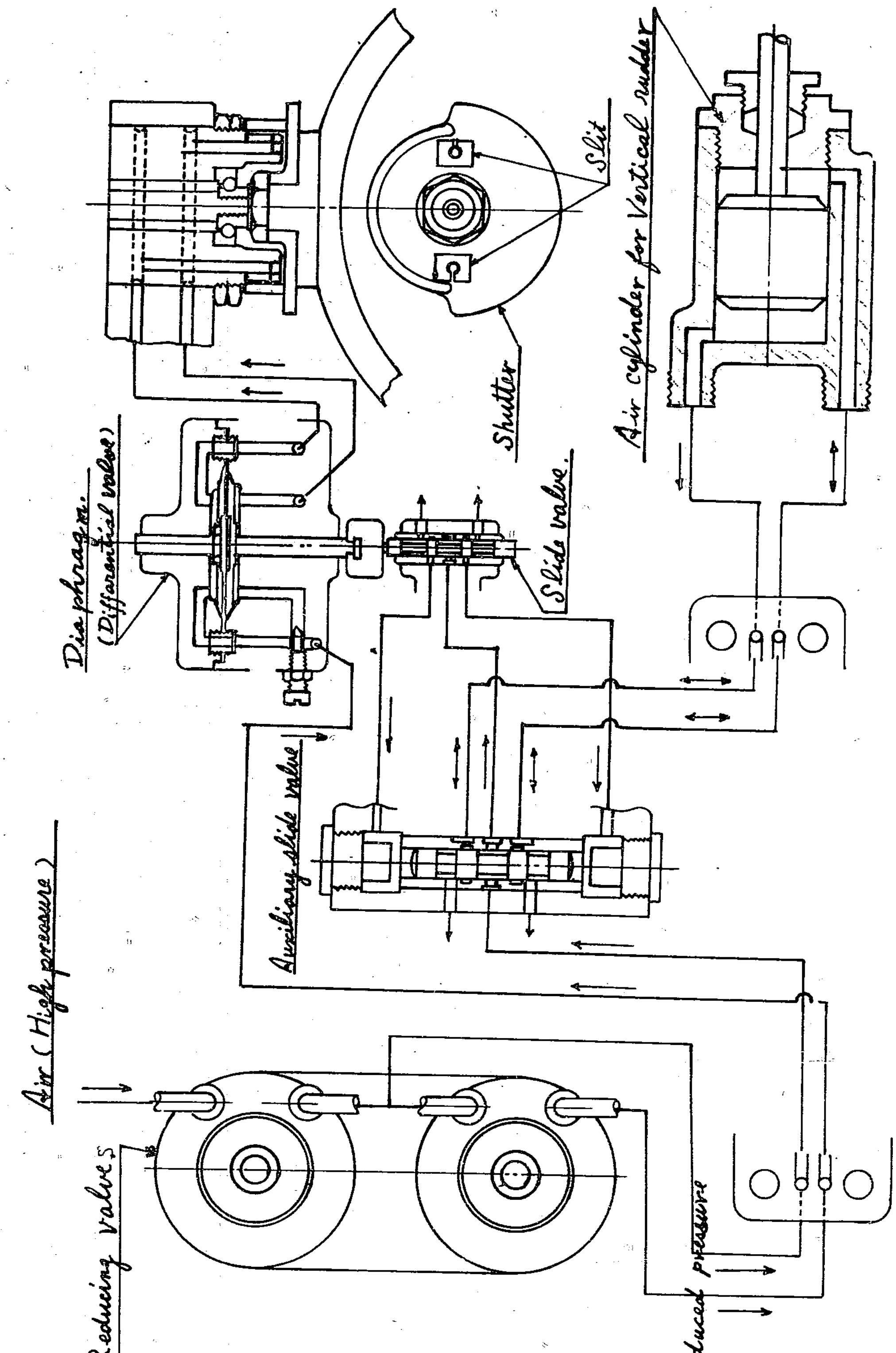


FIGURE 139
GYROSCOPE, TYPE 98, AIR CIRCUIT

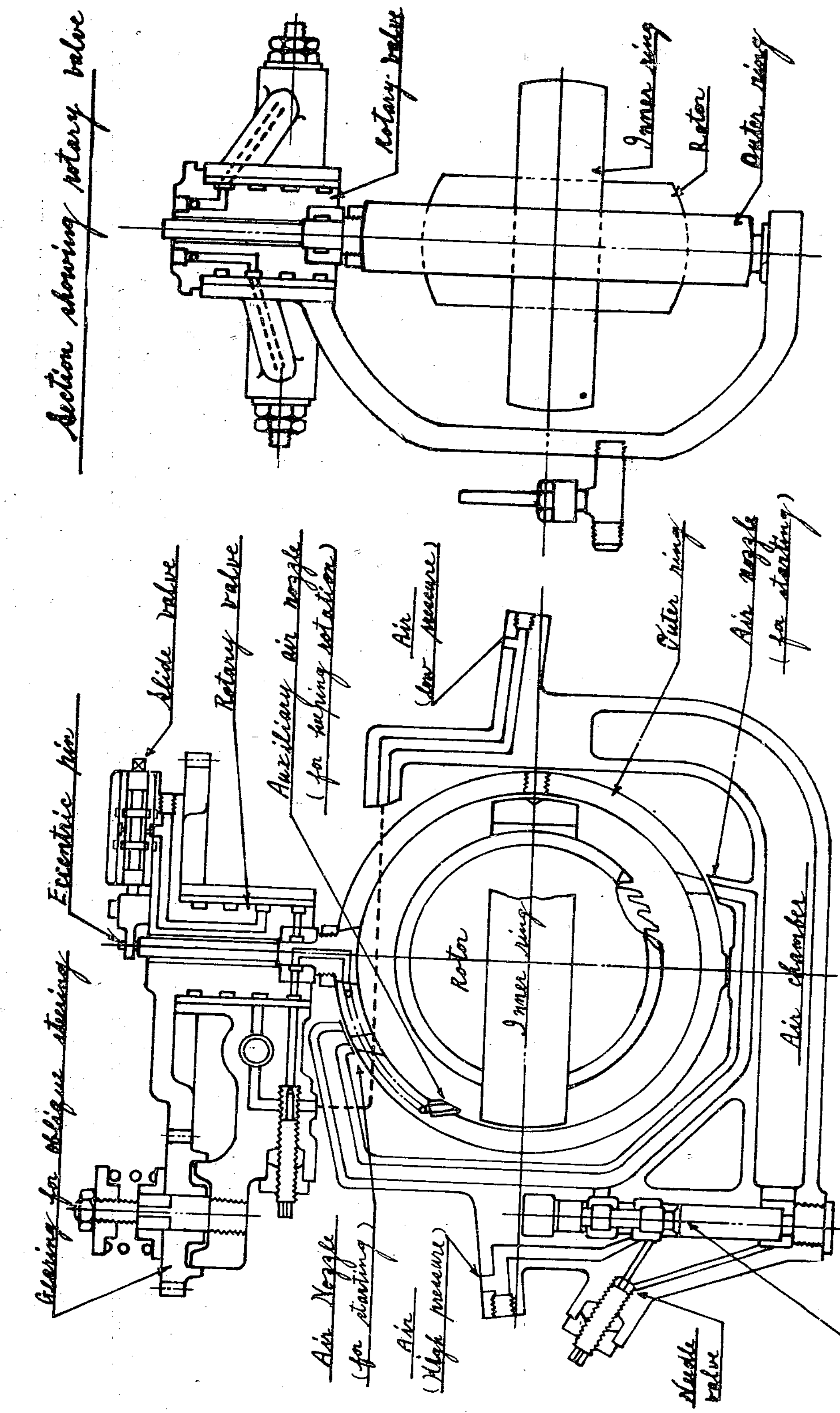


FIGURE 140
GYROSCOPE, TYPE 02

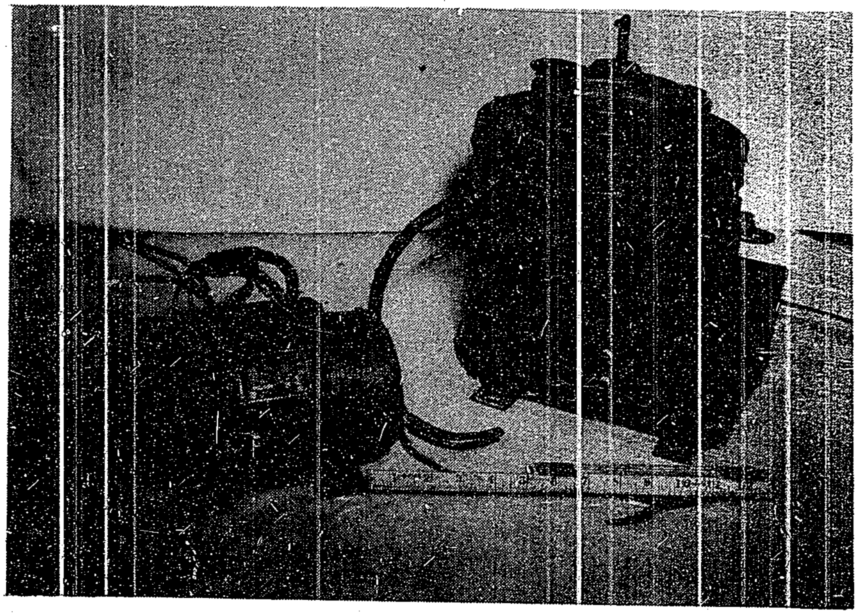


FIGURE 141
ELECTRIC GYROSCOPE CASING

The leading particulars are:

Weight	5.5 kg	totally enclosed
RPM	6600	constant speed
Cycles	330	reduced from 400
Input	24	volts
Output	120	volts

Gyroscope

Casing

The gyroscope is mounted in a metal casing having a glass insert at the top for reading the scales. (See Figures 141 and 143). Through the center passes a spindle for setting the course. At the bottom are two disc type reducers which reduce the pressure from 200 kg/cm^2 (2830 lbs/in^2) to the working pressure (not known) for operating the servomotors. When the gyro is functioning the air in the casing acts as a coolant for the motor. Since the casing is air-tight (tested to 25 kg/cm^2; 355 lbs/in^2) there is a gradual rise in pressure due to leaks from the servo mechanism. The actual pressure reached was not known.

Frame

The gyroscope system is mounted vertically in a bronze frame octagonal in shape. (See Figures 142 and 144). On one side of the upper part are the servomotor systems for operating the steering engine. The rotary valve is incorporated in the upper bearing of the gimbal system together with mechanism for the pilot's control which is operated manually through a worm drive. On the lower part of the frame the gimbal locking arms are bolted. A pair of arms lock the inner and a single arm locks the outer. These prevent the gyroscope from taking control until the normal speed has been reached. The delay is approximately five minutes. Above the worm drive are two scales, the top one being attached to the outer gimbal and the lower one being set by the pilot through the worm gear.

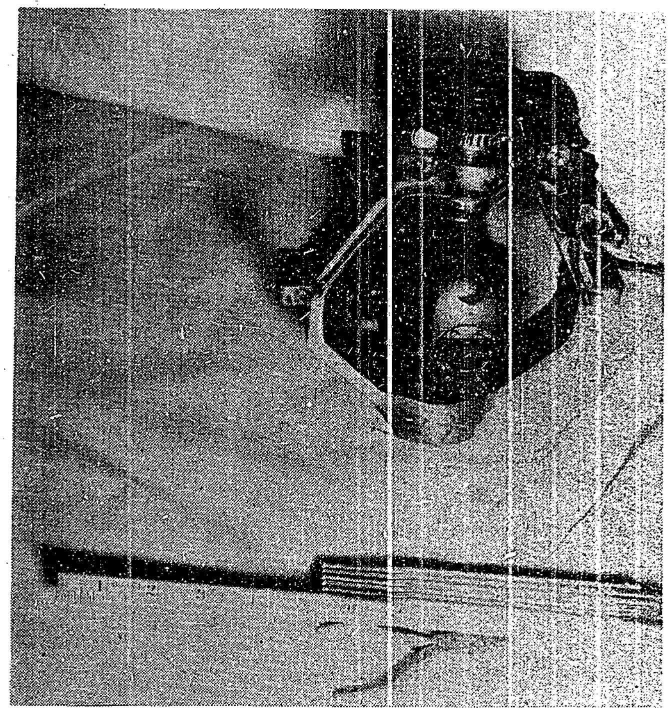


FIGURE 142
ELECTRIC GYROSCOPE ASSEMBLY

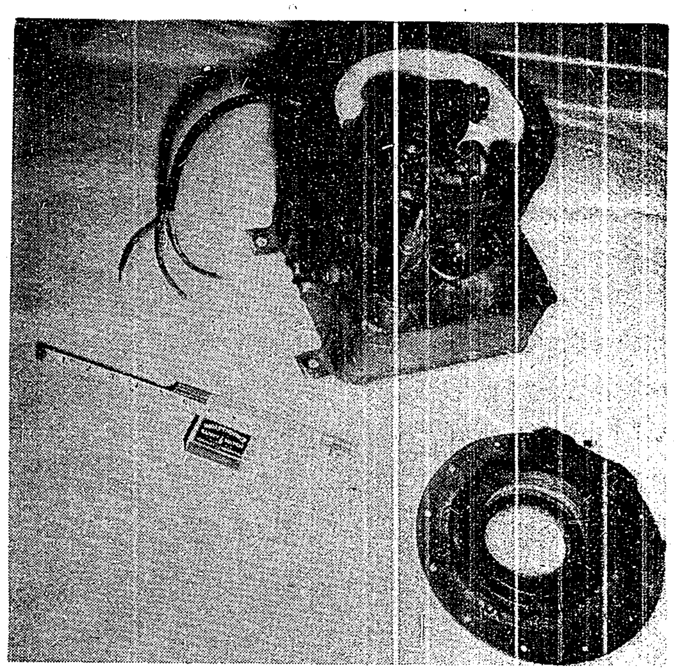


FIGURE 143
ELECTRIC GYROSCOPE MOUNTED IN CASING

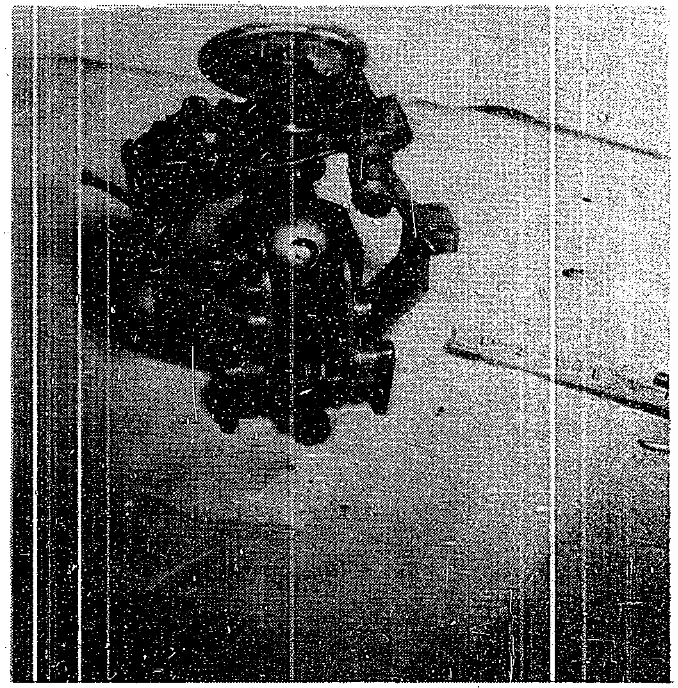


FIGURE 144
ANOTHER VIEW OF ELECTRIC GYROSCOPE

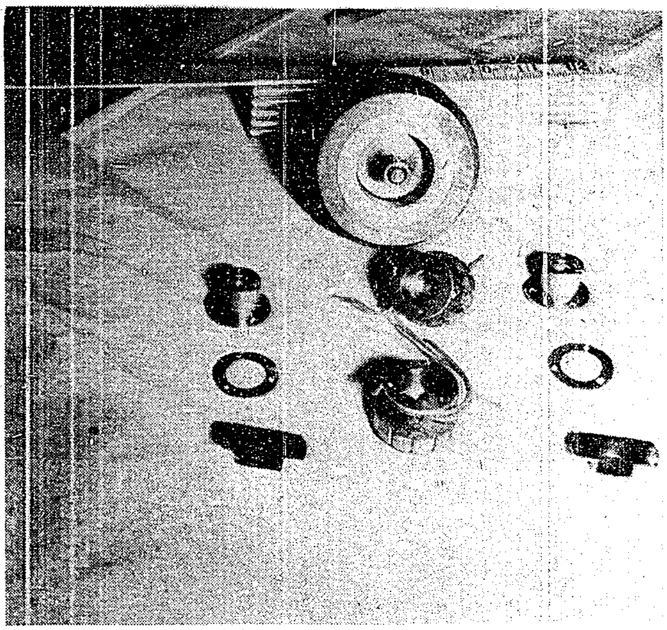


FIGURE 145
GYROSCOPE WHEEL DETAILS

Air Circuit

The balanced diaphragm of Type 98 is used. The pilot can steer the KAITEN torpedo by revolving the rotary valve through a worm drive. The servo mechanism now functions independently of the gyroscope.

Gyroscope Wheel

The wheel weighs 1075 grams (2.4 lbs) and is electrically driven by a squirrel cage motor. (See Figure 145). The motor is designed so that the rotor is on the outside and the stator on the inside. The unit was built by a subcontractor whose name was not known. Originally it was designed to operate at 400 cycles; this was reduced later to 333.

The circuit is shown in Figure 146. There are three-phase windings having two wires and a ground. The two phases are led through one spindle of the outer and both spindles of the inner gimbal. One phase passes through a slip ring on the outside of the shaft and the other by a spring-loaded contact through the end of the spindle, which is insulated by a vulcanite bush.

The rotor revolves at 1500-1800 RPM and is statically and dynamically balanced. The error is said to be 3° in a test of 10 hours. The rotor is of steel recessed at each side around the spindles to house the stators and is mounted on two small ball races. The normal cast-in squirrel cage construction is used, light alloy having been poured in.

The stator is in two parts, effectively two separate motors, each fed with current through their spindles and mounted on one end of the rotor spindle The stators have been bored out to carry the external housing of the ball races.

To keep wheel revolving air pressure of 16 kg/cm² (227 lbs/in2) is used. This also operates the steering engine.

Bench Testing of Gyroscopes

The gyroscope is mounted vertically on a frame on the bench and the wheel is run at constant speed. The frame is oscillated at constant frequency and amplitude approximating that of the torpedo and a diagram is drawn by a pencil attached to the steering arm.

Details of test of gyroscope Type 98

Duration of test	30 minutes
Oscillation	
Amplitude (degrees)	8
Frequency (cycle/min)	35
Permissible deflection (degrees)	<± 0.25

Summary of Types

Type of Gyro		Type (4th year)	Type 4th year (Modif. 2)	Type 92	Type 98	Type 02
Type of Torpedo		Type (6th year) Type (8th year)	Type 6th year Type 8th year Type 89 Type 90 Type 97 & 98	Type 89 Type 90	Type 92 Type 93 Type 95 Type 96	Type 02
Weight	kg	5.200	6.3000	7.700	8.550	4.500
	lbs	11.4	13.9	16.9	18.8	9.9

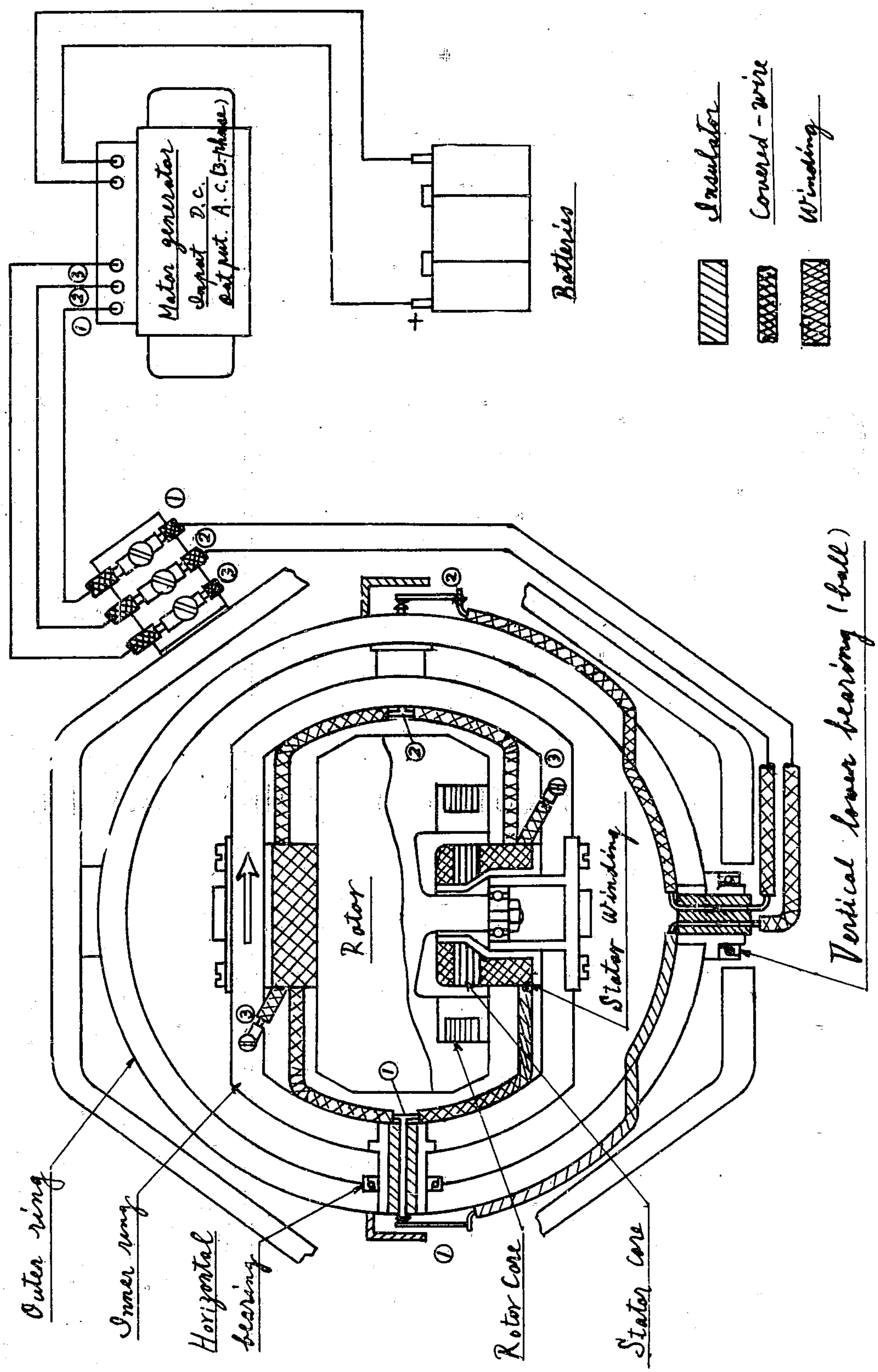


FIGURE 146
CIRCUIT DIAGRAM ELECTRIC GYROSCOPE

Type or gyro	Type (4th year)	Type 4th year (Modif. 2)	Type 92	Type 98	Type 02
Weight of wheel kg lbs	1.150 2.53	1.150 2.53	1.160 2.55	1.160 2.55	0.750 1.65
RPM of wheel	6500	7000	9000-12,000	9000-12,000	7000-8000
Method of starting	Turbine wheel 4 nozzles	Turbine wheel 4 nozzles	Turbine wheel 4 nozzles	Turbine wheel 4 nozzles	No turbine wheel. Blast nozzle of gyro wheel used.
Wheel	Nickel bronze	Nickel bronze	Nickel bronze	Nickel bronze	Nickel bronze
Material frame	Phosphor-bronze	Phosphor-bronze	Phorphor-bronze	Phosphor-bronze	Phosphor-bron[illegible]
Gimbals	Forged Al. bronze	Forged Al. bronze	Forged Al. bronze	Forged Al. bronze or stainless steel	stain[illegible]ess steel
Type of wheel dia. bearings no. (ball bearing)	1/8" 7	1/8" 7	1/8" 7	1/8" 7	1/8" 7
Method of mountings	Laminated steel spring	Laminated steel spring	Laminated steel spring	Rubber vibration absorber	Rub[illegible]er vibration absorber
Control gear (diameter of piston)	22mm 0.866 in	22mm 0.866 in	23mm 0.906 in	23mm 0.906 in	23mm 0.906 in
(air pressure) kg/cm^2 lbs/in^2	20 284	20 284	16 227	12 170	16 227
Blast pressure	steering air pressure	steering air pressure	steering air pressure	steering air pressure	steering air pressure
Number of nozzles	one	one	one	one	two
Position in torpedo	Rear buoyancy chamber	Rear buoyancy chamber	Rear buoyancy chamber	Rear buoyancy chamber	Rear buoyancy chamber
Special fittings	No	No	No	Circling apparatus	No
Accuracy of direction keeping (deflection angle-time)	± ¼ deg.-10 min.	± ¼ deg.-10 min.	± ¼ deg.-15 min.	±¼ deg.-30 min	±¼ deg.-3 min.

ADDITIONAL DEVELOPMENTS

Guiding and "Homing" Torpedoes

Historical

Experiments were carried out with hydrophone-equipped torpedoes designed to "home" on a sound source by acoustical response. Two distince methods were employed; the more simple, and the only one extensively developed, was dependent on comparison of sound intensity, whereas the second relied upon the phase difference of sound received at two separated points. The experiments appear to have been confined to electrically driven torpedoes, and no information is forthcoming whether any operational success was achieved.

Sound Intensity Method of Control

General Principle

A Type 92 electric torpedo was fitted with two hydrophones in the head in positions 30° to port and starboard. Each hydrophone was connected in turn, through an amplifying circuit, to a differential relay which discriminated between the respective sound intensities and through a further relay system applied port or starboard rudder.

Apparatus Employed

The two hydrophones, magneto-striction type, 22.5 kilocycle, with total surface area of 78 cm^2, are carefully recessed into position and rendered flush with the torpedo body by the addition of an ebonite plate. The response angle of each is approximately 70°. (See Figures 147 and 148.)

Change-over Device

The alternate connection of the hydrophones to the amplifier and of the amplifier output to the respective coils of the differential relay was achieved by a simple change-over switch operated mechanically by a water-wheel 25 times per second.

Amplifier

This represented a conventional five-valve heterodyne circuit, with automatic gain control, and overall amplification of approximately 120 db. The heterodyned output was 10 kc, rectified by a full-wave selenium rectifier.

Relay System

A total of eight relays was employed, two of a sensitive differential type operating on 50 microamps., standard telephone types.

Power Supplies

The 220V and 6V amplifier supplies together with the 50V supply for the relay system, were obtained from the main battery.

Sequence of Operation (See Figure 148)

When the pick-up of one hydrophone is in excess of the other, relay M closes in the corresponding direction. Relay A(or B) will be operated and

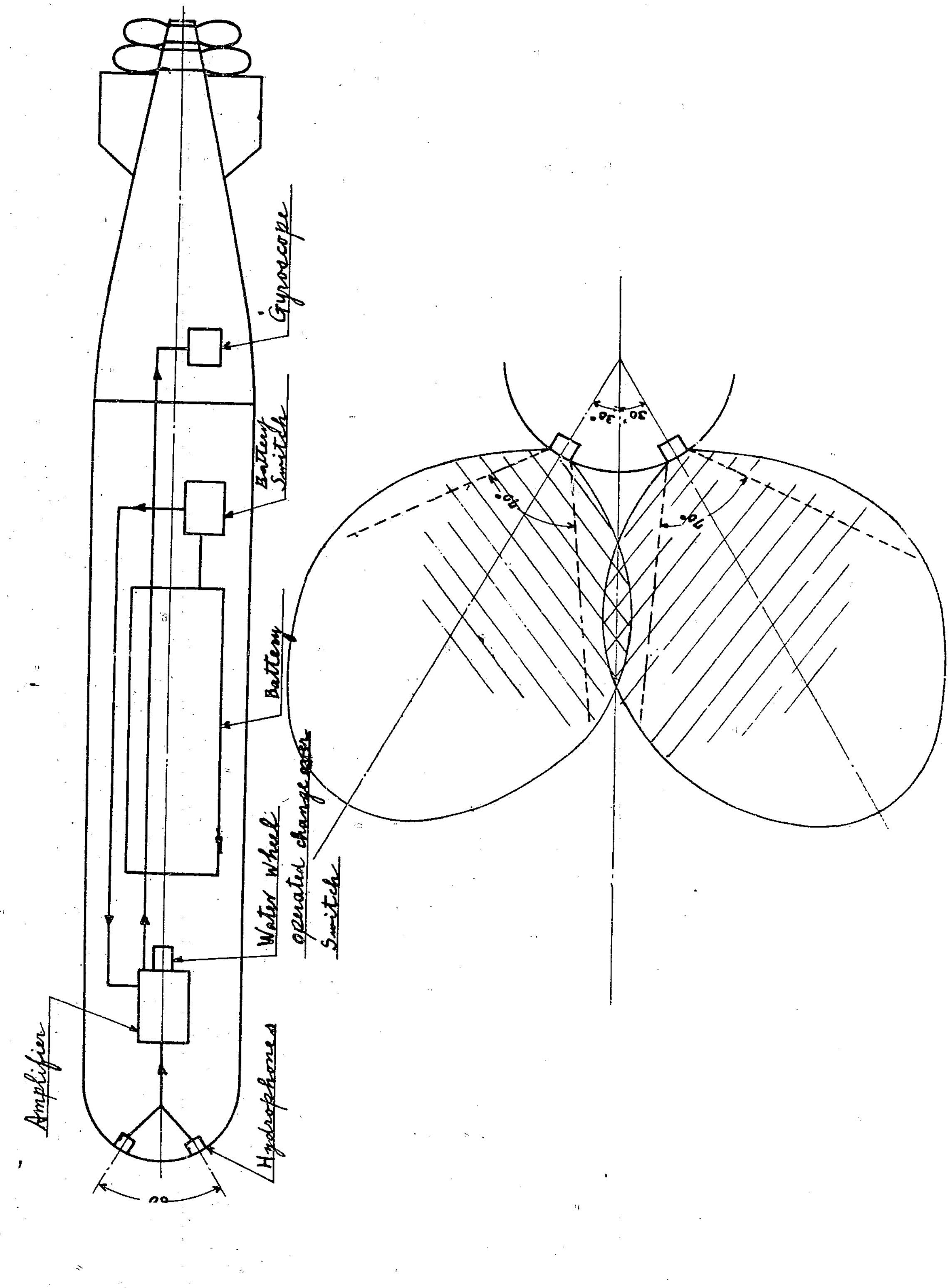


FIGURE 147
GENERAL ARRANGEMENT ACOUSTIC TORPEDO

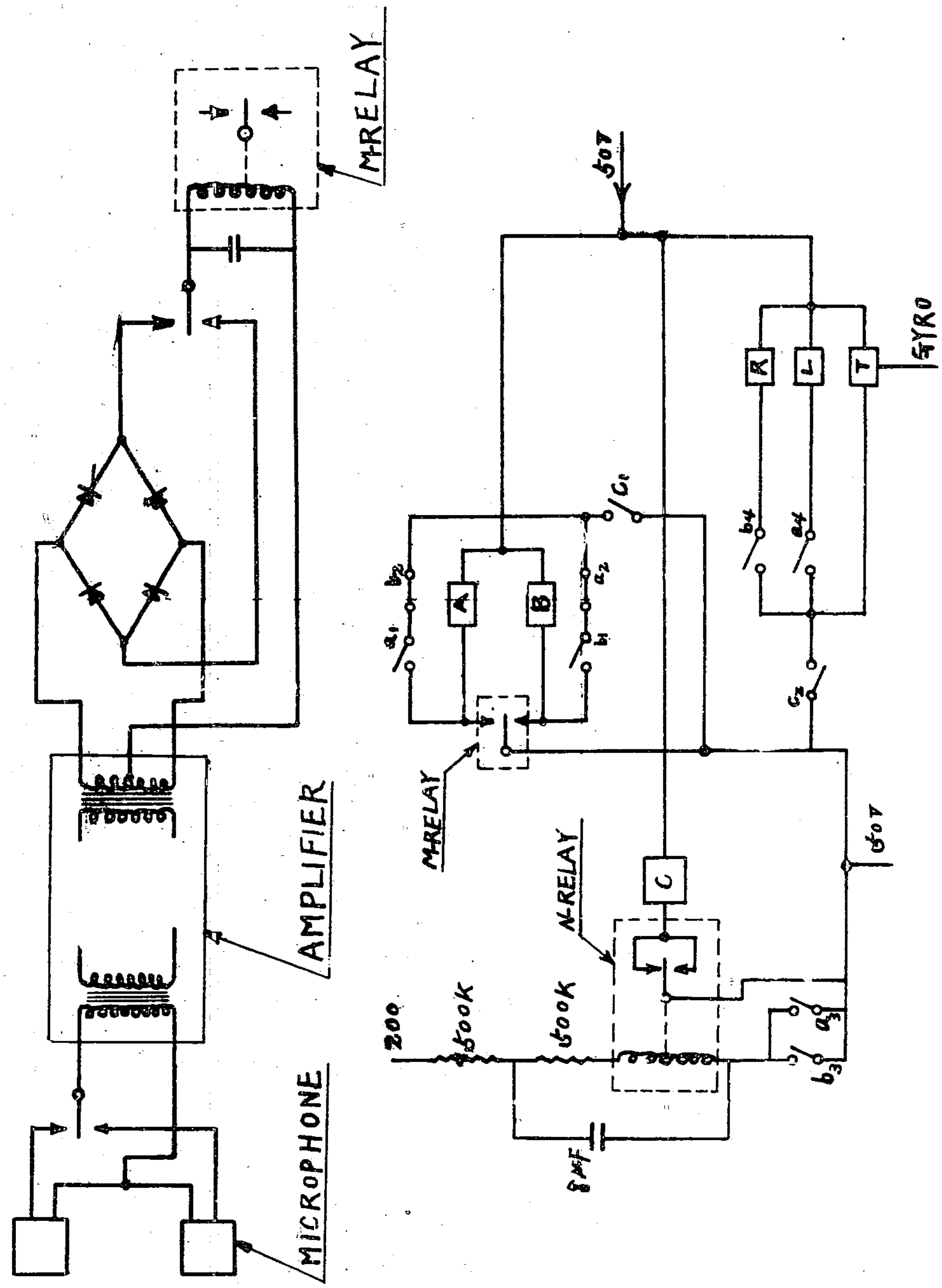


FIGURE 148
ACOUSTIC TORPEDO CIRCUITS

in turn, will connect relay N and its associated time-delay resistance/condenser circuit, the function of which is to prevent relay N closing until relay A(or B) remains operative for at least two seconds. When relay N closes, relay C is operated, enabling relay A(or B) to remain closed through its own contacts. It also operates relay T which disconnects gyroscope control of the rudder and renders it responsive to the air valves operated by relays R or L (depending on which direction relay M has been closed and hence relay A or B). Port (or starboard) rudder will be applied and this condition will continue until the other hydrophone has the greater pickup and opposite rudder applied.

Experimental Results

Tank tests showed an angular sensitivity of 2° and running trials were generally satisfactory up to 20 knots. Failures were frequent above this speed and were attributed to the greatly increased background noise generated by the torpedo itself. It was hoped that the more careful fairing-off of all projecting surfaces might yield some improvements.

Control by Phase-difference Method

General Principle

This method of control is dependent upon the fact that if two separated hydrophones receive noise from a single source, there will be a phase difference of the wave form varying according to the orientation of the source with respect to the hydrophones. The electric torpedo adapted is referred to as the "NR" fitted with a Type 91 head. Immediately aft of the head are fitted the hydrophones, which are connected to an amplifying circuit of special design generating a rectangular wave form, by virtue of which the operation is independent of sound intensity. The selection by differential relay is then applied according to positive or negative phase difference. (See Figures 149 to 152.)

Apparatus Employed

Hydrophones: Experiments appear to have been confined to the carbon granule type, the units being carefully mounted in rubber surrounds and rendered flush with the torpedo body.

Amplifier

The amplifier channels are shown in detail in Figures 150-152, and from these the method of phase comparison of the two output waves may be observed.

Relay System

The relay control system employed is similar to that previously described.

Power Supplies

A small auxiliary battery is utilized to provide such supplies as cannot be taken from the main battery.

Experimental Results

The main advantages of this form of control were considered to be: (a) Independence of sound intensity. (b) Greater angular sensitivity providing increased discrimination. (c) Possibility of controlling depth-keeping hydroplanes for use of torpedo against submerged submarines.

In practice the disadvantages proved to be: (a) Extreme precision required

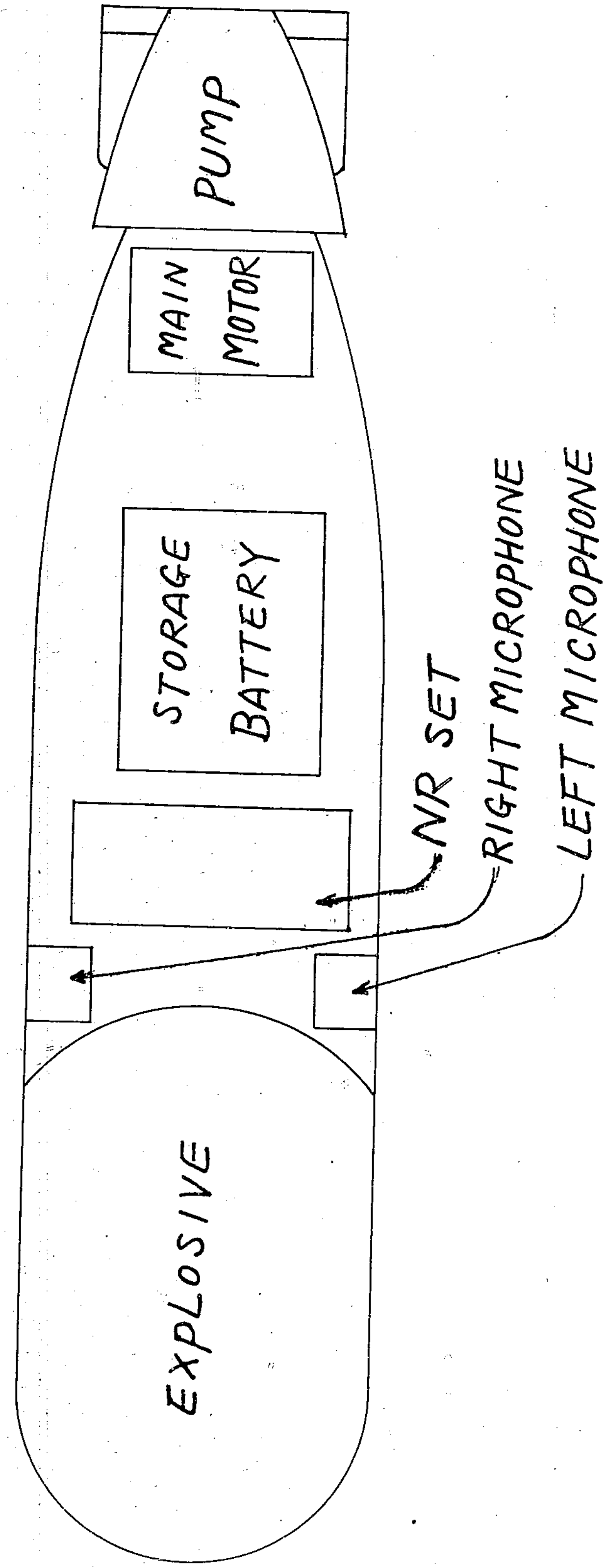


FIGURE 149
ARRANGEMENT OF DETAILS IN NR TORPEDO

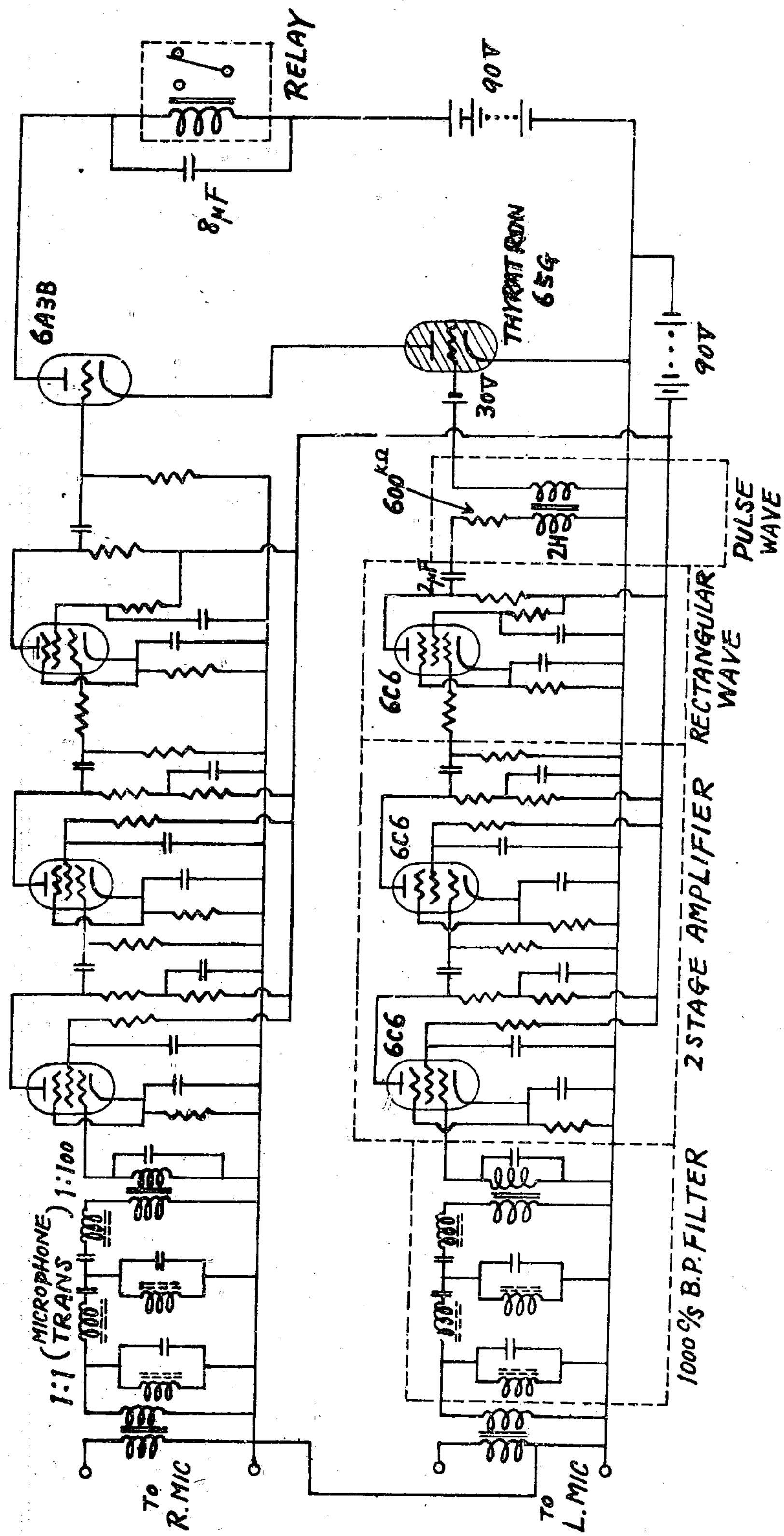


FIGURE 150
DIAGRAM OF CONNECTIONS OF NF SET

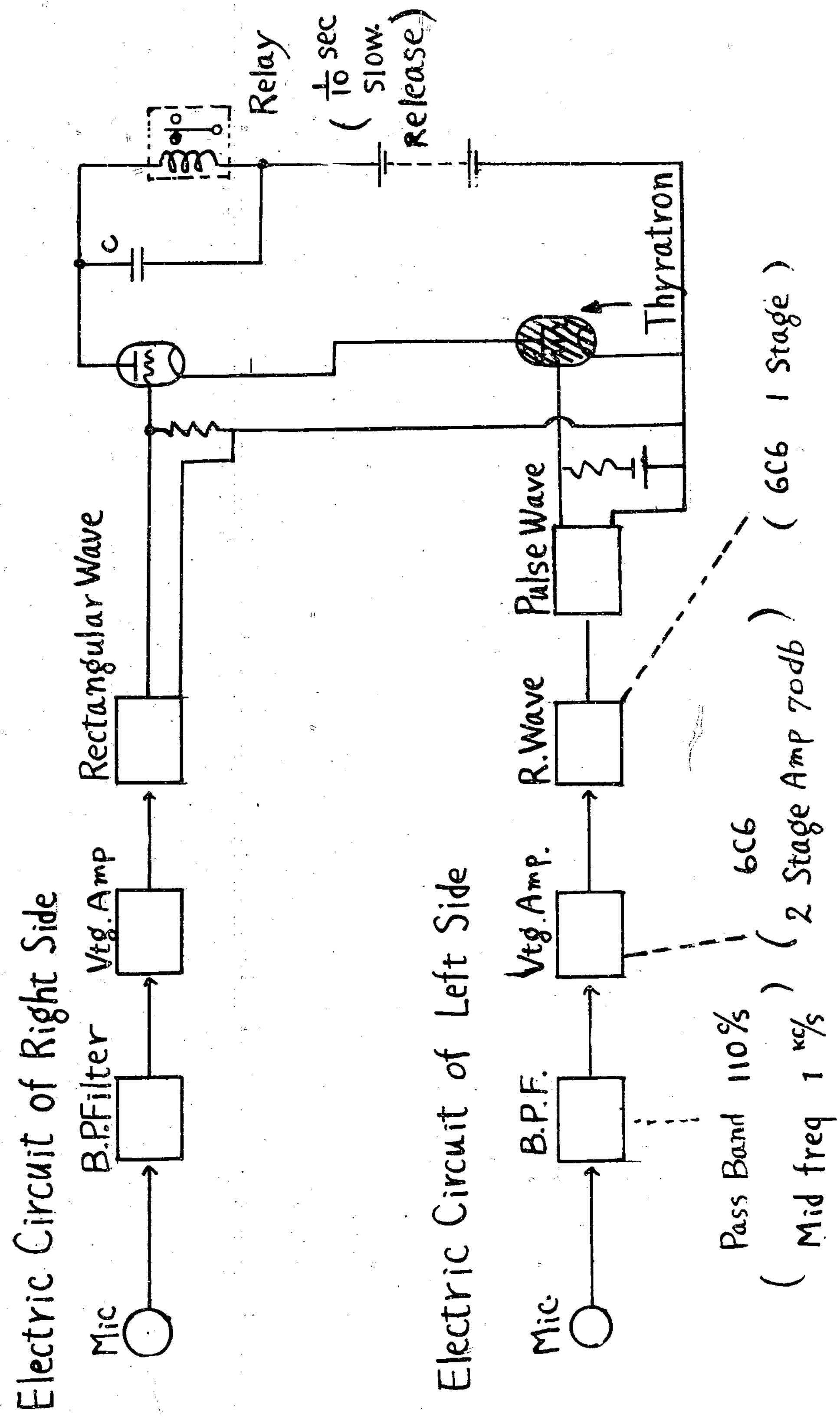


FIGURE 151
CIRCUITS OF NR SET

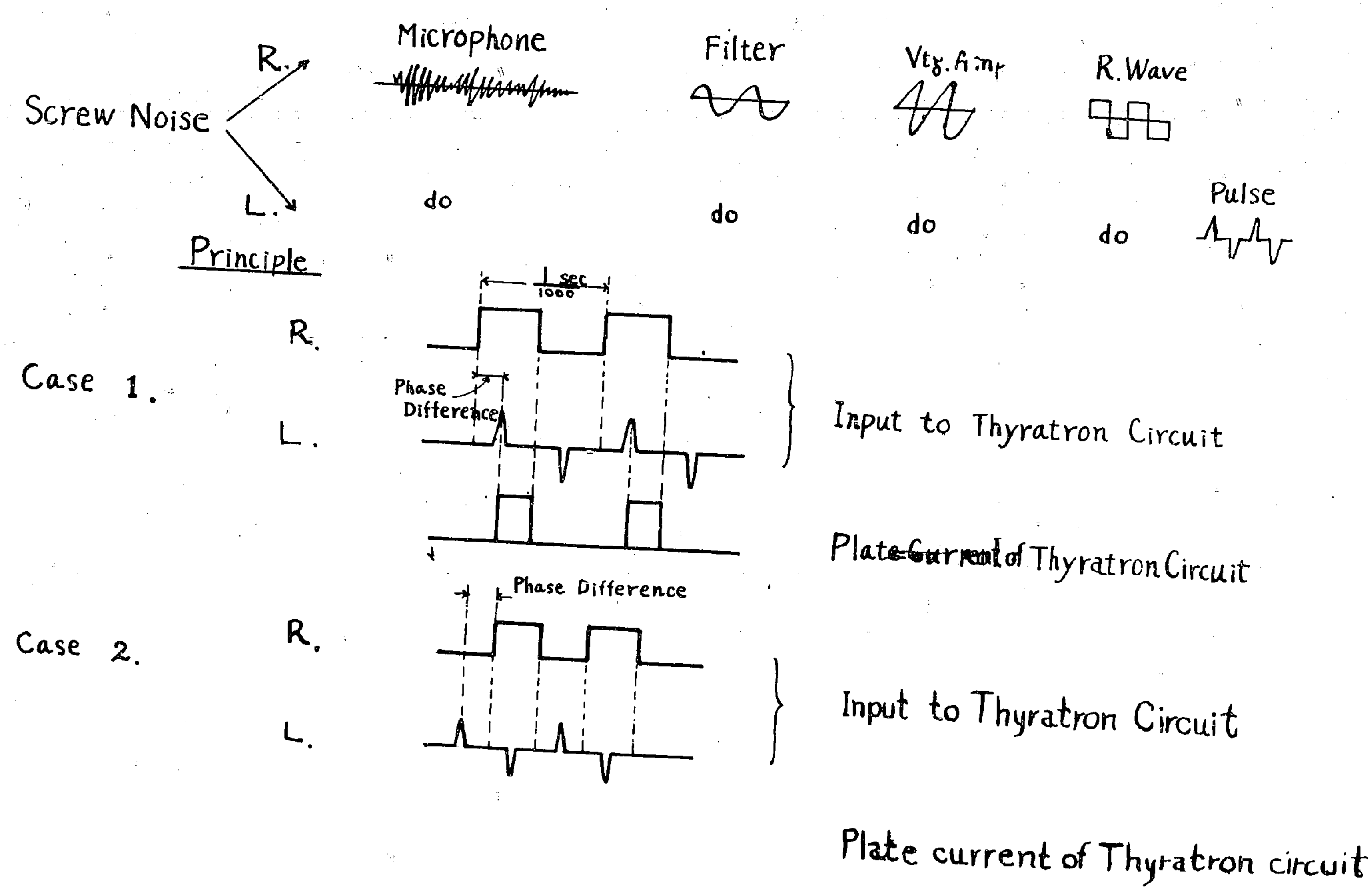


FIGURE 152
WAVE FORM OF NR CIRCUITS

in adjusting the electronic circuit. (b) Liability of the electronic equipment to mechanical shock. (c) High level of background noise generated by torpedo masking the noise emanating from a slow moving target. (d) Difficulty in control of horizontal hydroplanes to relevant hydrophones being responsive to reflections from surface of water.

Experimental data recorded -

(a) Angular sensitivity was $1\frac{1}{2}^{\circ}$ using 1 kc sound source.
(b) Maximum range of acoustic control from submerged submarine at five knots was 100 meters.
(c) Normal water-noise background being considered as one unit over wide frequency range, a submerged submarine at 5 knots and 100 meters distant was found to measure 6 units at 300-4000 cycles.

Future Developments

If experiments had not been finally abandoned, attempts would have been made to minimize self-generated noise by comprehensive rubber cushioning of all machinery and by trying a single impeller in the axial flow water jet propulsion pump, preventing roll by tail guide vanes.

Influence Firing Systems

Type M Magnetic Pistol

This pistol was designed for use in the Type 5, Model 2 warhead, and consisted essentially of a coil rod unit constructed of nickel and iron dust compressed to form a rod of "Sendust" bound with varnish. This was coupled to the grids of two valves, the output of the valve being fed to a relay for firing the warhead. The warhead was also fitted with a standard inertia pistol as a secondary firing system. The general layout of the apparatus in the warhead is shown in Figure 153.

Operation of Firing System

The fan wheel (Figure 154) drives a generator at 3000 RPM when the torpedo is running through the water and this provides the power supply required to operate the electric circuit. The machine has a double-wound armature providing 120 volts and 100 milliamperes for the anodes and six volts two amperes for the heater and ignition circuit. A regulator is incorporated to keep the voltage within 5%, irrespective of speed variations from 2800 RPM to 4500 RPM.

An extension of the generator shaft drives a magnetic clutch (Figure 154) through reduction gearing at approximately 60 RPM, and the clutch, when energized, drives a cam shaft having four cams which operate switches S_1, S_2, S_3, and S_4. Three of these switches are used when the pistol fires operationally, that is S_1, S_2, and S_4. S_3 is incorporated to energize the second grids G'_1 and G'_2 in order to cut off the discharge after 0.8 sec., when trials are being carried out.

Passage of the C.R. unit by a ship causes a potential to appear across the C.R. unit, and, depending upon the direction of the ship's magnetic field (and therefore of the potential), either valve V_1 or V_2 is energized. The output operates the magnetic clutch, S_4 closes 0.3 secs. later, and the warhead explodes.

The voltage inducted in the C.R. unit is 2 volts, with a rate of change of field of 100 milligauss per second and this is the minimum value required to actuate the valves.

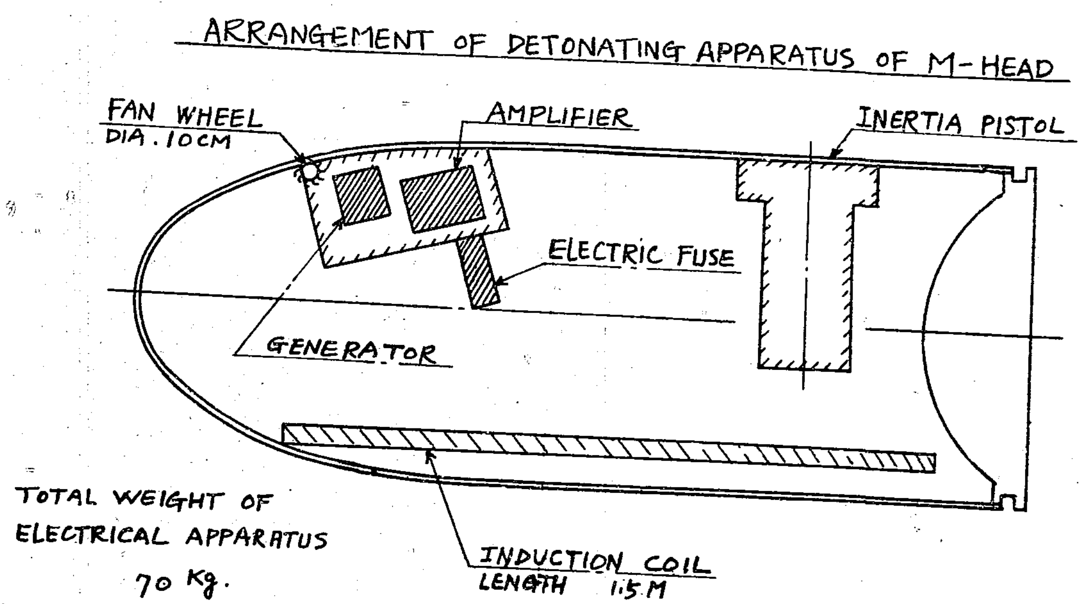


FIGURE 153
TYPE 5, WARHEAD

A hydrostatic anti-countermining switch is provided to break the detonator circuit and the clutch circuit in the event of near explosions. Voltage terminals are provided for test instruments on the amplifier and a revolution counter can be fitted when trials are carried out.

Functioning Tests

Functioning tests were carried out under ships with the torpedo set to run two to three meters below the bottom. It was stated that 90% of the exploders fired under the ships. Details of the trials are as undernoted:

Name & type of ship	Average speed of torpedo	Track of torpedo relative to that of ship (values approximate)	Number of torpedoes fired	Failures
JINGEI (submarine depot ship)	40	90°	4	
Submarine I - 22	40	90°	4	1
ATADA (transport)	40	90°	2	
Destroyer HAMANAMI	40	90°	6	1
Battleship YAMASHIRO	40	90°	2	1 ran deep
MISHIKI-MARU (merchant ship)	48	90°	4	2 valve leakage

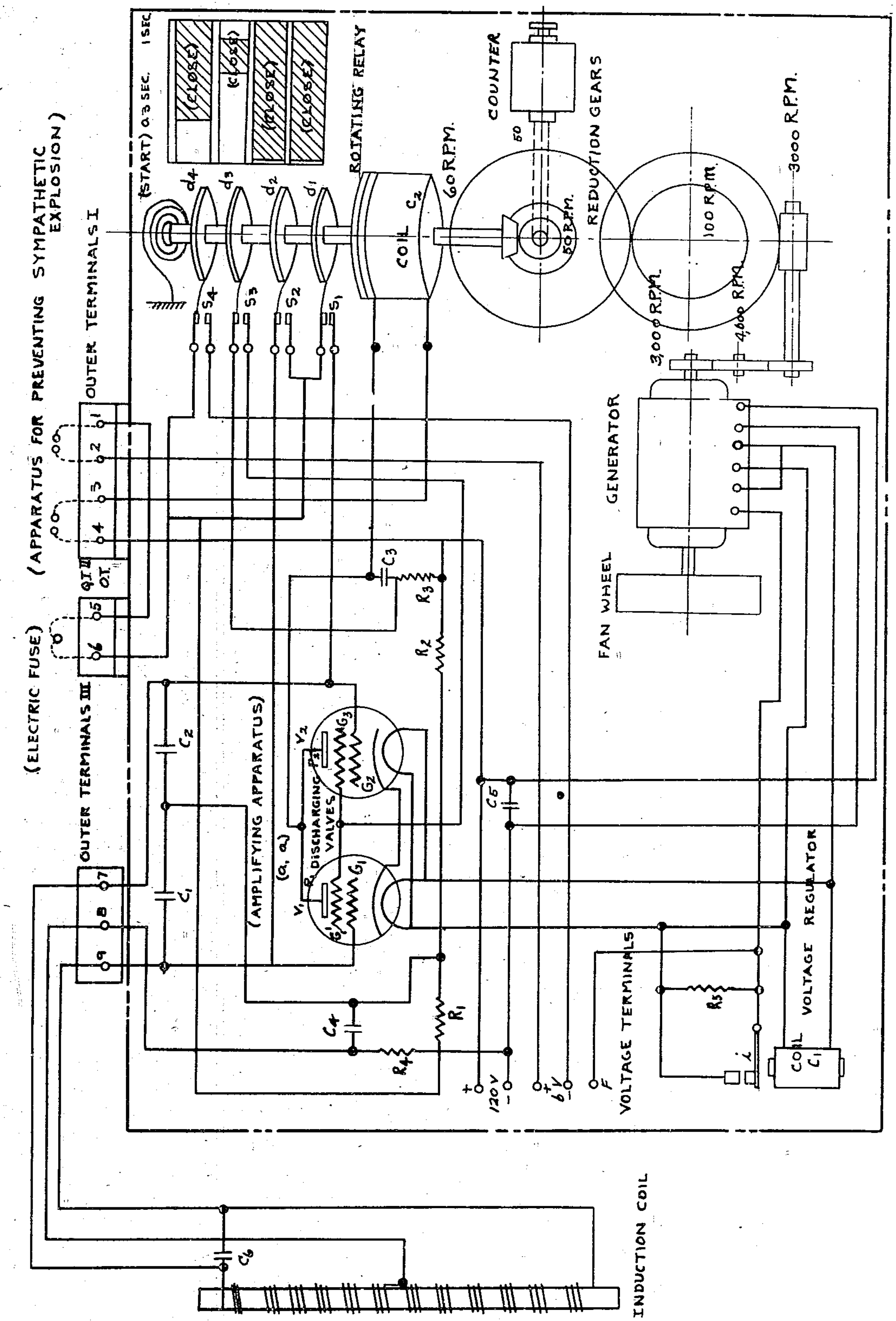


FIGURE 154
TYPE M MAGNETIC PISTOL CIRCUIT DIAGRAM

MISHIKI-MARU (merchant ship)	48	90°	4
MISHIKI-MARU (merchant ship)	48	90°	4
MISHIKI-MARU (merchant ship)	48	30°	4

Fifteen torpedoes also were run to test for prematures and proximity explosion. None occured.

Three torpedoes also were tested for the correct functioning of the inertia pistol.

Operational Use

This pistol was accepted for service in July 1944 and 80 were constructed and sent to Maizuru Navy Yard for use on the Type 95 torpedo.

The only safety device appears to be the fan wheel generator, which revolves only when the torpedo is running.

Type OR Magnetic Pistol

This was a magnetic pistol in the very early stages of development and upon which trials had not been completed. No details concerning the method of operation could be obtained. Its development seems to have been carried out outside the naval research establishment by a private manufacturer. Figure 155 shows the electrical circuit of the apparatus, and Figure 156

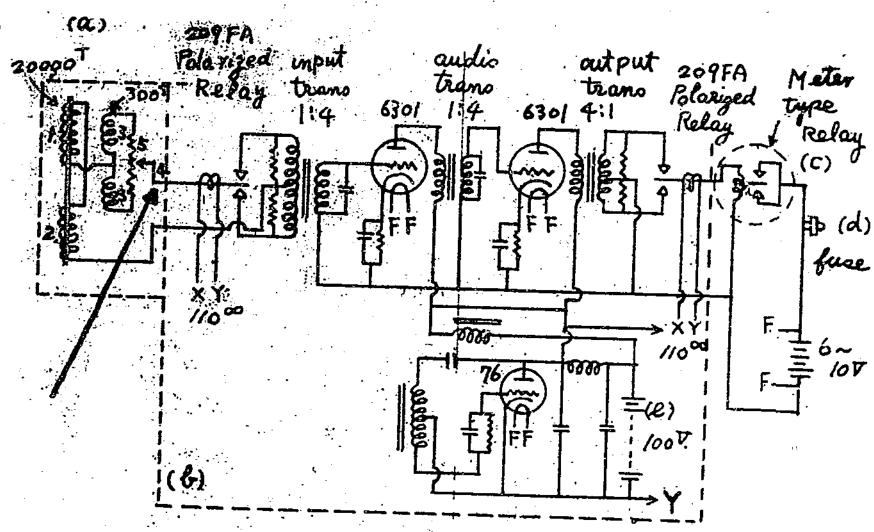


FIGURE 155
MAGNETIC PISTOL, TYPE OR, CIRCUIT DIAGRAM

shows the relationship between rate of change of magnetic field and rate of change of field along the axis of the C.R. unit.

The C.R. unit is wound differentially in order to limit the chance of premature firing due to change of position in the earth's field. This trouble cannot be overcome completely, but it was found that angular changes of velocity of 144°/sec could be handled without a premature fire.

In order to adjust the C.R. unit for satisfactory compensation of changes in the earth's field, the complete unit was mounted in the torpedo which was then suspended and rotated through 360° in 25 secs. Contact 4(Figure 155) was adjusted until the rotation could be carried out without firing the circuit.

It is presumed that different adjustments must be made to cover field strength variations in different parts of the earth's surface.

Turbine Torpedoes

Historical

The development of turbine torpedoes was undertaken in 1934 (about the same time as the 24" Type 93 torpedo) to meet a staff requirement for a high-speed torpedo having a single speed of 60 knots to 8000 meters.

The Japanese decided to use a turbine, in spite of its poor specific air consumption, and not to attempt to develop a reciprocating engine because of its size and weight and the mechanical difficulties involved.

In all, four units were designed and manufactured. The first was a power unit only, with an output of 750 hp, and was built at YOKOSUKA for dynamometer tests to obtain design data.

In 1936, at the same time that the development of the 750 hp unit was in hand, the design of turbine units F 1, 2 & 3, all suitable for 24" diameter torpedoes, was undertaken at KURE. The same general design was adopted, making use of the experience gained with the YOKOSUKA unit. Complete torpedoes were designed, manufactured and run in the sea. The development of the three all overlapped.

The stages in the development covered by each were:

F1: Tests of both fresh and salt water as diluent and the development of zinc chloride to prevent salt deposition.

F2: Tests of zinc chloride under running conditions and improvements to the design of the turbine unit and depth gear.

F3: Final design based on the experience gained with the two previous types.

750 Hp Unit

Yokosuka Naval Arsenal designed this unit making it suitable for a 21" torpedo.

Design

The turbine design was a velocity compound, three-stage, Curtis type having two rows of moving blades mounted on a single disc with a fixed row in between. The center-line was offset from that of the torpedo, the rotor being placed in the top half of the afterbody.

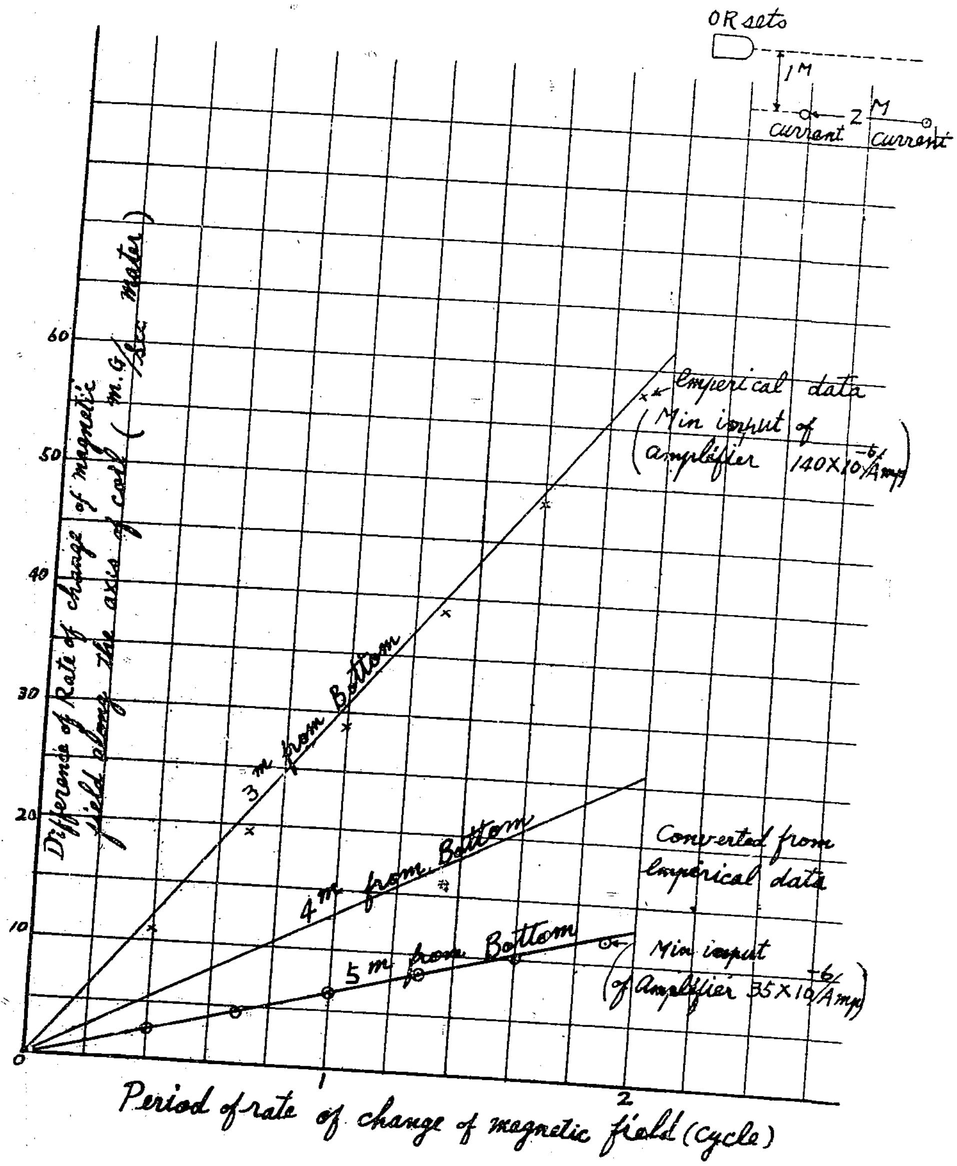


FIGURE 156
RATE OF CHANGE DIAGRAM

The combustion manifold was circular in cross-section having a diameter of 30mm (1.18"). The turbine nozzles were screwed into the discharge side of the manifold. The exhaust manifold was similar in shape at the top but had a larger diameter. At the bottom the section changed to form an exhaust chamber which was connected to the exhaust casing of the propeller shafts.

The rotor shaft was mounted on two ball bearings and carried a small pinion wheel which meshed with an intermediate wheel forming the first reduction gear. To the after end of the intermediate wheel was keyed the pinion for the second reduction, which meshed with the pinion on the propeller shaft.

The gear box shafts were mounted on ball bearings.

The drive for the auxiliaries was situated at the forward end of the propeller shaft. From this gear the sea water pump for cooling and the lubricating oil pump were driven. They were placed in the lower half of the afterbody below the turbine.

Since 100% oxygen gives practically superheated steam, a standard turbine design was suitable and was used. The unit was designed by the torpedo development section after studying turbine design with ship designers. This course was adopted because the turbine for a torpedo is simple from the point of view of the ship designer, i.e. low efficiency and short life whilst the torpedo control problems are much more complex.

For tests at YOKOSUKA, air was used because steam, at sufficiently high pressure and temperature, was not obtainable at that time. Kerosene was used as fuel and fresh water as the diluent.

In 1936, the unit was taken to the Kure Naval Arsenal and the development carried on using 100% oxygen.

Testing Equipment

To carry out the tests on oxygen a special testing equipment was necessary. A steel plate 2" thick surrounded on three sides the tank in which the power unit, oxygen, and fuel vessels, were submerged. A similar thickness of steel formed the top cover. The dynamometer was mounted at one end of the tank outside the protective plating, the shaft being led through it. Controls and connections for the recorders were taken through the side.

Pressure and temperature measurements were made in the inlet and exhaust manifolds and were recorded on recording gauges. It was stated that the turbulence in the generator was much better than that in the generator of the standard reciprocating engine so that the gas temperature was uniform and of the order of 500-600°C. The thermocouples therefore were not damaged. Two units were wrecked in the course of the testing.

Results of Tests

It was found that the exhaust pressure must be as low as possible to obtain the required output (750 hp). The unit was therefore redesigned with an extremely large exhaust passage.

The performance was stated to be:

Length of run	15 min (using special vessel)
Horsepower	750
RPM	
Rotor	18,000
Propeller shaft	1,600
Oxygen consumption	5.28 lbs/BHP/hr

This consumption is slightly worse than that of the engine of the Type 93 torpedo. The generator was found to be too small so a second one was added during the course of the trials. The two generators were the same and were connected together by a T-piece at the engine inlet.

Ball bearings were used in the first instance but were not found to stand the high temperature involved. The design was finalized by using plain bearings for the rotor shaft and ball bearings for the shafts of the gear box and the propellers.

Type F1

The Type F1 torpedo was designed with a diameter of 24" to carry fresh water for the diluent in the balance chamber.

The design of the turbine was similar to that of the 750 hp unit except that it was larger in size to give 1000 hp and had taper roller bearings for the rotor spindle. Although the tests were mainly satisfactory, trouble was experienced with the taper bearings. It was evident that no known form of bearings would function satisfactorily under the loads resulting from the side thrust from the gear teeth.

Use of Zinc Chloride to Prevent Deposition of Salt

To prevent the blocking of nozzles with salt, Prof. AOKI (Precision Engineering Department, Tokyo University) in 1939 suggested the use of zinc chloride or magnesium chloride. These materials lower the melting point of sodium chloride to such a degree that crystallization of the latter in the nozzles of the turbine is prevented, even though the temperature may be far below the melting point of pure sodium chloride (M.P. 792°C).

Admiral NARUSE carried out experiments on the lines suggested above. In a series of experiments he investigated the effect of introducting a solution of zinc chloride into the generator at different points--through head, through wall, and into the connection between the generator and turbine. NARUSE found that injection of zinc chloride solution just before the induction ring proved the most effective.

Similar experiments were conducted using magnesium chloride solution.

Results: The experiments showed that the deposition of salt in the nozzles could be prevented by regulating the concentration and proportion of zinc chloride solution used.

The disadvantages of the method lie in the fact that both zinc chloride and magnesium chloride decompose, leaving a deposit of the oxide in the nozzle. In the case of zinc chloride, the deposit is less than 1mm thick after one run and is not considered serious. It is cleaned off by scraping with sand paper after each run. Melting point of zinc chloride is 262°C.

Magnesium chloride, however, is unstable and decomposes rapidly above 186°C and, therefore, the oxide deposit is much larger in this case. A secondary disadvantage is the low solubility of magnesium chloride (54 parts in 100 parts of water at 15°C) in water. This necessitates the use of large quantities of water (with resultant cooling of combustion gases) in order to introduce the calculated quantity of magnesium chloride. For these reasons the experiments with the latter were discontinued.

Zinc chloride is used in an aqueous solution of 65% concentration. (Solubility of $ZnCl_2$ is 330 parts in 100 parts of water at 10°C.)

Ratio $\frac{\text{Diluent water to generator}}{\text{Zinc chloride solution}} = \frac{15 \rightarrow 18}{1}$

This proportion of zinc chloride depresses the melting point of sodium chloride to the region of 240°C, according to HORI. The proportion is not critical since excess $ZnCl_2$ will melt at 262°C.

The zinc chloride solution is pumped from two storage tanks to the point of injection by a two-cylinder 400 RPM reciprocating pump. No buffer chamber or other smoothing device was used to make the flow uniform.

Type F2

The design of the Type F2 torpedo included a two-cylinder reciprocating pump for the zinc chloride together with the zinc chloride bottles. In addition, modifications were made in the gearing design to overcome the side thrust from the gear wheel teeth. A second train of intermediate gear wheels was introduced diammetrically opposite the first as shown in Figure 157. Two plain bearings were also used for the rotor shaft.

Range tests indicated that the zinc chloride was effective in preventing salt deposition but that zinc oxide was deposited instead and had to be removed after each run.

The second train of gear wheels overcame the defects in the rotor shaft and a torpedo speed of 50 knots was obtained. The running of the torpedo at this speed was stabilized by a slight improvement to the Type 93 depth gear. The weight of the pendulum was increased from 8 kg to 10 kg so that the depth gear mechanism operated when the angle of inclination of torpedo was reduced from 1° to 50'.

The reason given for the modification of the depth gear was that while it was satisfactory for the Type 93, the F2 was a heavier and shorter torpedo and therefore less stable.

The development of the F2 was stopped for two reasons: (1) there was a shortage of manpower, and (2) Type F3 had been completed.

Type F3

The Type F3 torpedo was designed on the basis of experience gained on Types F1 and F2 and with the object of cleaning up the general arrangements. (See Figure 158.)

The leading particulars were as undernoted:

General

Diameter	61 cm (24")
Length	8.550 m (336.6")
Weight	2.7 tons (6048 lbs)
Length of head	1.450 m (57.08")
Weight of explosive	500 kg (1100 lbs)

Performance

Speed	60 knots
Range	8,000 meters (8755 yds)
Depth	6 meters (19.6 ft)

This range was a calculated one. In practice the type F3 was run to 3,000 meters. The speed was measured by a recorder.

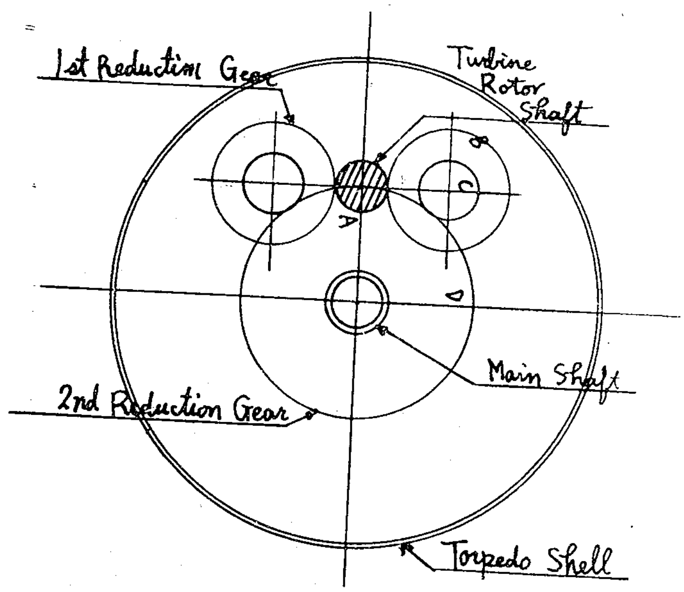


FIGURE 157
REDUCTION GEAR SYSTEM, TURBINE TORPEDOES

Turbine (See Figure 159)

Inlet pressure		40 kg/cm^2 (568 lbs/in^2)
Output		1,000 hp
RPM	Rotor	17,500
	Propellers	1.650
Oxygen consumption		5.28 lbs/BHP/hr
Oxygen/fuel ratio		3.0
Water/fuel ratio		7.0
Gas inlet temperature		550°C.

Oxygen-fuel ratio: The figure 3.0 is slightly greater than that of the Type 93 torpedo and may be explained by the fact that the better mixing of gases in the generator gives more complete combustion of oxygen. Thus, less 'overfuelling' is required.

Water-fuel ratio: This is less than that of the Type 93. The following reasons may be put forward for this fact:

(1) Two generators are used in Type F and therefore the gases reaching the turbine are more completely mixed. Thus, the cooling effect due to latent heat of diluent water is more fully used, since more complete evaporation takes place.
(2) The heat losses from the pipe leading from the twin generators to the turbine, are a cooling factor which is not present in Type 93 to the same degree.
(3) The flame from twin generators in Type F has greater difficulty in reaching the engine.
(4) The injection of zinc chloride solution causes further cooling.

Performance

The efficiency of the torpedo turbine was stated to be lower than that of

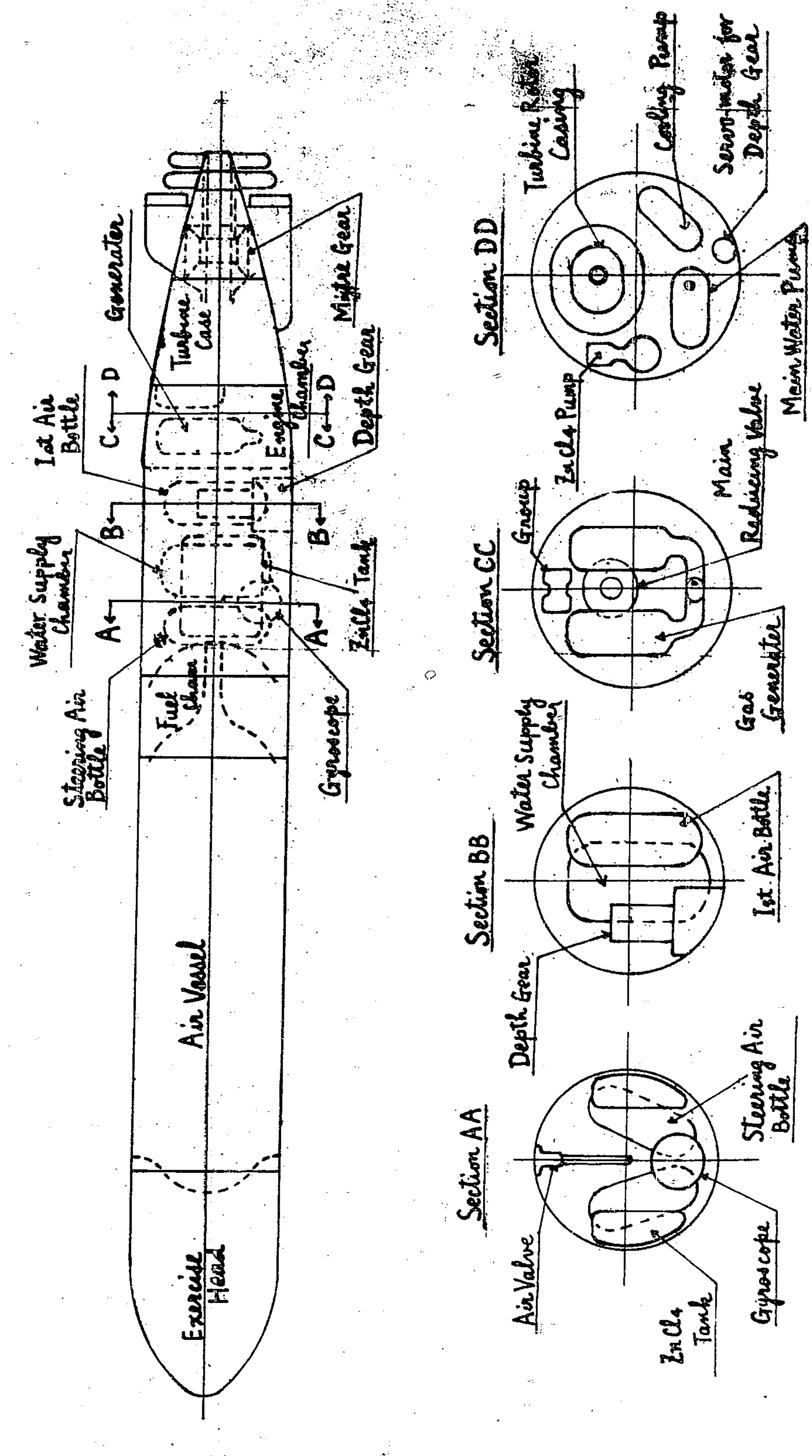


FIGURE 158
GENERAL VIEW OF TURBINE TORPEDO, F 3

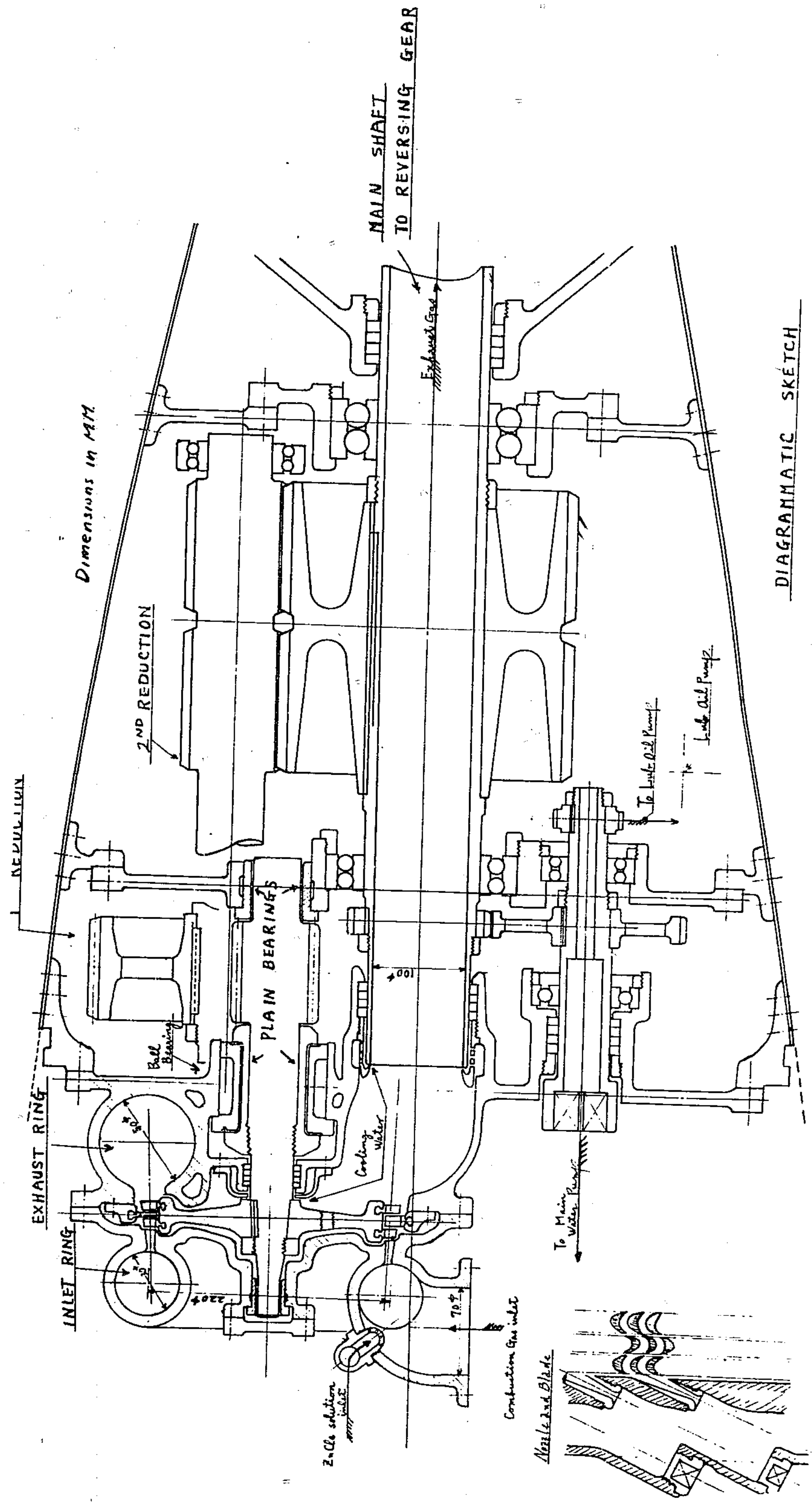


FIGURE 159
POWER UNIT TURBINE TORPEDO, F 3

the steam turbine because of the presence of drops of water in the steam due to incomplete evaporation. The water very soon erodes the edges of blades.

On the other hand it was stated that the fluid consumption was nearly as good as that of the torpedo reciprocating engine because the drop in thermal efficiency was counter-balanced by the greater mechanical efficiency of the turbine.

Design

Forebody

Oxygen vessel

Volume	750 liters (26.5 ft^3)
Pressure	215 kg/cm^2 (4730 lbs/in^2)
Charge	100% oxygen

Fuel vessel

Volume	60 liters (2.12 ft^3)
Weight of fuel	108.2 lbs

Balance chamber

Steering air bottles	2
Starting air vessel	1
Zinc chloride bottles	2
Water bottle	For priming sea water diluent pump.
Depth gear	Similar to F2
Gyroscope	Standard F type
Oxygen, fuel and water valves	

Afterbody

Group	Standard design
Reducer	Single-stage diaphragm type controlled by an ordinary small two-stage reducer. (See Figure 161).
Generator	Twin type connected together at the engine inlet
Igniters	Two per generator
Turbine	Velocity compound, 3-stage, Curtis type steam turbine
Nozzles	Seven, 10.5mm (0.413 in) diameter, 20° angle
Rotor dia.	220mm (8.66")
Blades	80 per row Rotor-2 rows Stator-1 row

Reduction gear ratio 10.6:1

The rotor has three plain white metal-lined bearings. Particular care is taken in the cooling of the rotor shaft. The bearings are water-cooled from the pump at a pressure of 5-6 kg/cm^2 (85 lbs/in^2); this supply is bifurcated to cool the end bearings at the main shaft; watertight packing rings being used.

The critical speed as designed was very high, over 50,000 RPM. It was stated that in a future design only two bearings would be used to get simplicity. This modification would lower the critical speed below the running speed. This was not considered serious in practice.

The rotor is keyed to the shaft, the blades being attached by the normal method used in steam practice. In a future design the rotor and shaft would be made integral.

It was said that the gyroscopic effect of the rotor was not noticeable.

Two holes are drilled in the rotor disc to balance the pressure on each side.

Weight	Rotor	10 kg (22 lbs)
	Turbine and gear box	400 kg (880 lbs)
	Twin generator	40 kg (88 lbs)
	These are only approximate.	

Materials	Rotor disc)	Nickel-chrome steel to the same
	Rotor shaft)	specification as the oxygen vessel.
	Gears)	
	Blades	18% chromium, 8% nickel steel.
	Inlet casing	Standard phosphor-bronze casting.
	Exhaust casing	"SILZIN" bronze casting.

Governor: The water flap (See Figure 160) was used to control the oxygen supply to the generator and thus govern the turbine speed. It operated the spindle of the two-stage reducer supplying oxygen to the lower side of the diaphragm.

When the flap moved forward, the oxygen in the lead from the controlling reducer to the main reducer was released to atmosphere. The diaphragm of the main reducer was unbalanced and the reducer closed. By the design the oxygen supply was cut off completely, in practice a small leak occurred which together with the oxygen remaining in the system kept the generator all right for the duration of the break surface.

Pumps: Both sea water pumps are of the gear type, the diluent pump delivering against a pressure of 50 kg/cm^2 (710 lbs/in^2) with an output of 300 liters/min (10.6 ft^3/min) and the cooling pump which works at 10 kg/cm^2 (142 lbs/in^2) with a delivery of 200 liters/min (7.1 ft^3/min).

The former pressure is unusually high for a gear pump. It was stated that its efficiency was low.

The zinc chloride pump, two-cylinder, double-acting, has a delivery pressure of 45 kg/cm^2 (639 lbs/in^2) and an output of 15 liters/min (4.25 ft^3/min).

The lubricating oil pump is of the gear type and is immersed in the oil pump; it lubricates all the power unit parts. The oil is slightly heavier than the standard turbine oil and is cooled by contact with sea water through the afterbody shell.

Afterbody Shell and Propellers

The afterbody shell forms part of the reduction gear casing, the lower portion of which forms the lubricating oil storage chamber. The gear wheels are keyed to their shafts. Splining would have been preferred but the machine shops were not able to produce it.

As a result of general propeller trials the shape of the four blades of the propellers for the F3 torpedo were modified as undernoted:

(1) Variable pitch decreasing near the tip.
(2) Wider blade with 30-40% increase in area.
(3) Single arc section.

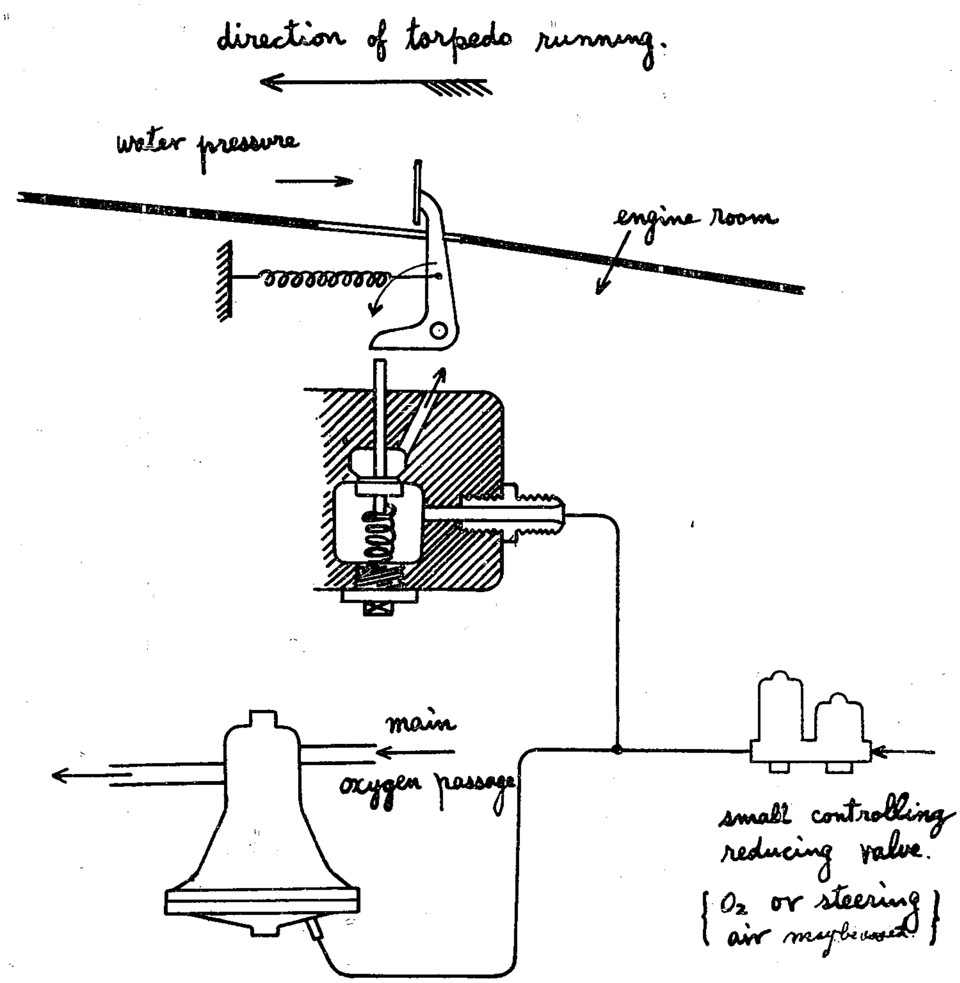


FIGURE 160
GOVERNOR TURBINE TORPEDO, F 3

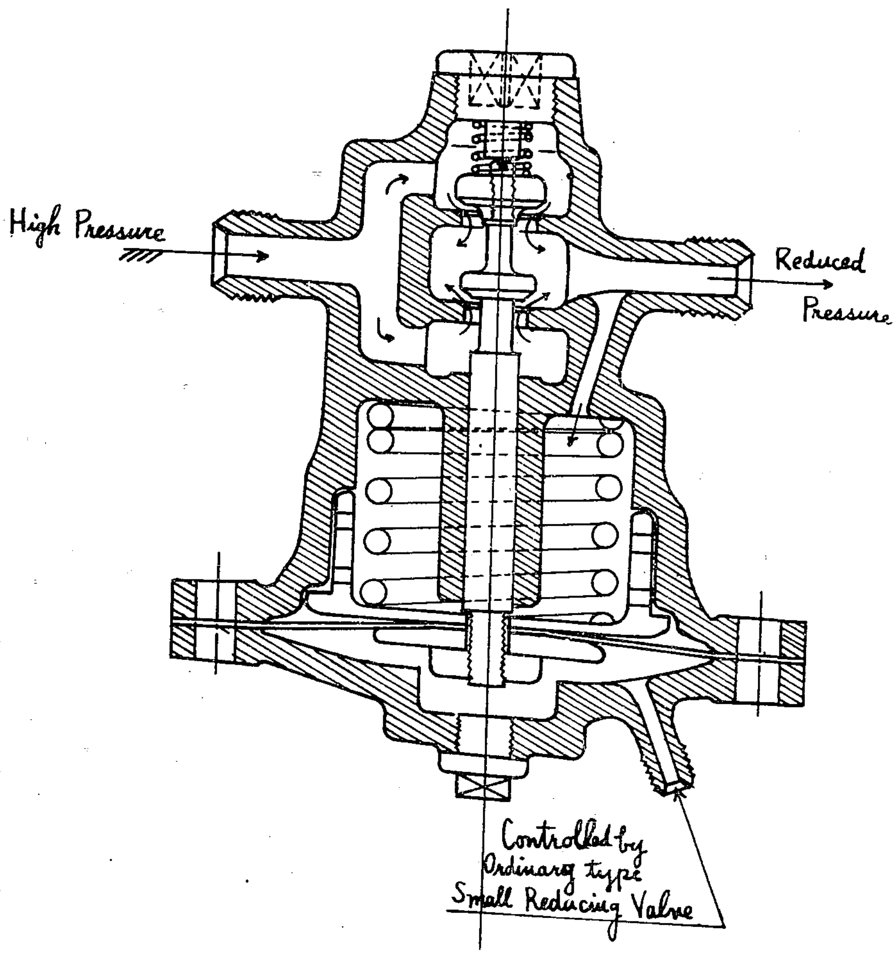


FIGURE 161
MAIN REDUCER, TURBINE TORPEDO. F 3

Conclusion of Experiments

In all, running in the sea consisted of:

Type F1	15 runs
F2	20 runs
F3	40 runs

The tests were considered to be a failure for two reasons:

(1) Difficulty in preventing break surface. Even if the governor shut off the power correctly, the time lag in picking up afterwards was such that the torpedo could not recover its depth without the rudders being again locked.

(2) The Naval Staff now considered that the original requirement of 8000 meters at 60 knots was too short. In addition, the Staff needed a low-speed setting of 40 knots with a range of over 30,000 meters.

It was not possible to meet these demands, particularly as to the low-speed setting, due to the mechanical complexity (a change-speed gear box connected to the reducer being necessary, as well as adjustments to the turbine nozzles).

For these two reasons the turbine development was dropped and the development of Type 93, Model 2 torpedo was undertaken.

Early I.C. Engine Experiments

Over 15 years ago, before the development of the oxygen torpedo, when the Naval Staff produced a requirement for a long-range torpedo, a proposal was put forward for a torpedo powered by an internal combustion engine.

The torpedo was designed at Nagasaki Heiki by the engineering staff (principal H.O. INOUE, Doctor of Engineering).

Principal characteristics:

Diameter	61 cm (24.03 in)	
Length	8.5 meters (334.9 in)	
Weight	2500 kg (5500 lbs)	
Speed (knots)	26	38
Range (meters)	51,000	20,000
(yards)	55,794	21,880

Power Unit·

This was a specially designed four-cycle, six-cylinder, vertical, in-line engine, which operated on alcohol:

Horsepower	250
RPM	2300
Propeller RPM	1020

The engine started on special fuel (petrol) and ran on ethyl alcohol.

Starting System

Compressed air with a special distributor

Ignition System

High tension magneto - sparking plugs 18mm standard lodge

Carburation

Solid injection and hot spot

Cylinder Cooling

Forced circulating system using sea water

Valves

Cylinder - poppet
Exhaust - rotary

The experimental tests in NAGASAKI were comparatively successful but the ignition system was not reliable, and the development work was therefore given up.

Nitric Acid Research

The use of nitric acid for rocket propulsion was proposed by Professor T. OKUNO of Kyushu Imperial University, toward the end of 1944. Research work was undertaken at this university under the auspices of OKUNO and his assistant, W. SAKAI. Parallel work was carried out at the same time at Nagasaki Heiki K.K.

Concentrated nitric acid (90% - 98%), often referred to as "A" liquid was used for the experiments. For "fuel" or "B" liquid, as it was called, methyl alcohol (CH_3OH) was used. The alcohol was saturated with ammonia gas (NH_3) or with a mixture of ammonia and hydrogen sulphide (H_2S).

Initial experiments were made using nitric acid and methyl alcohol saturated with ammonia and hydrogen sulphide. It was found that the latter promoted a vigorous reaction.

"A" Liquid

Specific gravity	1.498
Concentration	93%

"B" Liquid

Specific gravity (9°C)	0.876
Composition by weight	
H_2S	20.4%
NH_3	27.0%
CH_3OH	52.6%

Catalyst

Metallic copper was found to be an efficient catalyst in promoting a rapid reaction. It was best used as a powder and, in experiments, it was mixed with coal tar and smeared on the inside of the skirt around the nozzle. Copper plate and copper electroplating were not as good catalysts as the powder.

Combustion Experiment

Using the "A" and "B" reactants described above, a combustion experiment was made and the products of combustion were exhausted through a venturi. A mild steel container, passivated by the nitric acid, was suitable for "A" liquid. The reactants were fed with compressed air to a nozzle similar to that used in KAITEN 2. The duration of the experiment was 25 seconds. Results are shown below:

All the pressures are in kg/cm^2 units.

Time (secs)	5	10	15	20	25
Pressure of supply	20.5	21.5	21.5	21.5	20.5
Pressure in "A" bottle, P_1	18	20.5	21	21	19
Pressure of "A" liquid at nozzle inlet, P_2	15.3	17.8	18.3	18.3	16.3
Pressure in "B" bottle, P_3	19.5	21	21	21	19.8
Pressure of "B" liquid at nozzle inlet, P_4	16.6	18.1	18.2	18.1	16.9
Pressure of combustion chamber, P	14.5	14.7	14	14	2.5
$P_2 - P$	0.8	3.1	4.3	4.3	13.8
$P_4 - P$	2.1	3.4	4.2	4.1	14.4
Pressure in venturi	7	8.5	8.0	8.2	3
Thrust (kg)	112	136	128	132	50
Calculated temp. of exhaust (°C)	1200	> 1600	>1600	>1600	>1600

Combustion Chamber

Diameter	175mm
Length	600mm

Consumptions

"A"		0.488 kg/sec
"B"		0.211 kg/sec
"A" + "B"		0.699 kg/sec
"A"/"B" ratio	(1) by weight	2.32
	(2) by volume	1.35
Maximum thrust		136 kg

Max. thrust/kg/sec liquid reactant $= \frac{136}{0.699} = 195$

Under similar conditions, hydrogen peroxide is said to give a thrust of 180 kg per kg/sec of liquid reactant.

During the experiment a very high temperature was attained, and after 15 seconds running the narrow section of the venturi melted.

Generator Experiments

Combustion experiments were carried out using a generator similar to KAITEN 2.

"A"/"B"/Water ratio = 1.0/0.435/1.8.

In this experiment the temperature of exhaust gases was 1000°C.

Owing to the corrosive nature of the sulphur acids formed from the sulphuretted hydrogen, this material was later dispensed with. Then "B" liquid consisted of CH_3OH saturated with NH_3. It was found that copper powder was sufficiently effective to promote a good reaction, even in the absence of H_2S.

Further Experiments at KYUSHU

The experiments at Kyushu University were of rather an academic and fundamental nature. No horsepower measurements were made, and many of the observations were of the qualitative kind.

Work on the effect of the concentrations of the nitric acid and methyl alcohol on combustion was done. The complex crystalline compounds precipitated on the saturation of methyl alcohol with NH_3 and H_2S were investigated. Experiments to discover the combustion limits of nitric acid with mixtures of CH_3OH, NH_3 and water were also undertaken.

JAPANESE TORPEDO PRODUCTION

Manufacture

The main Japanese ship torpedo manufacture was centered in six naval arsenals and one civilian firm, with assistance from three major private subcontractors and numerous small-parts manufacturers. Major produceers and subcontractors of modern torpedoes are shown below:

Location (See Figure 162)	Torpedo Type	Details
Yokosuka Arsenal	18" Type 02	Manufacture of complete torpedoes, less warheads, fuzes, igniters, and gyroscopes.
Kure Arsenal	24" Type 93 18" Type 02 18" Types 97 & 98 (before war)	
Sasebo Arsenal	24" Type 93	
Maizuru Arsenal	18" Type 02	
Hikari Arsenal	21" Type 95	Complete torpedoes except explosives and igniters.
Kawatana Arsenal	21" Type 95	Complete torpedoes except explosives and igniters.
Nagasaki Heiki Co.	21" Type 95	Complete torpedoes except explosives and igniters.

(All the above establishments assembled complete torpedoes and ranged them.)

Aichi Heiki Kyushu Heiki	Afterbody sub-assemblies only for the above types of torpedoes including engines	Subcontractors for the above Navy Arsenal; not direct order from Navy Department.
Matsuyama Heiki	18" engines	

In addition to the above named producers, many other naval and private establishments were engaged in production of individual parts and smaller sub-assemblies for the use of the major plants. This production is shown below:

Detail	Torpedo	Controlled Firm
Explosive and detonators	All types	Third Naval Explosive Factory, MAIZURU
Pistol	All types	MITSUE SEIKI, TOKYO SASEBO Arsenal
Heads	All types	AICHI HEIKI, MAIZURU
Oxygen vessels raw material	24",21" & 18"	KURE Arsenal NIHON SEIKO, MURORAN SUMITO SEIKO, OSAKA
Small Hp vessels	Many types	SUMITO SEIKO, OSAKA
A.R. copper tube (used instead of copper about 1941)	Many types	SUMITO SEIKO, OSAKA
Stainless steel castings	Many types	SUMITO SEIKO, OSAKA
Low pressure castings		TEIKOKU TOKUSHU CHUKO (Imperial Special Foundry)
Propeller material	Many types	SUMITO SEIKO, OSAKA
Drop forging-materials	Many types	KOA SEIKI, OSAKA
HP valves		RIKEN KOGYO, OSAKA NIHON TANKO, AMAGASAKI MEIJI KIKAI, TOTTORI

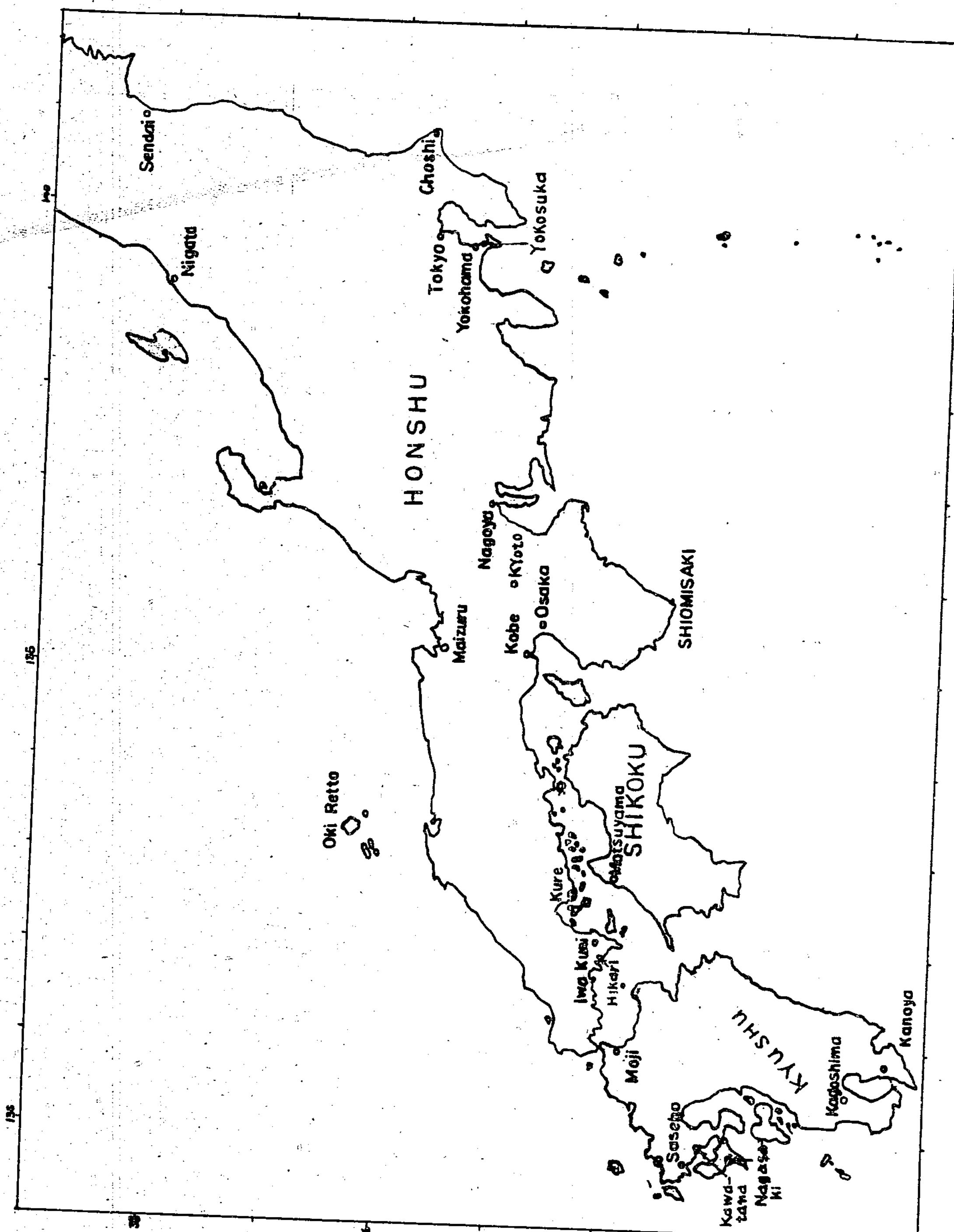


FIGURE 162
MAP OF SOUTHERN JAPAN

Detail	Torpedo	Controlled Firm
Depth gear	Many types	AMANO SEISAKUSHO, KAWASAKI MITSUI SEIKI, TOKYO
Gyroscopes	Many types	RIKEN KOGYO, NIIGATA MITSUI SEIKI, TOKYO
Oil and water pumps	Many types	SHIMAZU SEISAKUS YO, KYOTO
Oil distributor	Many types	SHIMAZU SEISAKUS YO, KYOTO
Reducer	Many types	TOKYO RIKA, TOKYO
Forebody details, shell, ribs, oil bottle	24" KURE, SASEBO	TSUYOSHI SEISAKUSHO, EHIME
	24") 21") KURE	AICHI, NAGOYA
	18"	MATSUYAMA HEIKI, EHIME
Engine	21"	ISHIBASHI JUKO, SHIMANE MATSUBARA TESS TUKO, OSAKA
Propellers	All types	KURE, SASEBO

Output

Some data on the number of torpedoes produced from 1931 - 1945 were obtained from the U.S. Strategic Bomb Survey. No differentiation appeared to have been made between the types of the various diameters so Figure 163 gives only the total production and cannot be split into types, except in the case of the 18" Type 02. From the curve it is clear how small the numbers were - quite inadequate for the services for which they were intended.

Drawings

All Japanese engineers work to a Japanese system called Japanese Engineering System for tolerances ("JES").

In torpedo drawings it is the practice to:

(1) Run together a number of sections to show the functioning of the part.
(2) Not to employ any hatching.

Machine Shop Facilities

No modern machine tools were available. Grinding was employed where required on details except large pressure vessels; these were turned with tungsten-tipped tools. Thread grinding was used for the bevel gears of the engine shafting.

Hand fitting was employed and there was no mass production in the European sense.

Engineer officers inspected production, and plant executive officers supervised ranging. All were subject to orders from the chief production manager.

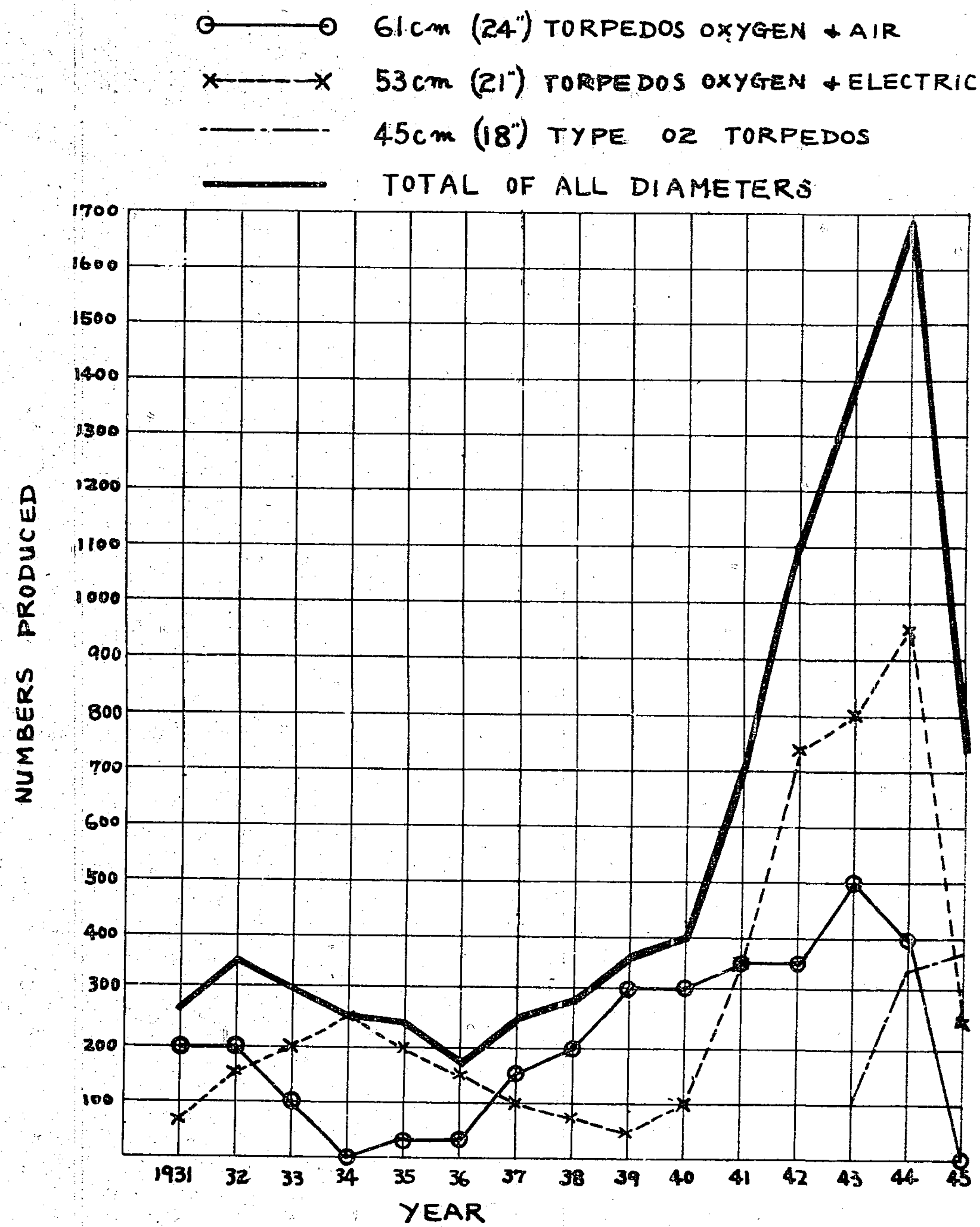


FIGURE 163
OUTPUT CURVES

[illegible] as [illegible] eight-cylinder, two-bank, vertical [illegible]

Bore	[illegible] ([illegible] ins)
Stroke	[illegible]mm ([illegible] ins)
Output	[illegible]
RPM	[illegible]
State of Development	Under development - two made.

Type [illegible]

Construction:	Specially designed
Power Unit:	Oxygen, wet heater, sea water as diluent. The same eight-cylinder, two-bank, vertical engine as in Type 2.
State of Development	Under development - about 50 made.

Type 10

Construction:	Pilot's cockpit and two external air vessels for controls added to the Type 92 electric torpedo.
Power Unit:	Electric motor and batteries. Propelling mechanism of Type 92 used.
State of Development:	Under development - about six.

Dimensions and Performance

		Type 1	Type 1 Mod. 1	Type 2	Type 4	Type 10
Diameter	cm	100	100	135	135	[illegible]
	ft	3.05	3.05	4.12	4.12	[illegible]
Length	cm	1450	1474	1650	1650	900
	ft	45	45	50.32	50.32	[illegible]
Wt. of explosive	kg	1550	1550	1550	1800	300
	lbs	3410	3410	3300	3960	600
Performance						
(1) Speed	kt	12	12	20	20	7
Range	m	78,000	78,000	[illegible]	62,000	35,000
	yds	85,332	85,332	[illegible]	67,828	38,290
(2) Speed	kt	20	20	24	30	
Range	m	43,000	43,000	50,000	[illegible]	38,000
	yds	47,042	47,042	54,700	41,572	
(3) Speed	kt	30	30	40	40	
Range	m	23,000	23,000	25,000	27,000	
	yds	25.162	25,162	27,350	29,538	
Total weight	kg	8,000	8,300	18,370	18,170	3,050
	tons	8.05	8.17	18.08	17.87	3.0

KAITEN Type 1 and Type 1 Modification 1

Particulars

Additional particulars of KAITEN Type 1 are as follows (See Figure 164):

			Type 1	Type 1 Modification 1
Date of Production			1944	1945
Number Produced			100	230
Reserve Buoyancy		kg	100	100
		lbs	220	220
Trim			level	level
Oxygen Vessels	Volume	liters	1550	1550
		ft^3	54.76	54.76
	Weight	kg	1076	1076
		lbs	2367.2	2367.2
	Weight of charge	kg	435	435
		lbs	957	957

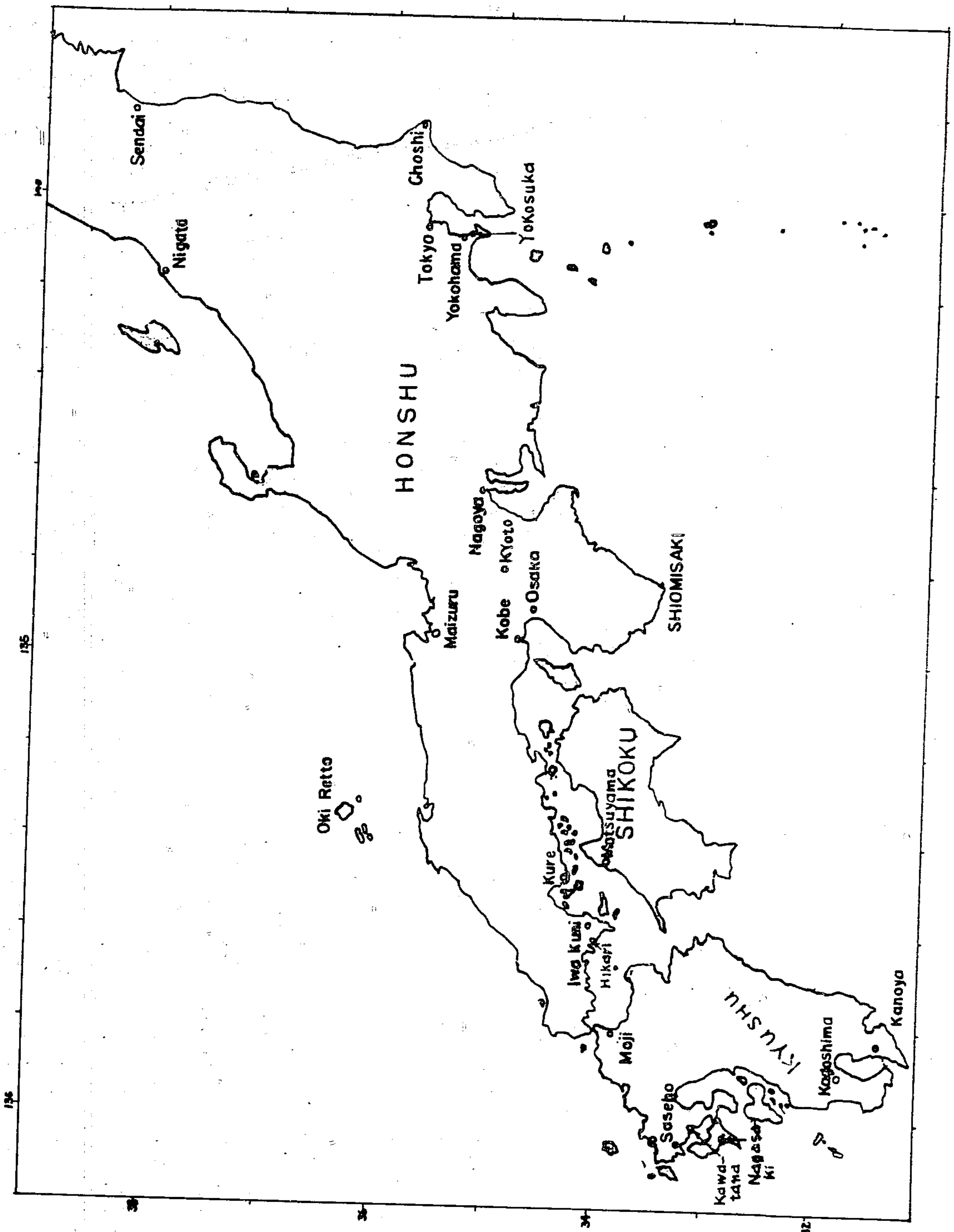


FIGURE 162
MAP OF SOUTHERN JAPAN

Detail	Torpedo	Controlled Firm
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Oil distributor	Many types	SHIMAZU SEISAKUS YO, KYOTO
Reducer	Many types	TOKYO RIKA, TOKYO
Forebody details, shell, ribs, oil bottle	24" KURE, SASEBO	TSUYOSHI SEISAKUSHO, EHIME
	24") 21") KURE	AICHI, NAGOYA
	18"	MATSUYAMA HEIKI, EHIME
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Propellers	All types	KURE, SASEBO

Output

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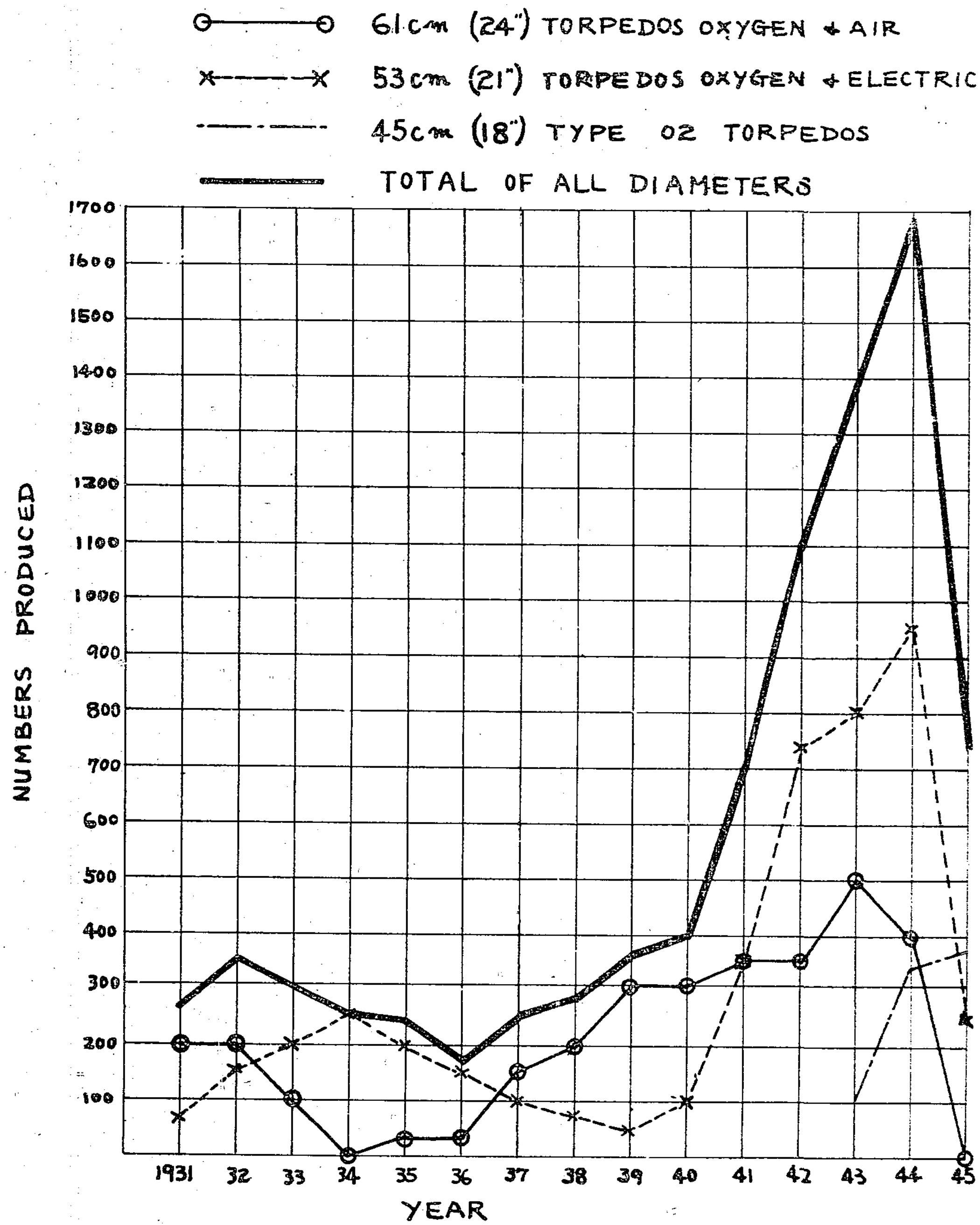


FIGURE 163
OUTPUT CURVES

KAITEN TORPEDOES

(See NavTechJap Report, "Japanese Suicide Craft", Index S-02.)

General Particulars

The KAITEN or "human torpedo" derives its name for Kaiten igyo which means "a great undertaking."

In view of the unfavorable trend of the war in 1943 from a Japanese point of view, suggestions were put forward for the use of a "human torpedo" in an effort to restore Japan's waning fortunes. At first the suggestions were disregarded by the Japanese Naval Staff, but it was later agreed that experiments should be undertaken. Research began in January 1944.

In June 1944, the first model of the KAITEN (essentially Type 93, Mod. 3 torpedo, without the warhead) was built. The Type 93 fitted into the after end of the shell of the KAITEN, which was one meter in diameter. The gyro was replaced by an electric gyro fitted in the pilot's cockpit in which speed and depth controls also were fitted.

This first experimental model was not fitted with a forward A.V., and preliminary trials were run without a pilot and with ballast in place of forward A.V.

Weight of model	8000 kg
Positive buoyancy	3000 kg
Trim	Even

Diving trials were carried out using rudders only, but it was found that recovery was too sharp due to large positive buoyancy. The latter was reduced to 100 kg and a running angle of 1-3° nose-down was used.

When travelling on the surface, the pilot's vision became obstructed with spray. To obviate this difficulty, a requirement for a surface speed of less than five knots was put forward. For a speed of five knots the reducer pressure is 3 kg/cm^2 and this is considered the minimum pressure which is consistent with smooth running. Thus five knots is the minimum speed attainable with engine running.

Cruising speed	12 knots
Other speeds	20 knots
	30 knots

Transport of KAITEN

The KAITEN is conveyed to an attack position by:

(1) Submarine
(2) Cruiser or destroyer (never actually used)
(3) Land transport

The following classes of submarines carried KAITEN:

I - 363, 366, 367	5 KAITEN
I - 36, 47, 53, 58	6 KAITEN (formerly 4)
I - 156, 157, 158, 162	2 KAITEN

The KAITEN is fastened to the deck of the submarine with a clamp ring and rests on wooden blocks. A tube, large enough for the passage of the pilot from the submarine to the KAITEN, connects the submarine with a hatch in the bottom of the KAITEN.

Before the pilot enters the KAITEN, the first liquid bottle is charged and the cockpit blown through from the submarine to remove residual fumes of carbon tetrachloride. The pilot then enters through the communicating tube, and the submarine which is at periscope depth (about 9 meters) gives the pilot final instructions regarding target, speed, course, etc, by telephone. The navigator of the submarine informs the pilot of the course which he should follow to intercept the target.

The KAITEN is released from the submarine. If the KAITEN is forward of the conning tower the pilot starts his engines before release to avoid being fouled by the submarine.

Attack Procedure

The point of release is about 6000-7000 meters from the target. The KAITEN follows the course (controlled by gyro) set by the navigator of the submarine, at six meters depth for a calculated time and then surfaces. At this point the target should be about 1000 meters distant. The pilot adjusts his course so that the KAITEN will strike the ship and then dives to the most suitable depth (consistent with ship's draft) for travelling the remaining 1000 meters. If the pilot misses his target he surfaces, changes course and makes a second attempt.

In the case of launching from land, a launching slip or ramp is used.

Types

In all there are four types, the main dimensions and performance of which are shown in the table which follows:

Type 1

Construction: Superstructure, pilot's cockpit, controls and forebody added to Type 93 torpedo.
Power Unit: Wet heater cycle using oxygen. Propelling mechanism of Type 93, Model 3 torpedo used unchanged.
State of Development: 330 production models made and used in service.

Type 2

Construction: Specially designed, based on the experience gained with Type 1.
Power Unit: Hydrogen peroxide and hydrazine hydrate, wet heater cycle, sea water as diluent. Eight-cylinder, two-bank, vertical engine.

Bore	185mm (7.29 ins)
Stroke	200mm (7.88 ins)
Output	1500 hp
RPM	750
State of Development	Under development - two made.

Type 4

Construction:	Specially designed
Power Unit:	Oxygen, wet heater, sea water as diluent. The same eight-cylinder, two-bank, vertical engine as in Type 2.
State of Development:	Under development - about 50 made.

Type 10

Construction:	Pilot's cockpit and two external air vessels for controls added to the Type 92 electric torpedo.
Power Unit:	Electric motor and batteries. Propelling mechanism of Type 92 used.
State of Development:	Under development - about six.

Dimensions and Performance

		Type 1	Type 1 Mod. 1	Type 2	Type 4	Type 10
Diameter						
cm		100	100	135	135	53
ft		3.05	3.05	4.12	4.12	1.72
Length						
cm		1450	1474	1650	1650	900
ft		45	45	50.32	50.32	29.5
Wt. of explosive						
kg		1550	1550	1550	1800	300
lbs		3410	3410	3300	3960	600
Performance						
(1) Speed	kt	12	12	20	20	7
Range	m	78,000	78,000	83,000	62,000	35,000
	yds	85,332	85,332	90,802	67,828	38,290
(2) Speed	kt	20	20	30	30	
Range	m	43,000	43,000	50,000	50,000	38,000
	yds	47,042	47,042	54,700	41,572	
(3) Speed	kt	30	30	40	40	
Range	m	23,000	23,000	25,000	27,000	
	yds	25,162	25,162	27,350	29,538	
Total weight						
	kg	8,000	8,300	18,370	18,170	3,050
	tons	8.05	8.17	18.08	17.87	3.0

KAITEN, Type 1 and Type 1 Modification 1

Particulars

Additional particulars of KAITEN Type 1 are as follows (See Figure 164):

			Type 1	Type 1 Modification 1
Date of Production			1944	1945
Number Produced			100	230
Reserve Buoyancy		kg	100	100
		lbs	220	220
Trim			level	level
Oxygen Vessels	Volume	liters	1550	1550
		ft^3	54.76	54.76
	Weight	kg	1076	1076
		lbs	2367.2	2367.2
Weight of charge		kg	435	435
		lbs	957	957

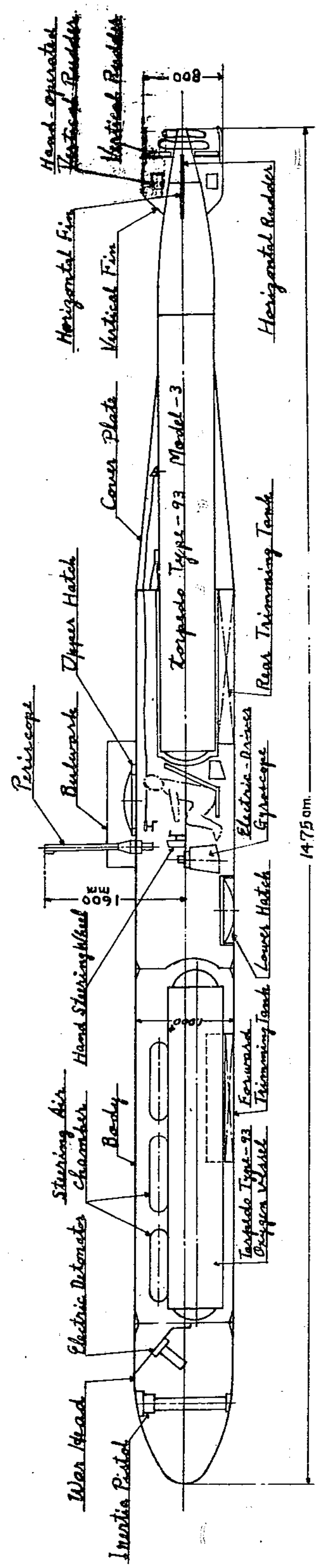


FIGURE 164
GENERAL ARRANGEMENT, KAITEN TYPE 1

Steering air	6 bottles in body 20 liters each 3 bottles in torpedoes 13.3 liters each	8 bottles in body 20 liters each
Total liters	160	160
ft^3	5.65	5.65
Trimming	2 tanks 80 liters each	4 tanks 40 liters each
Total liters	160	160
ft^3	5.65	5.65
Negative Tank liters	none	100
ft^3	none	3.53
Fuel Volume liters	196	196
ft^3	6.92	6.92
Weight lbs	3535	3535
Propulsion System		
Carbon Tetrachloride Bottles	In Torpedo	In Cockpit
Buffer Chamber Capacity-liters	5.5	5.5
in^3	335.6	335.6
Engine Type		Reciprocating, two cylinder, double-acting
Horsepower	550	550

The afterbody of a 24" Type 93, Model 3 torpedo was used. In addition the mechanism for closing the hatches was improved and the controls generally simplified in the Modification 1.

General Description

A view of the weapon is shown in Figure 165.

Head

The KAITEN was fitted with both a warhead and an exercise head having the same weight and shape. The heads are of sheet steel of welded construction and are of streamlined form. In the Type 1, Modification 1 the oxygen vessel and steering bottle ends project into the rear part of the head.

Exercise Head

The head is fitted with a buoyancy chamber of 600 liters capacity and has two blowing mechanisms:

1- Pilot operated.
2- Automatic mechanism which blows if KAITEN goes below a certain depth.

The mechanism consists of a spring-loaded hydrostatic valve, the tension on the spring being adjusted to suit the pressure.

Both mechanisms operate on the same chamber. Since the automatic mechanisms always operated too late, it was normally set to open at a pressure slightly lower than necessary. The hand control was normally used and latterly, only the hand control mechanism was fitted.

Warhead

In this instance no blowing compartment was fitted, the whole head being

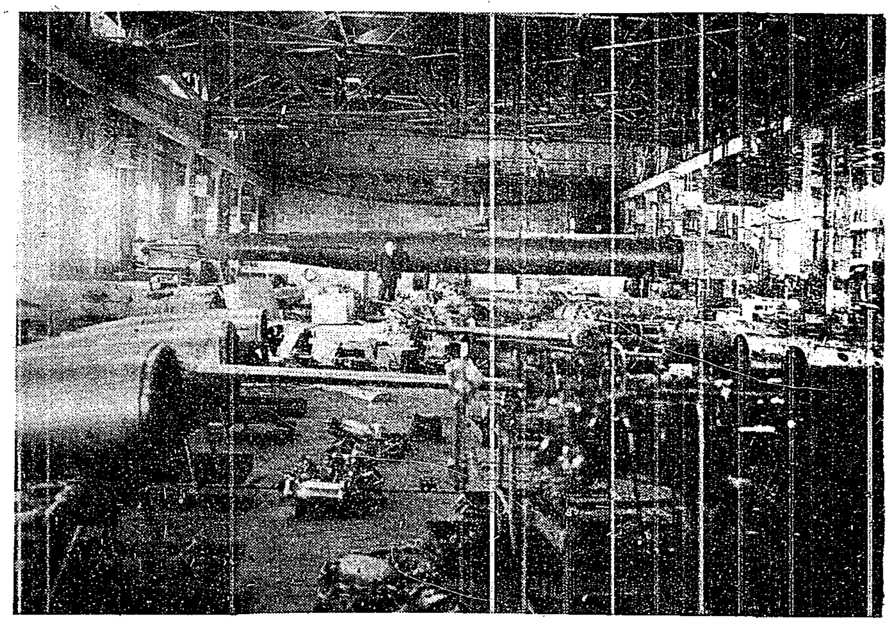


FIGURE 165
GENERAL VIEW OF KAITEN TYPE 1

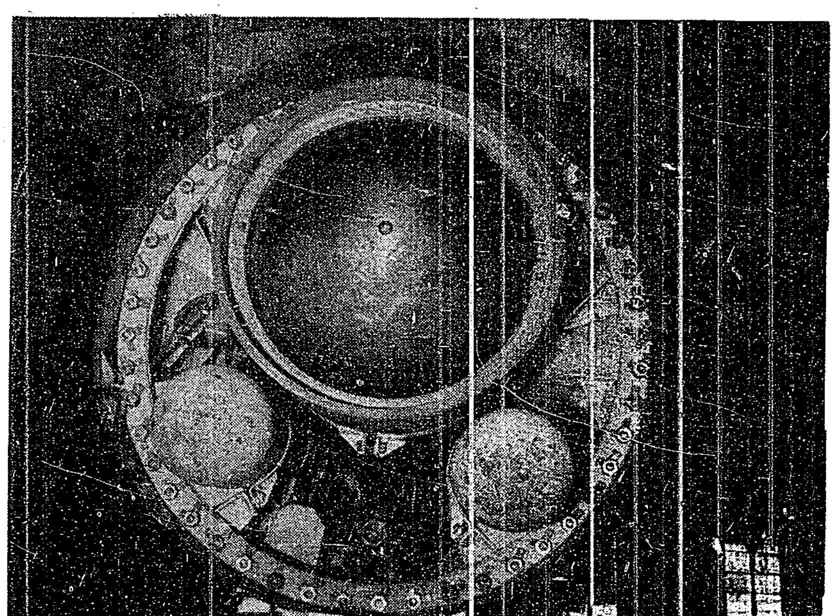


FIGURE 166
FORWARD COMPARTMENT, KAITEN TYPE 1 (END VIEW)

filled with explosive.

Two detonators were fitted, one electric (with two fuses) and one of the inertia pistol type. The two electric fuses are operated by the pilot, the inertia pistol being a larger edition of the torpedo pistol.

The release of the safety mechanism was controlled by the pilot.

Midship Section

This is made in two parts welded together.

The forward section contains the combined oxygen and fuel vessels of the Type 93. Model 3 torpedo, steering air bottle and forward trimming tanks. (See Figure 166.)

The central section is the control room and is placed between the two oxygen vessels. It contains:

- Two hatches, upper and lower
- Periscope and its elevator
- Depth gauge
- Hand steering wheel for vertical rudders
- Controls for starting, depth, speed and direction
- Electric gyroscope
- Pistol safety device release
- Firing key for detonator
- Telephone
- Batteries (12)
- Negative trimming tank (Modification 1 only)
- Sodium peroxide tin

Steering

The electric gyroscope is used as compass and will maintain the torpedo on its initial course; the pilot has control over it and can adjust the course. For emergency there are large vertical rudders which are operated independently of those of the gyroscope.

The steering air stop valve is in the pilot's cabin and is opened by the pilot. Air at 200 kg/cm^2 (2840 lbs/in^2) is admitted to the servomotor disc reducer, from which low pressure air is supplied to the steering engine by external piping. High pressure air is also supplied to the gyroscope since the disc reducers are in the casing.

Depth Control

Variation in the depth is controlled through rods and gearing by adjusting the tension on the depth gear spring. The depth is recorded on a gauge similar, but of smaller size, to that used in a submarine.

Trim Control

There are four trimming tanks, two forward and two aft, situated in the lower half of the body surrounding the oxygen vessels. Adjustment is made by admitting water.

In the Modification 1 a fifth tank is fitted in the center and is called the negative tank. This is flooded to submerge at the start of the run.

During the run the weight of the KAITEN decreases due to the drop in pressure in the vessels so that the control becomes bad and it is difficult to submerge.

By venting the tanks, water can be admitted either to one tank alone to adjust the trim or in equal quantities to one forward and one aft to maintain the trim while submerging.

An inclination gauge indicates whether the torpedo is positively or negatively buoyant, since the running angle will be up when the torpedo is negatively buoyant and vice versa.

The oxygen consumption is approximately:

1 kg/minute (14.2 lbs/in^2) at a speed of 12 knots
3 kg/minute (42.6 lbs/in^2) at a speed of 20 knots
7 kg/minute (99.4 lbs/in^2) at a speed of 30 knots

The corresponding decrease in weight is:

2 kg/minute (4.4 lbs/min) at a speed of 12 knots
6 kg/minute (13.2 lbs/min) at a speed of 20 knots
14 kg/minute (30.8 lbs/min) at a speed of 30 knots

The pilot has an indicator to show the weights of water entering the tanks.

Firing Key for Electric Detonator

This is a pistol handle which the pilot grasps. At the instant of impact his weight is thrown forward, closing the switch.

Telephone

The pilot also has a telephone which was used, when the KAITEN was carried on a submarine, to talk to the captain or navigator. It was of the standard gun turret type. There was also a set of leads for charging the batteries.

Sodium Peroxide Tin

The sodium peroxide was carried in a tin. The powder was poured into the lid of the tin and exposed to the air, where it absorbed CO_2 and gave off oxygen. It usually was used after five or six hours depending upon the sensations of the pilot.

After End

A Type 93, Model 3 torpedo minus its head is fitted into the main compartment for a distance of 172 cm. (See Figures 167 and 168.)

A steel fairing is used to get streamlining between the body and the torpedo.

Charging of the vessel with oxygen can be done from inside the pilot's control room if necessary, but normally it is charged before being assembled into the unit.

Power Unit

Starting and stopping is accomplished by a fore and aft motion of a rod connected to the tube-starting lever. No water flap is used.

The reducer setting is adjusted by a worm and wheel connected to the second reducer spindle, an extension of the shaft adjusts the water-fuel ratio, so that the correct ratio is used for each reducer setting. A special rating plug is fitted to the shell of the torpedo and the one in the generator is

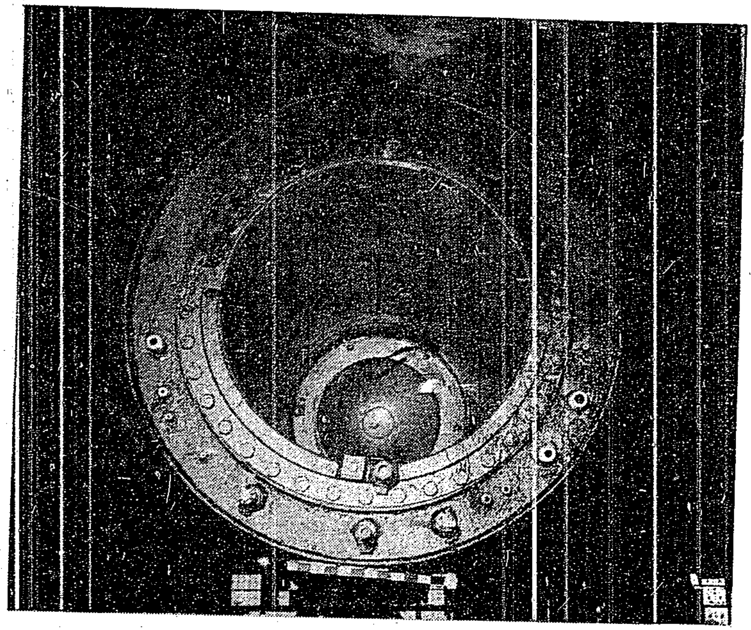


FIGURE 167
AFTER END OF MIDSHIP SECTION, KAITEN TYPE 1

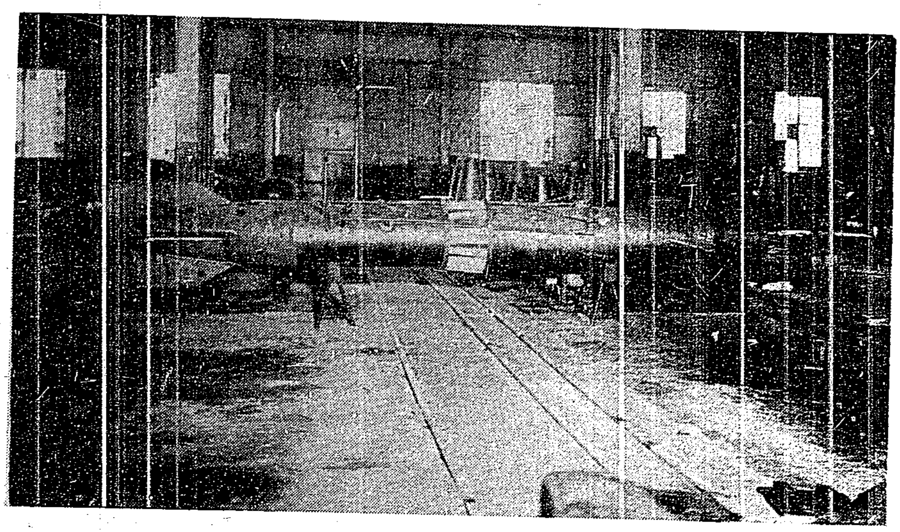


FIGURE 168
TYPE 93 TORPEDO READY FOR FITMENT TO KAITEN TYPE 1

not used.

The approximate reducer pressures are:

3 kg/cm²	(42.6 lbs/in²)	3-5 knots on surface
9 kg/cm²	(127.8 lbs/in²)	12 knots submerged
20 kg/cm²	(284 lbs/in²)	20 knots
40 kg/cm²	(568 lbs/in²)	30 knots

The maximum reducer pressure is similar to that of the Type 93, Model 3 torpedo, but the speed is 19 knots less.

Oxygen from the after vessel passes forward to the pilot's control room where a stop valve governs the supply from both vessels. Incorporated with the stop valve is the carbon tetrachloride unit. From the valve the oxygen is led to the group by an external pipe.

There are two fuel containers, connected in series. Water from the buffer chamber displaced fuel in the forward bottle first. External piping is used.

The lubricating oil system in the KAITEN is different from that in the Type 93 torpedo. The oil is displaced by sea water from outside the body. Originally a second oil bottle was fitted in the shell but it was found unnecessary since the consumption was low.

Controls

The control rods are arranged along the shell of the torpedo. They are fitted with Hooke's joints and pass through a supporting bracket, bolted to the T-shaped guide on the oxygen vessel shell. Through this bracket also passes the rods for the hand operated vertical rudder.

Fins and Rudders

The area of the fins and rudders is increased above that of the Type 93, Model 3 torpedo in proportion to the cross-sectional area of the KAITEN in each direction, i.e. horizontally and vertically.

Propellers

The standard Type 93, Model 3 torpedo propellers are used.

Defects in Service

Water Leaks

In the Model 1, leakage of water into the control room occurred through the hatches and through the two parts of the body which were originally bolted together. Subsequently the hatch design was modified and the two halves welded together. Leakage did not occur them till the depth exceeded 50 meters.

The 'mother' submarine would leave Japan and cruise for two or five days on the surface until reaching Allied-occupied waters, when it would submerge to a depth of 30 to 40 meters, surfacing only at night.

Under these conditions the power unit of the KAITEN was subjected to a water pressure of 3-4 kg/cm² for a long time and became water logged. On occasions when sea water reached the group, explosions had occurred; due, it was stated, to oil picked up from the engine.

Many measures were taken to prevent this water leakage, such as fitting a rubber plug in the tail shaft and a rubber sheath between the propeller shafts. The latter was sheared when the propellers started to revolve. In the diluent sea water pump, a small hole was drilled in the cap to allow the water pressure to assist in keeping the valve closed.

It was not found possible, however, to exclude the water. Experiments carried out on starting with the engine and leads filled with water showed that explosions would occur in two out of every five torpedoes fired.

Arrangements were therefore made to displace the sea water through a drain hole in the valve chest, air pressure being supplied by a small hand pump operated by the pilot.

Corrosion

Corrosion occurred due to the presence of carbon tetrachloride. If the liquid leaked from the bottle into the group or reducer they would rust in two or three days. When no leakage occurred the valves remained serviceable for about two weeks.

To prevent this, waterproof grease was spread very thinly on the valve of the group and the spindle of the reducer. In addition, if possible, the valve of the group was cleaned shortly before a firing. Reliance was placed on the presence of the carbon tetrachloride to prevent explosions by washing it away. As a further precaution carbon tetrachloride was poured into the oxygen delivery stop valve.

These two measures were successful in preventing the corrosion, but the cleaning routine was not discontinued because of the danger of so much oil being left in the pipes that the quantity of carbon tetrachloride would be insufficient to wash it all away.

KAITEN Type 2

Historical

In parallel with the development work on KAITEN Type 1, the Japanese Naval Staff decided that an investigation should be undertaken of the potentialities of hydrogen peroxide as an oxygen carrier for a new type of KAITEN. This requirement was put forward to the Mitsubishi-owned company of Nagasaki-Heiki K.K. at NAGASAKI in April 1944. The latter company was already experimenting with hydrogen peroxide for the "R.S. Rocket" and for aircraft "assisted take-off."

German Information

The information on hydrogen peroxide sent to Japan from German sources was meager. No great detail was received, but rough explanatory drawings (non-dimensional) and photographs of the following were furnished:

Turbine pump for suppling peroxide and hydrazine hydrate
Controlling valves
Combustion chamber
Spraying nozzle
Rough data on the peroxide torpedo system

With the exception of the data on the peroxide torpedo, all the above information concerned aircraft systems. No peroxide torpedoes were received from Germany.

Tactical Requirement

The Japanese Naval Staff formulated the following requirements for KAITEN 2:

(1) Speed — 50 knots
(2) Range — 55,000 yards
(3) Must be capable of diving to 300 feet.

These were modified later in view of technical difficulties.

Work at Nagasaki Heiki K.K.

In May 1944, the Naval Technical Department, TOKYO, decided that the Torpedo Department should play a more active part in the development of KAITEN 2. As a result, Lieutenant Commander H. KAWASE of Kure Torpedo Department was directed to collect available information on hydrogen peroxide propulsion systems.

As a starting point in his work, KAWASE made a visit to NAGASAKI to discover how far Nagasaki Heiki K.K. had progressed in the development of KAITEN 2, and to collect all the information on hydrogen peroxide that this company possessed. The following data were obtained:

1. SUGGESTIONS FOR R.S. ROCKET

(a) 80% hydrogen peroxide (H_2O_2)
40% sodium permanganate ($NaMnO_4$)

(b) 40% H_2O_2
40% $NaMnO_4$, Weight Ratio 1/18
Resulting chamber temperature 400°C

(c) 60% H_2O_2
80% hydrazine hydrate ($N_2H_4H_2O$), Weight ratio 1/1.6
Resulting chamber temperature 1000°C

(d) 60% H_2O_2
80% $N_2H_4.H_2O$, Weight ratio 10/1
Resulting chamber temperature 600°C

In the last case, the excess oxygen formed by the decomposition of the peroxide can be burnt with methyl alcohol.

All the above information on the R.S. Rocket had been obtained from Germany, but had not been verified by experiment in Japan by May 1944. Two engineers (FUKUDA and MUKUGI) at Nagasaki Heiki K.K. had begun preliminary experiments, in collaboration with the Mitsubishi Aircraft Manufacturing Co., at NAGOYA.

2. COMBUSTION EXPERIMENTS

In an effort to obtain the result stated in 1 (c) above, combustion experiments with a Type 95 torpedo generator were carried out at Nagasaki Heiki.

Pressure of supply	18 kg/cm^2 (255.6 lbs/in^2)
60% H_2O_2	
80% $N_2H_4 \cdot H_2O$	Weight ratio 1/1.6
A temperature of 1000°C was sought.	

The reactants were fed through the generator head as follows:

Nozzle	$N_2H_4.H_2O$	Center of head
	H_2O_2.	Around $N_2H_4.H_2O$

Fuel	Through holes around the nozzle
Water	Through outer circle of holes

The feeding valves were opened in this order:

Time (seconds)	Valve
0	Hydrazine hydrate
1	Hydrogen peroxide
5	Fuel
7	Water

These valves were closed in the order:

(1) Fuel
(2) Hydrogen peroxide
(3) Hydrazine hydrate
(4) Water

These first experiments were qualitative. Combustion was smooth, producing a steady supply of superheated steam.

Ordinary copper pipes were used for conveying the reacting liquids to the generator head. The supply bottles of peroxide and hydrazine hydrate were made of steel.

3. "N" APPARATUS

This apparatus was designed on the rocket principle and aimed at an "assisted take-off" for aircraft. It consisted of a steel cylinder which tapered at the after end to a venturi.

The dimensions of the unit were approximately:

Length	10 feet
Diameter	18 inches
Weight	1000 pounds
Ratio H_2O_2(80%)/$NaMnO_4$(40%)	18

Two bottles, one containing 80% peroxide the other 40% sodium permanganate were fitted in the cylinder. These liquids were fed to a combustion chamber by compressed air carried in two bottles in the unit. The products of combustion exhausted from the venturi with a jet action. Combustion was not smooth.

The propulsive power of the unit was measured by attaching a 1000 pound weight beneath the cylinder and suspending the whole unit from two ropes; when the jet action started, the unit swung forward and upward on the ropes; by means of a pen tracing system, it was arranged that the movement of the unit traced its own curve. From the curve, the propelling force could be calculated.

4. EXPERIMENTAL KAITEN DESIGN

Nagasaki Heiki K.K. was in the process of designing a KAITEN torpedo to run on peroxide and hydrazine hydrate. The proposed dimensions were:

Total Weight	18.1 tons
Displacement	16.1 tons
Length	47.6 feet
Diameter	5.0 feet
Speed	35 knots
Range	87,000 yards
Power	1,000 hp
Running time at full power	5,000 seconds

For the propulsion system of this torpedo, the use of two Type 93 engines was envisaged.

A Type 93 oxygen vessel was carried in the forebody and this vessel supplied compressed air for feeding the peroxide, hydrazine hydrate and fuel to the combustion chamber.

	60% H_2O_2	80% $N_2H_4.H_2O$	Fuel
Pressure of supply			
(1) kg/cm^2	40	40	40
(2) lbs/in^2	570	570	570
Volume of vessel			
(1) liters	3700	500	920
(2) ft^3	131	18	33
Weight of liquid			
(1) kg	5000	500	750
(2) lbs	11,000	1100	1650
Weight of vessel			
(1) kg	3600	830	1520
(2) lbs	7920	1826	3344

A torpedo to this design was never built.

Following KAWASE'S visit to NAGASAKI, the Naval Technical Department made a survey of the information, available in Japan, concerning the use of concentrated solutions of hydrogen peroxide for propulsion systems. As a result, it was decided that the Torpedo Research Department in KURE should undertake an investigation into the use of concentrated hydrogen peroxide and hydrazine hydrate for torpedo propulsion, with a view to meeting the Naval Staff requirements for KAITEN 2. Lieutenant Commander KAWASE was put in charge of the physico-chemical research involved, and he worked in collaboration with the chief torpedo designer at KURE, Comdr. HORI.

Experiments at KURE

The experiments at KURE were conducted in the open air and operators worked behind armour plate about three inches thick (see Figures 169 and 170). In general, the apparatus used for experiments was placed over a water tank in which a continuous flow of water was maintained. The investigation was remarkable for its speedy, methodical progress, its practical nature (from point of view of torpedo propulsion) and its freedom from accidents of any magnitude.

Initial experiments were of an elementary nature, and consisted of mixing concentrated solutions of hydrogen peroxide and hydrazine hydrate in an open dish. This was done by tipping (by remote control) a beaker of one reactant into a metal dish containing the other. The ensuing reaction always took place with explosive violence and with the generation of clouds of vapour. Controlled combustion experiments followed these preliminary observations.

The two reactants, hydrogen peroxide and hydrazine hydrate were called by the Japanese "A" liquid and "B" liquid respectively; for the sake of simplicity, this nomenclature will be used often in the following descriptions. In this work 80% peroxide and 80% hydrazine hydrate were used.

Controlled Combustion

Liquids "A" and "B" were placed in tin-plate containers (99.9% purity) which, in turn, were placed inside Type 94 torpedo generators as a safety precaution. The head and outlet of the generators were closed with steel plates bolted into position. Each generator cover was fitted with two

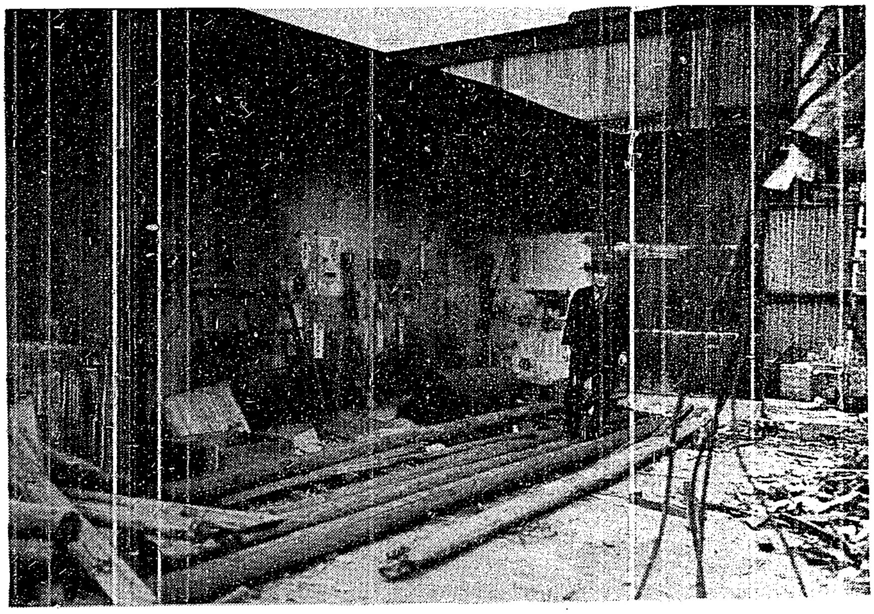


FIGURE 169
TEST CELLS FOR HYDROGEN PEROXIDE EXPERIMENTS

FIGURE 170
TEST CELLS FOR HYDROGEN PEROXIDE EXPERIMENTS

steel feed pipes (tin plated by dipping). These pipes were used for supplying a feeding pressure of compressed air to the bottles, and for conveying the liquids "A" and "B" to the combustion nozzle. (See Figure 171.)

The nozzle was rated to deliver the calculated quantities of reactants required. In addition, the relative quantities of liquids "A" and "B" placed in the bottles were in the same ratio as that required for combustion. Thus, if the nozzle was rated to deliver two parts of "A" to one part of "B", then the liquid "A" bottle contained twice as much fluid as the liquid "B" bottle. This precaution was observed in order to avoid using more liquid than that exactly required for the proposed experiment. Thus at the end of the experiment air could be blown through the whole apparatus without unnecessarily wasting material.

In the case of a ratio of "A"/"B" = 2/1 fed by a pressure head of 1 kg/cm2 (14.2 lbs/in^2) gradually increased to 5 kg/cm^2 (71 lbs/in^2), the following observations were made:

Vigorous reaction
Smooth combustion
Bluish flame
Very noisy

Nozzles

It was discovered that unless liquid "B" (hydrazine hydrate) is introduced into the reaction zone as a thin unbroken film, the reaction with the peroxide is more noisy and less smooth. In an effort to fulfill the best conditions for introduction of liquid "B", the design of nozzle illustrated in Figure 172 (a) was tried. Although this type of nozzle emitted liquid "B" as a thin film, the latter was frequently broken and the combustion was not smooth. The design was abandoned in favor of that illustrated in Figure 172 (b). In the latter design, a 'swirler' was included in the "B" liquid nozzle and the shape of the nozzle mouth was altered. This design proved satisfactory and ejected an unbroken thin film of "B" liquid. Combustion with this nozzle was smooth. The section on generator design deals with the latest types of nozzles.

In every design, a steel skirt was used around the nozzle and on this surface the reaction takes place. The Germans used this skirt in their early experiments, but later abandoned its use. The Japanese continued to use it in all their designs and found it necessary for satisfactory combustion. An accident occurred during these combustion experiments. One minute after the end of one experiment an explosion took place and destroyed the combustion nozzle. No one was hurt. The explosion was said to have been caused by hydrazine hydrate draining out of the nozzle and dripping into an accumulation of peroxide on the steel skirt. Subsequently, air was blown through the apparatus at the end of each experiment until all the liquids were exhausted, and a water spray played on the front of the nozzle.

Investigation of Catalysts

In order to render the decomposition of hydrogen peroxide by hydrazine hydrate rapid and complete, an investigation was made of possible catalytic agents. The Germans had suggested the use of potassium cuprocyanide ($K_3Cu(CN)_4$) as a catalyst and the activity of this material was tested by the Japanese in a series of experiments outlined below. Potassium cuprocyanide is soluble in hydrazine hydrate and is always introduced to the reaction zone via liquid "B".

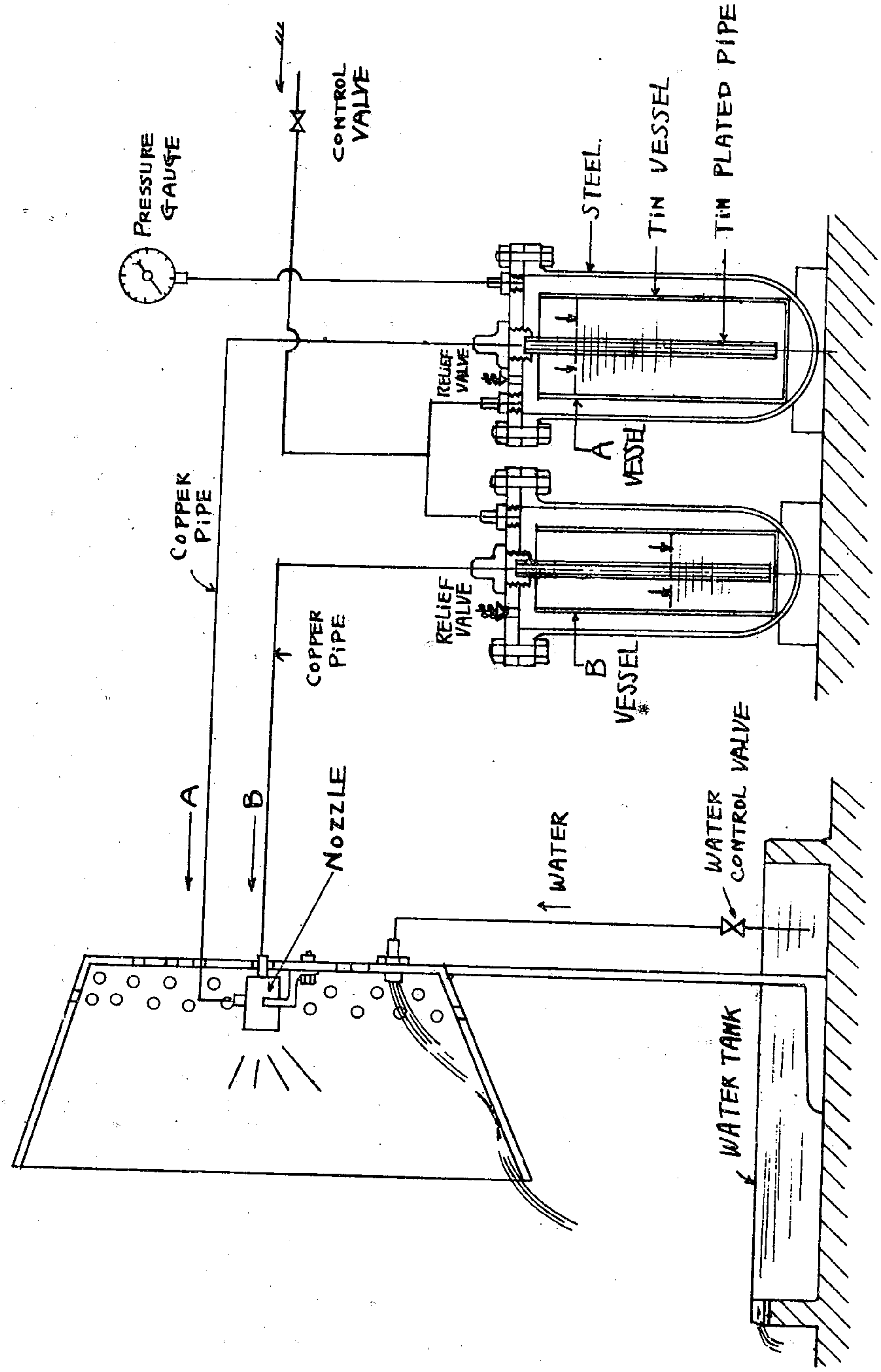


FIGURE 171
EXPERIMENTAL APPARATUS FOR "A" AND "B" LIQUID REACTION

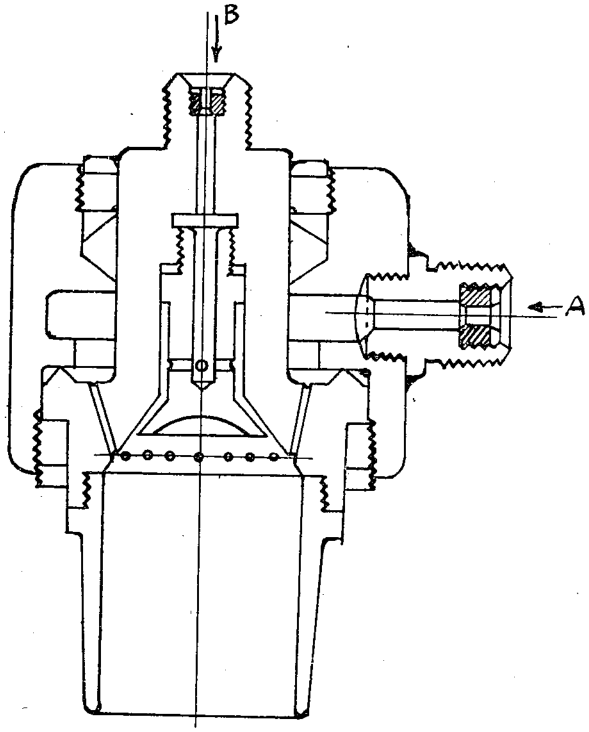


FIGURE 172 (a)
EXPERIMENTAL NOZZLE FOR KAITEN TYPE 2

(1) Experiments using "A"/"B" ratio of 4/1.

Material	Parts (by weight)	Consumption (liters/min)	Supply Pressure (kg/cm^2)
"A"	4	2.96	2
"B"	1	1.0	2

Observations:

(a) Without catalyst
Reaction good, almost complete
Flame slightly reddish

(b) With 2 gm $K_3Cu(CN)_4$ per liter of liquid "B"
Reaction good, almost complete
Flame greenish (due to copper)
slightly smoky (perhaps due to HCN)

(c) With 5 gm $K_3Cu(CN)_4$ per liter of liquid "B"
Reaction good, almost complete
Flame greener, more smoky

(2) Experiments using "A"/"B" ratio of 10/1.

Material	Parts (by weight)	Consumption (liters/min)	Supply Pressure (kg/cm^2)
"A"	10	7.4	2
"B"	1	1	2

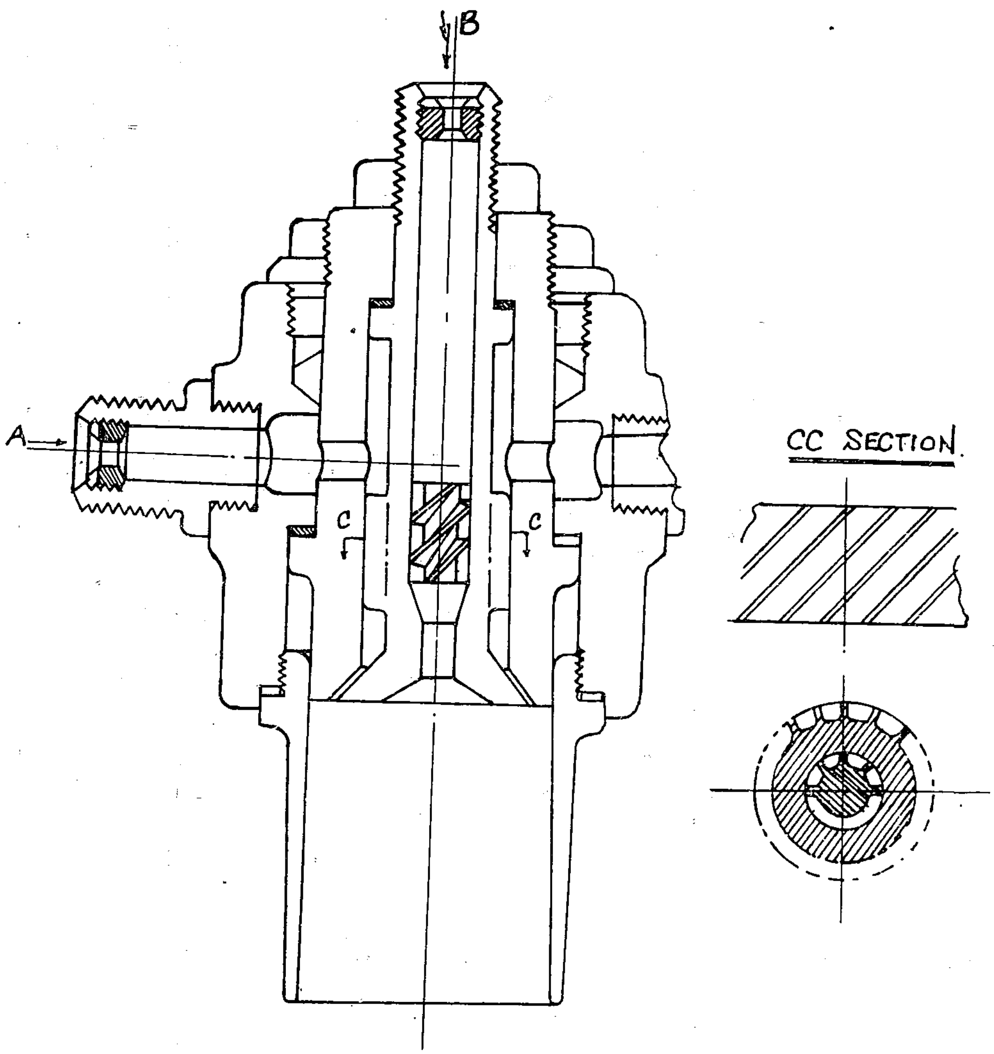


FIGURE 172 (b)
EXPERIMENTAL NOZZLE FOR KAITEN TYPE 2

Observations:

(a) Without catalyst
Reaction incomplete
Flame red and irregular, often extinguished
(b) With 7 gm $K_3Cu(CN)_4$ per liter of liquid "B"
Reaction good, almost complete
Flame steady, very green

From the foregoing experiments, it will be seen that the activity of potassium cuprocyanide is not very noticeable when the ratio of "A"/"B" is small. The quantity of hydrazine hydrate, under these conditions, is sufficient to decompose the peroxide almost completely.

In the case of a large "A"/"B" ratio, however, the reaction is poor and complete decomposition of the peroxide does not take place unless a catalyst is present. From a practical point of view, the case of a large "A"/"B" ratio is the more important one; since the aim is to decompose a large quantity of peroxide and burn the liberated oxygen with fuel. (If a large quantity of hydrazine hydrate is used to attain the desired end, there will be a lack of economy in material and the resultant temperature of the reaction may be too high).

The Japanese decided upon the use of potassium cuprocyanide as a catalyst, and in their later work used a concentration of 2 gm/liter of liquid "B".

Other Catalysts

Other material which were investigated, but which did not show marked catalytic activity in this reaction were:

Silver nitrate	$Ag\ NO_3$
Potassium ferrocyanide	$K_4Fe(CN)_6$
Potassium ferricyanide	$K_3Fe(CN)_6$
A lead compound	? ?

Combustion Chamber Experiments at KURE (10 October 1944)

These were carried out using a Type 93 torpedo generator body, fitted with a specially designed generator head. The peroxide reaction nozzle was fitted with a skirt and the two fuel inlet pipes were also fitted with short steel skirts.

The rating plugs were made to deliver the following quantities at a pressure of 1.5 kg/cm^2 (21 lbs/in^2):

	Delivery (kg/min)	Delivery (lbs/min)
"A" liquid	23.0	50.6
"B" liquid	7.0	15.4
Fuel	2.2	4.8
Water		13.2

During the experiments the measured consumptions were found to be:

	Consumption (kg)	Consumption (lbs)	Time (sec)
"A" liquid	20	44	116
"B" liquid	17	37.4	116
Fuel	6	13.2	116
Water	14	30.8	116

Gas analysis - The products of combustion were exhausted to atmosphere through the generator outlet vent. Samples of exhaust gas were taken at two points in the exhaust pipe, and analyzed.

No. 1 Sample

Time (mins)	CO_2	Hydrocarbon	O_2	CO	H_2	CH_4	N_2
0.5	0.8	44	14	2	Trace	Trace	78.8
1.0	1.2	7.6	10.8	4.4	14.8	2.4	58.8
1.5	8.8	0.8	2.8	18.8	-	-	-

No. 2 Sample

Time (mins)	CO_2	Hydrocarbon	O_2	CO	H_2	CH_4	N_2
0.5	0.4	9.6	7.4	14.6	13.4	16.0	38.6
1.0	0.4	14.4	2.0	10.4	18.0	15.2	39.6
1.5	4.4	6.0	1.2	20.0	8.8	15.6	44.0

The imperfect combustion indicated by these figures may be attributed to two main factors:

(1) The actual consumption of peroxide is less than the rated quantity required.

(2) During the experiment the steel skirt on the fuel nozzle was burned, and therefore, the fuel was introduced to the reaction zone too early. The length of the fuel nozzle was subsequently increased so that the fuel was introduced into the generator at a considerable distance from the "A" and "B" liquid nozzle.

Minor accident- About one minute after this combustion experiment finished, an explosion occurred in the "A" liquid stop valve. The stop valve was blown out, and the valve casing was deformed. Although the valve and pipes had been tin plated, by dipping, the accident was attributed to the presence of iron rust formed due to imperfections in the protective plating. Afterwards more attention was devoted to plating and the stop valve was made of 18/8 stainless steel.

Typical Combustion Experiment

The results of a typical analysis during a combustion test are shown below. In this test a ratio "A"/"B" of 4/1 was used at the start, until combustion became established and then a second rating nozzle was switched into the circuit after about one minute to give an "A"/"B" ratio of 10/1.

Nozzle ratings

	Time (min)	Weight ratio "A"/"B"	Volume (liters)	Supply Pressure (kg/cm^2)
"A"	1	10	9.0	2
"B"	1	1	1.2	2
Fuel	1	-	1.8	2
Water	1	-	16.0	2

As in the previous experiments, gas samples were taken from two points in the generator exhaust vent.

I.

Time (mins)	CO_2	Hydrocarbon	O_2	CO	H_2	CH_4	N_2
0.5	6.0	15.6	1.8	11.2	(2.1)	17.0	46.3
1.0	21.0	0.9	1.5	20.4	31.1	6.1	18.8
1.5	24.8	Trace	1.6	22.4	30.4	4.4	16.4
2.0	26.0	Trace	2.0	21.8	33.4	3.6	13.2

II.

Time (mins)	CO_2	Hydrocarbon	O_2	CO	H_2	CH_4	N_2
0.5	14.0	6.0	3.6	14.0	30.4	11.2	20.8
1.0	22.8	0.4	4.0	18.4	30.4	7.2	16.8
1.5	24.0	Trace	2.8	20.0	28.0	6.4	18.8
2.0	26.4	Trace	3.2	20.0	24.0	6.4	20.0

These data are typical for combustion in the KAITEN 2. Combustion was good, with only small amounts of hydrocarbon and oxygen appearing in the exhaust gases. Combustion was smooth, with an almost transparent exhaust near the point of ejection. The products of combustion left the generator with a very high velocity; Mach's waves could be observed in the exhaust.

Temperature measurement: In these combustion experiments a thermocouple, with the junction protected by a steel cover about 2mm thick, was placed just inside the wall of the exhaust pipe. The temperature recorded was about 200°C. Due to the proximity of the thermocouple junction to the wall, and due to the steel cover over the junction, these temperature measurements are not a true indication of the temperature of the exhaust gases, which are probably considerably in excess of 200°C.

Horsepower Experiment

After about ten combustion experiments, of which the previously described one is a typical example, horsepower experiments were undertaken. The Type 93 engine was used and dynamometer measurements were made.

Horsepower Data

Second horsepower experiment (18 September 1944). The data from this experiment are typical of the several horsepower experiments made.

Consumptions	Vol. (liters)	Weight (kg)	Ratio (by wt)	Rate of consumption (kg/min)
"A"	57.6	78.0	1.00	17.8
"B"	6.5	6.7	0.09	1.53
Fuel	19.5	15.6	0.20	3.57
Water	146.5	146.5	1.88	33.6

By dynamometer: BHP 245

Peroxide efficiency: 825 hp secs/kg peroxide
9.5 lbs peroxide/BHP hour

This peroxide efficiency is the usual figure for KAITEN 2, but, in some experiments, an efficiency of 900 hp sec/kg peroxide was obtained.

Gas analysis

	Time (mins)	CO_2	Hydrocarbon	O_2	CO	H_2	CH_4	N_2
Slide Valve	0.5	28.0	0.8	1.6	20.4	33.4	6.8	9.0
	1.0	29.0	0.6	1.6	20.2	36.4	6.8	5.4
	1.5	28.4	1.2	1.8	19.6	34.0	6.6	8.4
	2.0	27.8	0.2	3.0	18.6	29.2	8.2	13.0
	4.0	23.4	0.8	3.8	17.8	34.6	7.6	12.4
Crank-Case	0.5	33.2	0.6	4.0	18.6	28.6	5.4	9.6
	1.0	32.8	0.4	3.8	19.0	29.6	8.4	6.0
	1.5	30.4	1.6	3.6	19.3	33.8	7.0	4.3
	2.0	33.8	0.2	3.6	18.4	29.6	7.8	6.6
	4.0	34.0	0.4	3.6	18.6	29.8	8.8	5.2

In this experiment the feeding pressure was 20 kg/cm^2 (280 lbs/in^2).

Peroxide Inhibitors

Although not used with hydrazine hydrate, it is essential to use inhibitors in concentrated peroxide solutions to reduce the rate of thermal decomposition. Photo-chemical decomposition is not so important since it can be prevented easily by storing in dark glass bottles or opaque containers.

The Japanese have investigated a large number of inhibitors, of which the majority have been mentioned previously in scientific literature in connection with the stabilization of hydrogen peroxide.

The following materials were tested:

- Acetanilide
- Phenacetin
- Urea
- Orthophosphoric acid
- Phenol
- Sodium pyrophosphate
- Uric acid
- Barbituric acid
- Thymol
- Quinine Sulphate
- Aniline
- Hydroxy quinoline ("oxine")
- Pyridine
- Pyridine dicarboxylic acid
- Tin dioxide colloid

Of the above materials, the following were found to be the most effective:

- Orthophosphoric acid (H_3PO_4)
- Sodium pyrophosphate ($Na_4P_2O_7 \cdot 10H_2O$)
- Quinine sulphate
- Aniline
- Pyridine
- Tin colloid
- Oxine

Of these, pyrophosphate, orthophosphoric acid, oxine, and tin colloid are the best. Of these four materials, the first three are well-known stabilizers of hydrogen peroxide, but tin colloid is not so well known, particularly for concentrated solutions of peroxide. The investigation of this material was carried out at Sendai University under F. ISHIKAWA, Professor of Inorganic Chemistry. An account of this investigation is given in Enclosure D.

Tin colloid was not available for use in the standard inhibitors before the end of the war, owing to the lateness of its discovery.

The inhibitor used commercially for the stabilization of peroxide for KAITEN 2 was a mixture of the following, in the quantity stated:

	gm/liter 80% H_2O_2 solution
$Na_4P_2O_7 \cdot 10H_2O$	0.2
Oxine	0.3
H_3PO_4	0.15

(The phosphoric acid was not used as an inhibitor in the aircraft industry, since it poisoned the catalysts used to decompose the peroxide.)

Stability Tests

With the above mixed inhibitor added in the quantity stated, peroxide was stored in clear glass bottles and kept at a temperature of 40°C, in diffused daylight. Decomposition took place at a rate of less than 0.1% per day.

Parallel experiments carried out in tin beakers with the same inhibitor showed similar rates of decomposition.

At Sendai University stability tests were made with the following mixed inhibitor:

	gm/liter 80% H_2O_2 solution
Oxine	0.3
Tin colloid	0.15
Pyrophosphoric acid ($H_4P_2O_7$)	0.2

The inhibited peroxide solution was placed in a glass flask which was heated in a water bath to 100°C (peroxide was probably at about 96°C).

Rate of decomposition	1 to 2% per day

This result compares favorably with the German peroxide stability (with German inhibitors) which, the Japanese say, decomposes at the rate of nearly 5% per day when subjected to the same test.

Analysis

For estimating rates of decomposition, samples of the solution are diluted to standard volumes and titrated with potassium permanganate.

Life of Inhibitor

No data are available on the rate of decay of the activity of the inhibitors. Oxine colors the peroxide solution yellow, and as long as this color persists the solution is safely inhibited. If the color should fade, more inhibitor must be added.

Application of Inhibitors

These are put into the peroxide solutions at the place of manufacture. Initially, it was found that the rates of decomposition of inhibited solutions did not give consistent results. The naval chemical inspectors at the factories discovered that this was due to the lack of uniformity among the products of different manufacturers. This problem was solved by stipulating that the concentrated peroxide solution should be redistilled after manufacture. This, of course, resulted in a considerable loss of material due to thermal decomposition, but it was considered unavoidable in the interests of obtaining a uniform product.

Manufacture of Peroxide**

In June 1944, Edogawa Kogyo K.K. at YAMAKITA, near HAKONE, was the only manufacturer of concentrated hydrogen peroxide solutions (30%). This company was able to produce 80% peroxide on a laboratory scale.

Method of Manufacture

Edogawa Kogyo used Lowenstein's method which is outlined in the following chemical reactions:

(1) $H_2SO_4 + NH_3 \longrightarrow (NH_4) + HSO_4$

40-50% ammonia gas ammonium bisulphate aq. sulphuric acid

(2) $2(NH_4)HSO_4 \longrightarrow (NH_4)_2S_2O_8 + H_2$

Electrolysis ammonium persulphate

(3) $(NH_4)_2S_2O_8 \longrightarrow H_2O_2 \quad 2(NH_4)HSO_4$ return to source

Fractional distillation (40-50mm mercury)

Electrolysis

This is carried out in cells of glazed porcelain 108 cm long, 58 cm wide, and 55.5 cm high. Wall thickness is 3 cm. Each cell is divided into six smaller cells by two glazed porcelain partitions running laterally and by three glass partitions which divide each of the three cells thus formed into two equal parts. Each of the small cells is divided into three compartments by diaphragms of porous porcelain. The anodes are placed in the central compartment of each cell, the cathodes being in the outer compartments.

Anodes: The anodes consist of narrow, thin strips of platinum (about 40 cm long, 5mm wide and 0.05mm thick.) Each strip weighs two grams and in a unit of 28 cells there are 1680 anodes weighing in all 5 kg (11 lbs). Distance between anode strips is about 2.5 cm (1 inch). Loss of platimun 2.5 - 3 gm/ton 30% H_2O_2.

Cathodes: These are of sheet lead. Loss of lead 11 kg/ton 30% H_2O_2.

Current density:

Energy	350 kw
Volts	100-125
Amperes	2800
Current density	1 amp/cm^2

Arrangement of cells: The electrolytic cells are placed in units of 28. These are arranged so that there is a continuous gravity flow of solution from one cell to the next. Thus, a continuous supply of ammonium bisulphate is fed into the first cell, and the concentration of ammonium persulphate, formed by electrolysis, increases in each succeeding cell up to cell 28 which has maximum concentration.

**This subject is dealt with in detail in NavTechJap Report, "Japanese Fuels and Lubricants, Article 5 - Research on Rocket Fuels of the Hydrogen Peroxide - Hydrazine Type," Index No. X-38(N)-5.

Distillation

The ammonium persulphate solution is fed into lead pipes which are steam jacketed, and the persulphate undergoes thermal decomposition, forming hydrogen peroxide and ammonium bisulphate. The peroxide and water vapour into two fractioning columns which are packed with Raschig rings. Both the columns and the rings are made of white porcelain. From the bottom of the first column, distillation takes place at a reduced pressure and 30% peroxide (by weight) is drawn off as the final product in the process. The concentration of peroxide in the second column is about 10% and this is used as a reflux in the first column. The exhaust from the second column contains about 3% peroxide and some of this is returned to this column for reflux.

Higher concentrations of peroxide were produced by Edogawa Kogyo K.K. only on a laboratory scale. Using glass flasks of five liters capacity, 30% peroxide was distilled at 60-70°C under a reduced pressure of 40mm of mercury. The distillate contained 15% peroxide, while the concentration in the flask could be raised to 80%.

Transport and storage: The peroxide was stored and transported in glass bottles of 22 kg (50 lbs) capacity. Stoppers were made of glass and each of these was fitted with a small hole (about 2mm in diameter) to prevent pressure 'build-up'.

To meet the requirements of the proposed experiments which were to be undertaken at KURE, Edogawa Kogyo K.K. agreed to increase their production of 80% peroxide. An industrial plant was not designed, but the laboratory scale experiments were increased in number, until there were between 2000 and 3000 distillation flasks in action.

At the beginning of July 1944, the first quantity of 80% peroxide (one ton) was received in the Torpedo Department, KURE. The cost was ¥ 50 per kilogram. At the then existing rate of exchange, this was equal to the high cost of $5 per lb.

Production of Pergxide

With the increase in importance of concentrated peroxide as a potential war material, the Japanese Government requested the leading chemical manufacturers to undertake large-scale production of the material. The project placed a great strain on the Japanese chemical industry.

The table on the next page gives the names of the manufacturers involved, and the planned production from August 1944 to March 1946. In fact, only about one-fourth of the total projected quantity was produced. This was inadequate to meet the demands. The bulk went to aircraft researchers and the torpedo workers went short of material, as a result.

Handling of Concentrated Peroxide

Many precautions must be observed in the safe handling of concentrated peroxide. Owing to the shortage of suitable metal containers, the Japanese were compelled to use glass bottles for its transport and storage. The use of glass led to a number of accidents due to breakage. This usually resulted in fire and the breakage of adjacent bottles. In this wise, fires occurred at the Mitsubishi Aircraft Co., NAGOYA and also on a truck which was transporting peroxide.

In a similar way, a serious accident occurred on KAMIKURO SHIMA near KURE. On this island about 10 tons of 80% peroxide were stored in glass bottles in the open air. Sheets of zinc plate were placed over the bottles to protect them from the rain. One night fire broke out and the whole dump of peroxide exploded, leaving three holes about 15 feet wide and six to [illegible] feet deep. No person was injured.

The accident was attributed to the wind blowing off the zinc plate which then struck and broke one of the bottles. The escaping peroxide attacked organic matter in the vicinity (roots of trees, etc.) and a fire ensued which caused the explosion of the whole dump. A similar occurrence was reported from the First Naval Fuel Establishment at OFUNA.

HYDROGEN PEROXIDE MANUFACTURE
Production Plan
(Aug. 1944 - March 1946)

MANUFACTURER	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH
Sumitomo								
(1) OSAKA	10	10	17	17	17	17	17	17
(2) KYUSHU (a)		3	10	10	10	10	10	10
(b)				20	20	20	20	20
Nippon Chisso								
(1) KOREA		120	150	150	150	150	150	150
(2) KYUSHU			400	850	850	850	850	850
Hodogaya Soda YOKOHAMA		15	30	30	30	30	30	30
Showa Elect. Industries NAGANO Prefecture		10	20	20	20	20	20	20
Edogawa Kogyo Nr. HAKONE		10	20	20	20	20	20	20
Second Fuel Factory YOKKAICHI (a)		50	150	220	220	220	220	220
(b)				20	250	370	480	480
Mitsui Kozan KYUSHU			30	30	30	30	30	30
Nippon Kogyo			20	40	50	60	100	100
TOTAL	10	218	847	1427	1667	1797	1947	1947

The above units are liter/tons (i.e. weight of 1000 liters of material) of 30% peroxide. This liter/ton approximates the metric ton. (2200 lbs.)

Precautions

(1) In general, great care must be taken to avoid all contact between concentrated peroxide and organic matter - dust, wood, bamboo, straw, clothes etc. Curiously enough, oil does not appear to react violently with concentrated peroxide, in the absence of other organic impurities. On warming a hydrocarbon oil with peroxide, the oxidation of the oil was very slow. A 'boiling-up' of the mixture did not occur. This was found in the case of gasoline, kerosene, and lubricating oil. Ether shows the same inertness.

(2) The following substances should be excluded from peroxide:

Cement
Concrete

Zinc
Bronze

Alkali
Lead
Iron rust
Copper
Copper corrosion products
Heat
Sunlight

Natural rubber
Synthetic rubber
- Chloroprene
- Buna N.
- Buna S.
- Thiokol

Acrylic resins
Celluloid

The plunging of a piece of red hot iron into concentrated peroxide appears much the same as in the case of water. No serious decomposition takes place.

(3) Hydrogen peroxide should never be kept in a sealed container. A leak hole must always be incorporated to prevent big increases in pressure.

(4) When washing apparatus free from peroxide, use water which is free from organic matter. Distilled water is best. Well water is also suitable. Sea-water slowly decomposes peroxide.

(5) When handling "A" liquid, rubber gloves should be worn.

(6) Plenty of water should be available in the vicinity of dumps of concentrated peroxide.

(7) Where fires have been started by "A" liquid, water should be used to extinguish them.

The following materials are generally suitable for using in contact with "A" liquid, but in some cases the time of contact should not be long.

Chromium plating (but tends to be porous)
Tin
Aluminum
Stainless steel (18/8)
Glass - non-alkaline
"Almite" (electro-deposit of oxide on aluminum
Porcelain
Glazed enamel finish on iron
Paraffin wax
Hard blown asphalt
Vinyl chloride resins

This last named material was tried for washers, but was found satisfactory for only a few weeks. After that, it showed signs of attack and became soft.

Aluminum was never used to any extent for peroxide in the Japanese Navy. Material of sufficient purity was difficult to obtain, while tin in adequate supply was obtained from MALAY.

Manufacture of Hydrazine Hydrate

Hydrazine hydrate was manufactured by MITSUBISHI, KYUSHU from ammonia and sodium hypochlorite.

The units listed on the next page are in liter/tons of 80% hydrazine hydrate. This liter/ton approximates the metric ton (2200 lbs).

Only about one-fourth of the total projected quantity was actually produced. It was adequate, however to meet demands.

HYDRAZINE HYDRATE MANUFACTURE
Production Plan
(August 1945 - March 1946)

MANUFACTURER	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH
Mitsubishi KYUSHU	10	30	50	50	50	80	100	100
Nippon Chisso KOREA		50	100	100	100	100	100	100
Dai Nippon Chem. Co.		10	30	30	30	30	30	30
Mitsui Kozan KYUSHU		10	30	30	30	30	30	30
Toa Synthetic Ind.			10	15	50	50	50	50
TOTAL	10	100	220	225	260	290	310	310

Handling of Hydrazine Hydrate

(1) "B" liquid is easily oxidized in the atmosphere and therefore it must be stored in sealed containers. The Japanese used petrol tins which were plated internally with tin for corrosion protection. (Volume 18 liters.)

(2) "B" liquid is very toxic and the vapour should not be inhaled.

(3) "B" liquid reacts with organic matter such as wood, straw, etc. and may cause fire. Where organic material has become stained with "B" liquid, the material should be disposed of by burning.

Materials which are generally satisfactory to use in contact with "B" liquid are.

Natural rubber
Glass
Bronze
Steel
Stainless steel (18/8)
Tin

The following materials are not good:

Synthetic rubber
Other plastics

Peroxide Vessel Design

Experimental

A series of experiments with different containers was conducted at KAMEGA-KUBI, near KURE. The containers were of 27 liter capacity and were made of welded mild steel plate.

Three different kinds of internal treatment were used;

(1) Sand blast
(2) Sand blast and then spray with tin (0.5-1.0mm thick)
(3) Sand blast, spray with tin and then paint with a solution of hard blown asphalt (hardness 5°) in trichlorethylene

Sets of containers were treated in one of these three ways and then filled with 80% hydrogen peroxide. From a range of 50 yards rifle bullets (.303 in) were fired at the containers and the results were observed.

Nothing remarkable occurred, except in the case of the containers treated with asphalt. These exploded on being struck with rifle bullets. This was contrary to expectation, since previous experiments had indicated that hard blown asphalt did not react with concentrated peroxide. The container experiments were repeated with the same result. It was then suggested that incomplete removal of trichlorethylene might result in the residue of the latter forming an explosive mixture (as in the case of experiments with the Type 93 generator).

The experiments were repeated at the Second Naval Explosive Factory, HIRATSUKA. This time, great care was taken to insure complete removal of the trichlorethylene. When rifle bullets were fired into the containers, none exploded. These experiments appear to confirm the explosive characteristics of trichlorethylene under certain circumstances. It was decided to use hard asphalt for coating the inside of the peroxide vessel, but carbon tetrachloride was used instead of trichlorethylene as the solvent for the asphalt.

Final Design of "A" Liquid Vessel

The vessel is made of mild steel plate bent to circular cross-section and welded. The outer wall of the vessel forms part of the shell of the KAITEN 2, so it was designed with a large thickness to withstand hydrostatic pressures up to 300 feet (Naval Staff requirement). Thickness is about 16mm.

The vessel is divided into five compartments (six were found to be an unnecessary complication) so that movement of the peroxide during operations will not affect the trim and mixing of the separating liquid with the peroxide will be avoided. A steel pipe, near the upperside, runs through the vessel; through this pipe control rods and pipes running fore and aft are conveyed (fuel, water, etc.).

The partitions separating each compartment are bolted to mild steel flanges which in turn are welded onto the wall of the vessel and at right angles to it. The inner edges of these flanges are not symmetrical about the longitudinal axis of the vessel but on the upper side of the vessel they project considerably farther into the interior than at other places on the circumference. This projection supports the steel pipe for controls which runs longitudinally through the vessel. (See Figure 173.)

The assembly and internal treatment of the vessel is a long task requiring care and skill. It takes three or four men about two weeks to complete one vessel.

Details of Assembly

The forward end of the vessel is first welded into position then each of the internal flanges is welded in turn. The flanges are all fitted with round-headed stainless steel (18/8) bolts. The heads are firmly sealed to the flanges by welding, in readiness for the final assembly of the partitions. Next the after end is welded on, and the pipe for controls is pushed through the special holes in the ends and in the flanges provided for it. There is a manhole in the after end to allow a worker to enter the vessel and carry out internal treatment.

From the top of each compartment a pipe is welded into position and leads to a relief valve common to all compartments. This valve opens at a pressure of about 5 kg/cm^2 (70 lbs/in^2). The pipes are made of mild steel with

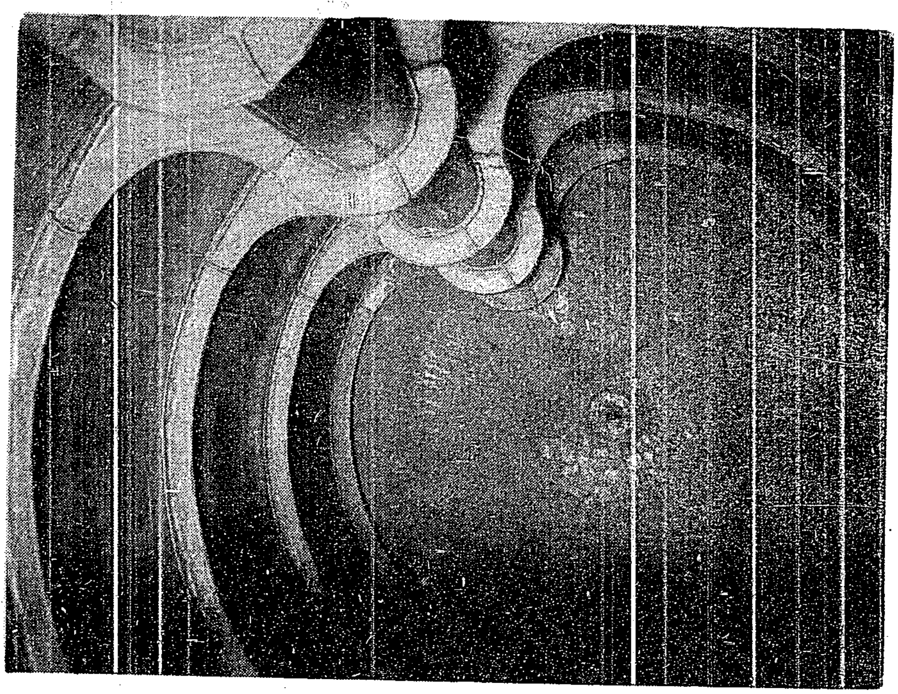


FIGURE 173
"A" LIQUID EXPERIMENTAL VESSEL

pressed 2mm tin linings. A filling cap of stainless steel is also fitted to the top of each compartment. A mild steel pipe is welded to the forward compartment for supplying sea water, and a feed pipe for peroxide to generator is welded to the after compartment. The latter is made of mild steel and lined with tin plate.

Internal treatment: All internal surfaces are sandblasted and then sprayed with tin (thickness 0.5-1.0mm). Next, the whole interior is painted with a solution of hard blown asphalt (hardness 5°) in carbon tetrachloride to a thickness of 1-2mm. During this operation the worker wears a mask and can remain only a short time in the vessel owing to the toxicity of the tetrachloride. He is relieved after about 10 minutes. When the asphalt coating has dried, it is covered with tin plate 1mm thick. This is the most tedious part of the construction, since the welding of the seams in the tin plate must be done slowly and carefully to ensure hermetic sealing. The flanges are similarly covered. At the entrance to the vessel the tin is "lipped" over the edge of the manhole. The connecting pipes between compartments are made of drawn tin 2mm thick.

There now remains the final closing of each compartment. Starting at the forward compartment a shaped piece of tin plate (2mm thick) is slipped onto the flange bolts which project aft. Then four steel bars (covered with tin plate) are placed over the plate to lend the latter support. The nuts are screwed tightly and the plate partition is welded around its outer edge to the flange. Finally small caps of tin plate are welded into position over each nut, completely sealing the latter from subsequent contact with the peroxide. The process is repeated for each compartment in turn, working towards the after end.

The last compartment (with the manhole) is closed by welding a circular sheet of tin plate onto the "lipped" edge of the internal lining. The steel manhole door finally is bolted into position supporting this circular piece of plate.

The result of each step in the elaborate internal treatment is as follows:

Sandblasting	Base for tin spray
Tin spray	Corrosion protection of steel
Asphalt coating	Inert to peroxide
Tin plate	Inert to peroxide

Tin spray is not sufficient treatment in itself, because it tends to be porous. The asphalt coating cannot be left uncovered, since it would be dissolved by the separating liquid which is used between the peroxide and sea water. On the other hand, the asphalt has not been dispensed with, because small cracks may appear in the welded joints of the final tin covering and allow peroxide to leak through the plate.

Welding: Welding of the tin plate is carried out with a small reducing hydrogen/oxygen flame (excess hydrogen). 'Criss-cross' welding across the seams is used to avoid the hair cracks which sometimes appear in smooth welding. A solution of stannous chloride ($SnCl_2$) in water is used for flux.

Vessel tests: Peroxide stored in the vessel deteriorated only 3% in two months during the summer. The vessel stood up well to a rolling and pitching test while full of liquid. In a previous design, polyvinylchloride sheet was used as partitioning material instead of tin plate, but leakage occurred at the partition bolts between compartments.

Separating Liquid

Sea water is used to push the "A" liquid from the vessel to the generator. Since sea water will dilute the peroxide and will also tend to decompose it, the two liquids are not allowed to come into contact with each other. A "separating liquid" is used between the water and the peroxide; it is stored in the forward compartment of the peroxide vessel.

Properties of Separating Liquid

The chief properties required of a separating liquid are:

(1) Inert to and insoluble in sea water
(2) Inert to and insoluble in 80% hydrogen peroxide
(3) Density between that of sea water and peroxide
(4) Stable
(5) Must not attack tin

To fulfill these requirements two liquids were chosen.

(1) The first consisted of a mixture of carbon tetrachloride (sp. gr. 1.6) and rape seed oil (sp. gr. 0.8) in such proportions that the final mixture had a specific gravity of 1.2-1.25.

	Sp. Gr.
80% Hydrogen peroxide	1.35
CCl_4/rape oil mixture	1.2
Sea water	1.0

The disadvantage of this separating liquid lay in the volatility of the tetrachloride; with evaporation of the CCl_4 the density of the mixture drops and the danger of the sea water coming in contact with the peroxide is increased. The use of this separating liquid was abandoned.

(2) The second liquid, which was finally adopted, was alpha-monochlornaphthalene. This compound is a liquid under atmospheric conditions and has a density of 1.194 at 20°C. It is insoluble in and stable to hydrogen peroxide and sea water. (The stability of the peroxide in contact with chlornapthalene was tested over a period of about two months.)

In practice there is usually a layer of separating liquid at least 40 cm thick (16 in) between the sea water and the peroxide.

Hydrazine Hydrate Vessel Design

The design of vessel for "B" liquid and the method of feeding "B" liquid to the generator with sea water pressure, are two problems which are closely related. "B" liquid has a density which is so close to that of sea water that a separating liquid, as is used for "A" liquid, cannot be successfully employed.

The Japanese hit on the idea of putting "B" liquid inside a flexible rubber bag which, in turn, is placed inside a mild steel cylindrical vessel and conforms to the shape of the latter. Now, if sea water is pumped into the vessel, outside the bag, it compresses the latter and forces the "B" liquid to the generator.

Design of Bag

The rubber bag is about 2.5mm thick and of composite structure. The inner layer, 2mm thick, is made of natural rubber which is resistant to attack by hydrazine hydrate. The outer layer of the bag (in contact with sea water) consists of a layer 0.5mm thick of oil-resisting synthetic rubber.

The purpose of this construction is two-fold.

(1) Natural rubber is not attacked by "B" liquid, synthetic rubber is attacked.

(2) Synthetic rubber is relatively resistant to attack by oil. Natural rubber is not resistant.

Thus, natural rubber is a good material to use in contact with "B" liquid, but it must be protected on the outside by an oil resisting material, in case engine oil is brought into contact with it by the feeding sea water.

Two "B" liquid vessels (used in parallel) are fitted in KAITEN 2.

Design and Operation of KAITEN Type 2

Particulars

Additional particulars of the KAITEN Type 2 are as follows:

Date of production	1945
Number produced	2
Reserve buoyancy kg	530
lbs	1166
Trim	level
Hydrogen peroxide vessel	
Volume liters	2630
ft^3	9.29
Weight kg	2236
lbs	4919
Weight of charge kg	3500
lbs	7700

Fuel chamber	
Volume liters	550
ft^3	19.4
Weight of fuel (lbs)	992
"B" liquid chambers	
Volume liters	360
ft^3	12.7
Weight kg	210
lbs	462
Steering air bottles	
Volume liters	430
ft^3	15.9
Pressure kg/cm^2	215
lbs/in^2	3053
Trimming tanks	
Volume liters	not known
ft^3	not known
Main engine	
Type No. 6	Two row, vertical
Maximum hp	1500

General Description

Views of the weapon are shown in Figure 174(a)(b) and a diagrammatic arrangement in Figure 175.

Head: There are two types of heads having the same weight and shape. They are of welded construction, the plate being 4mm (0.157 in) thick. A flange is welded to the after end which is bolted to the forebody.

Exercise Head

This has two blowing mechanisms. There are also two compartments to the blowing tank, the first for adjusting the depth and the second for raising the KAITEN if it sinks; one is connected to the automatic blowing device and the other is controlled by the pilot. Since the first compartment is located in the bottom of the head the object of the second compartment is to enable the pilot to increase the buoyancy should he run ashore and damage the head and the first compartment. This modification was made as a result of experience with Type 1. The mechanisms are exactly the same as in Type 1.

The recorder fitted is of special design. Since the range is so long the clockwork for rotating the paper is controlled by the pilot who can start and stop it at will.

Warhead

No blowing mechanism is fitted, it is filled completely with explosive. The two detonators which are fitted are similar to those in Type 1 and the method of firing is the same.

Midship Section

Forward Part

The forward ends of the steering air bottles and of the fuel tank project into the body of the head. The steering air bottles are of standard commercial design (Sumitomo Co., OSAKA) and have detachable ends held on by six bolts. A pipe in the center connects them. They are located in the upper half of the body above the fuel tank. (See Figure 176.) All these are carried on a U-shaped sea water tank.

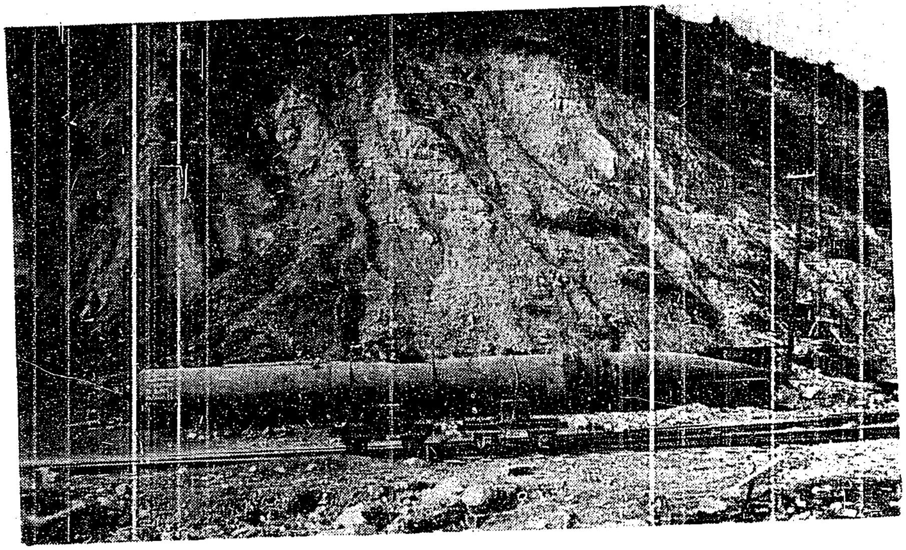


FIGURE 174(a)
GENERAL VIEW, KAITEN TYPE 2

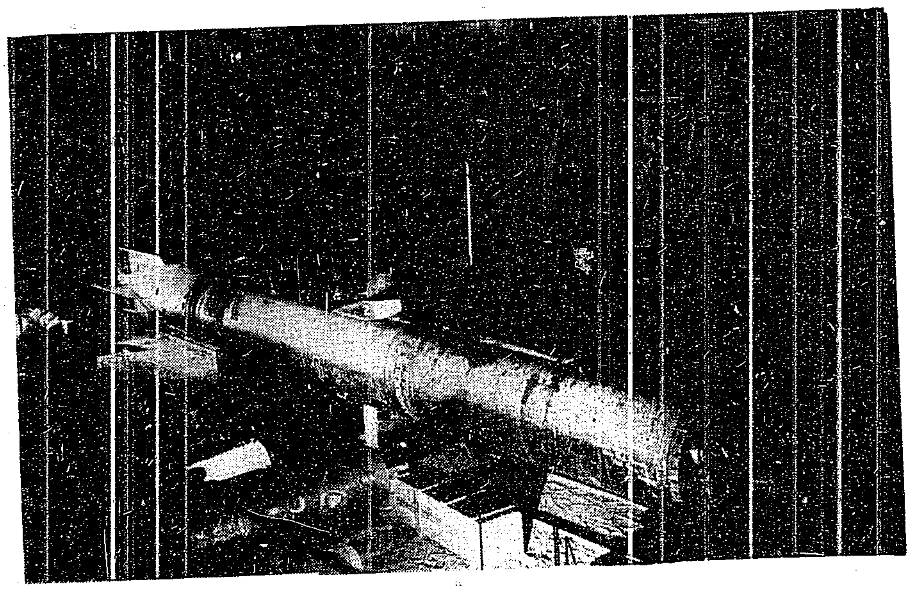


FIGURE 174(b)
GENERAL VIEW, KAITEN TYPE 2

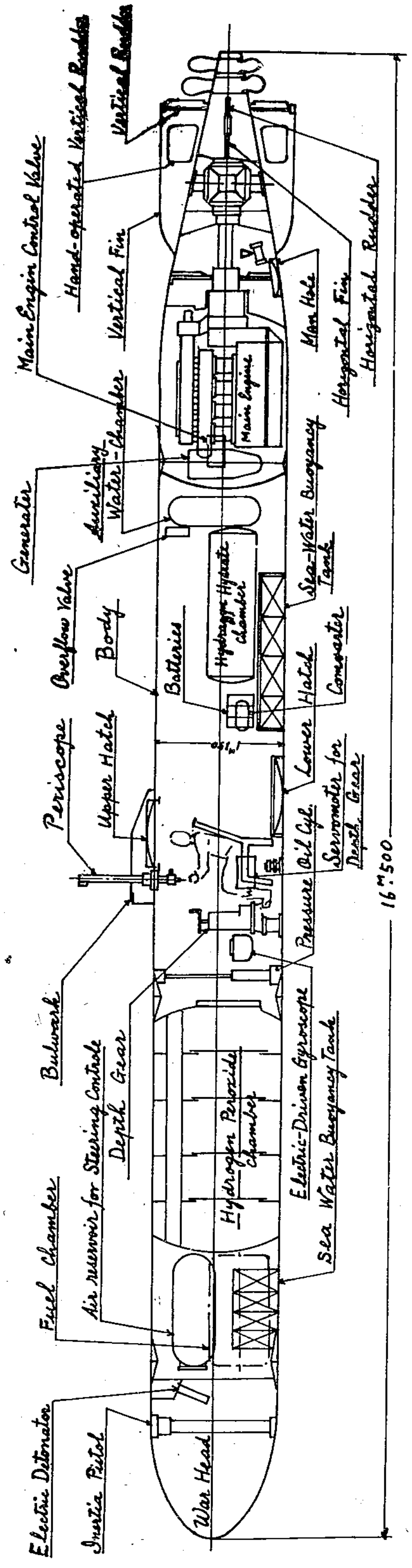


FIGURE 175
OUTLINE DIAGRAM. KAITEN TYPE 2

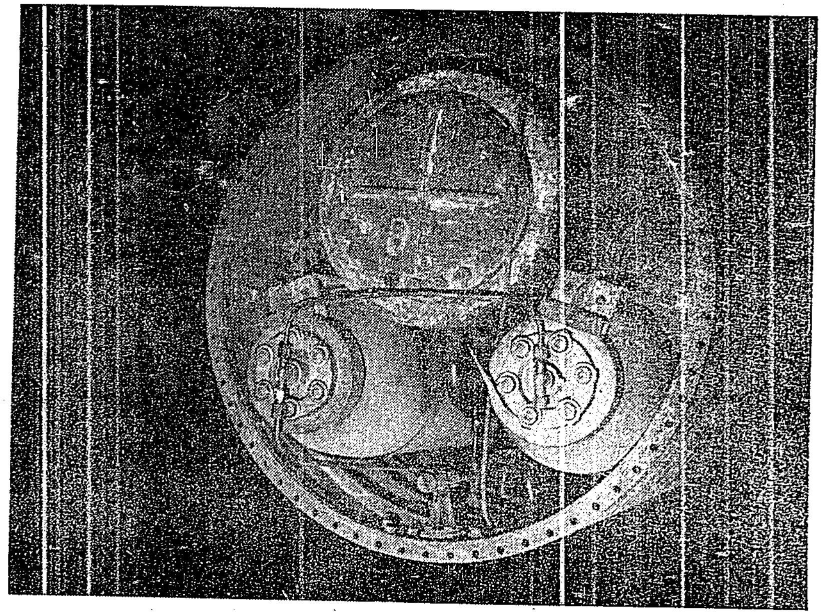


FIGURE 176
FORWARD END OF FORWARD PART OF
MIDSHIP SECTION, KAITEN TYPE 2

At the top of the body are two junction boxes for the electric detonators. In the center is the pistol safety mechanism control.

From the top of the fuel tank is the filling connection and branching into it is the sea water supply pipe for displacing the fuel.

At the after end of the tank is the fuel supply pipe to the engine.

From the four sea water tanks are vent pipes which run along the top of the chamber through the peroxide container to the pilot's control room.

The after end of the forward midship section forms the peroxide container. It is of welded construction, of mild steel plate lined with tin 1mm (0.0394") thick, gas welded. It is divided into five compartments and is tested to 30 kg/cm^2.

Five vent pipes, one from each compartment, are taken along the top to a safety valve on the external surface of the body. The forward compartment contains the separating liquid. Toward the top of the container a large diameter pipe is inserted throughout its length through which the leads and control pass.

The safety bulkhead is welded to the angle ring and stiffened by 14 triangular stiffeners and has an inspection door. (See Figure 177.)

<u>Pilot's Control Room</u>

The pilot's control room extends from the peroxide chamber to the engine room. (See Figure 178 to 180.) It contains:

- Periscope and elevating gear
- Gyroscope
- Depth gear
- Trimming tank controls
- Engine control

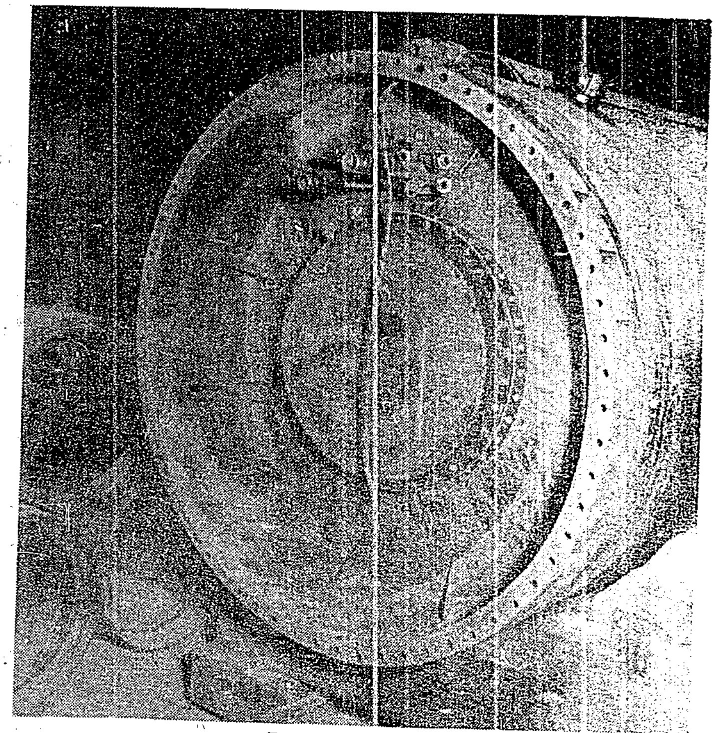


FIGURE 177
AFTER END OF FORWARD PART OF
MIDSHIP SECTION. KAITEN TYPE 2

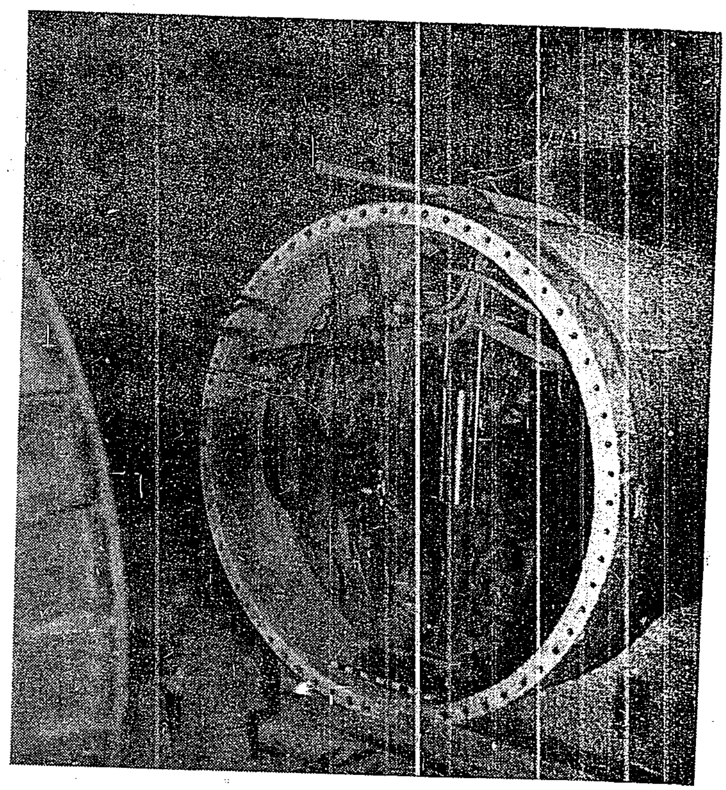


FIGURE 178
PILOTS CONTROL ROOM, FORWARD END. KAITEN TYPE 2

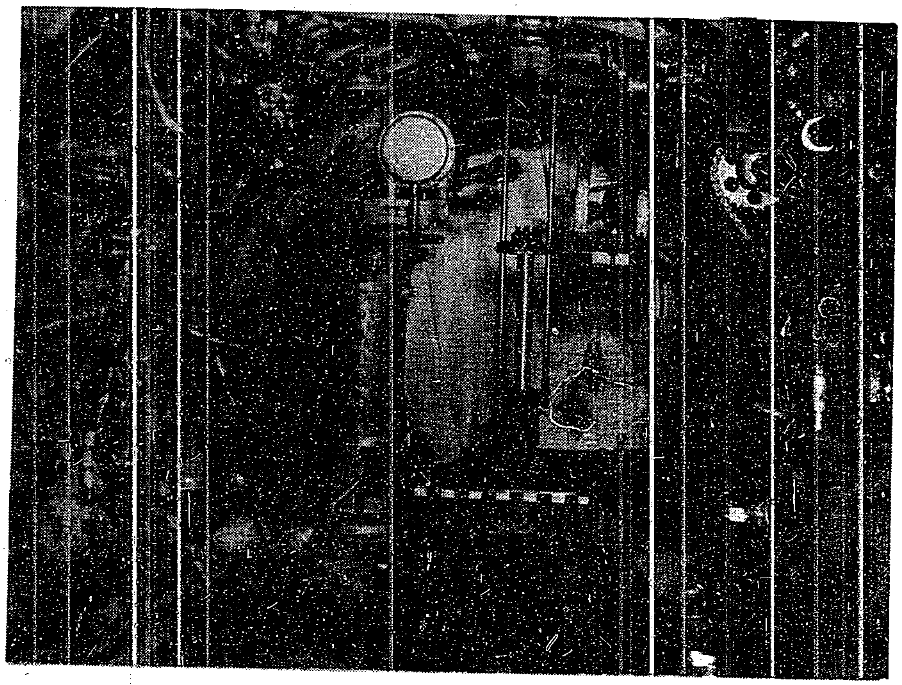


FIGURE 179
PILOTS CONTROL ROOM, GENERAL VIEW, KAITEN TYPE 2

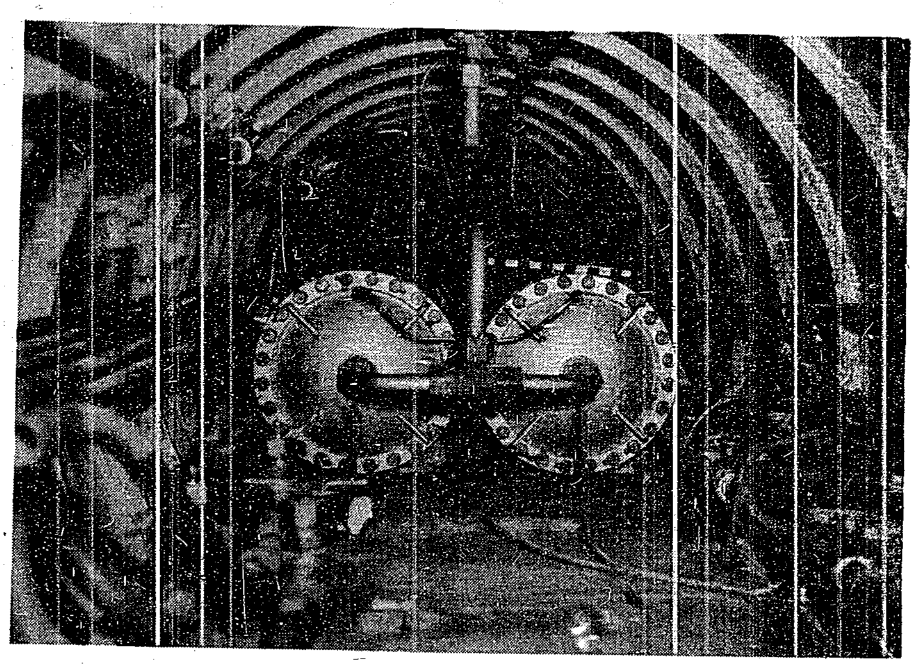


FIGURE 180
PILOTS CONTROL ROOM, AFTER END, KAITEN TYPE 2

Depth and inclination meters
Telephone

The pilot sits well forward in the compartment facing the periscope. The hoisting mechanism for the latter is forward and in the center of the compartment. It is operated by the pilot's right foot which controls a valve in the oil pressure supply line.

When sitting in his seat the pilot can operate the following:

Port Side

The depth gear: This is well forward and is mounted on a welded steel pedestal 5-6mm thick. It has a control wheel attached to the hydrovalve spindle.

The servomotor: The servomotor for the horizontal rudders is bolted to the shell just aft of the depth gear. It is fitted with an emergency control connected to the slide valve so that, should the depth gear fail, the pilot can control the servomometer by hand.

Trimming tanks: Level with the pilot and above the center line are a group of eight valves controlling the release of air from the trimming tanks. Water is admitted to the bottom through a valve on the floor level. There are two groups of four tanks, one group forward and one aft, with one inlet to each group. Trimming is done by control of the vents, water pressure being always on the tanks. A small Kingston valve for admitting sea water to the negative tank is aft of the main sea water inlet valve. The negative tank fulfulls the same purpose as in Type 1; i.e., it is used for the initial submerging.

Switchboard: Aft of the pilot, high up, is a switchboard for electric controls. The switches control:

Rotary converter
Roof light
External light
Depth and inclination gauge illumination

Rotary converter: A small rotary converter is needed to supply three-phase current to the electric gyroscope from the batteries which are mounted on a platform across the center of the control room aft of the lower hatch and forward of the "B" liquid bottles.

Oil reservoir: Right aft is a small bottle containing oil for the oil pressure circuit.

Starboard Side

Gyroscope: This is an electrically driven one which has been described in the gyroscope section.

Vertical rudders: Just above the gyroscope is the hand wheel of the hand-operated vertical rudders. The control is a bevel wheel type with a chain drive to balanced rudders in the vertical fins.

Engine control: Beside the pilot is the engine control. This is a small rotary type oil valve connected to the automatic engine control unit in the engine room on the port side of the engine near the generator.

Reducer unit: Aft of the engine control is a gas-tight rectangular container housing the main reducers for the engine, servomotor and steering engine. The container is vented to outside the shell.

Air from the air reservoirs passes through a main stop valve which when opened admits air to the starting reducer. The adjustment of this is fixed so that the pressure of the air entering the engine revolves it slowly. A branch from the main air line after the stop valve admits air through a second stop valve to the first stage of the reducer, from where it passes at a reduced pressure of 30 kg/cm^2 to the top of the oil bottle and through the second stage to the buffer chamber.

From the oil bottle the oil is supplied to the rotary engine control valve and to a slide valve used for emergency control. The handle of the latter is outside the shell of the KAITEN so that, if the pilot has an opportunity of escaping, he can turn his handle which sets the engine to full power and at the same time lowers the periscope before swimming away.

When the pilot moves the rotary valve handle into the first notch, oil is admitted to the low speed set of valves of the automatic engine control. These valves are opened, liquids are admitted to the generator and the engine runs hot.

When the handle is moved to the next notch, oil is admitted to the bottom of the second stage of the reducer, compresses the spring and increases the air pressure on the buffer chamber thus increasing the delivery of the liquids and hence the power of the engine.

For the next notch oil is admitted both to the second set of valves in the automatic engine control unit and again to the bottom of the second stage of the reducer. The power of the engine is increased due to additional quantities of liquids being supplied through two sets of valves at a higher pressure.

For the final notch the third set of valves is brought into operation and the engine output is increased to a maximum.

Air to the gyroscope and servomotor is supplied from the second stage of the reduder.

Gauges: Right forward three gauges are mounted in the overhead. They record:

Pressure in steering air reservoir
Reducer pressure of steering air
Pressure in oil circuit

Pistol: The safety mechanism for the two electric detonators is operated by the pilot by a lever mounted in the roof.

Depth gear: On the deck is the control valve for admitting sea water to the hydrostatic valve of the depth gear.

Fuel gauge: Forward of the pilot is a water meter which records the amount of water entering the fuel tank to displace the fuel. It thus acts as a fuel meter.

H.P. Sea water pump: A big stop valve near the pilot admits sea water to the high pressure diluent pump. The water displaces the "A" and "B" liquids and fuel and acts as diluent. In the "A" liquid circuit is another water meter to indicate the quantity admitted to the peroxide chamber, i.e. measuring the quantity used as in the case of the fuel.

Hydrogen peroxide: Beside the pilot is the main valve for admitting peroxide to the engine.

Engine starting: Above the pilot is the engine air-starting valve. When this is opened air from the main reducer passes to the generator and starts the engine.

Steering air: Slightly behind the pilot on the upper side of the shell is the charging valve for the steering air reservoirs.

Fuel and "B" liquid: The stop valves for the fuel and "B" liquid are located together. Opening the valves admits the liquids to the automatic engine control unit.

Training: Two small valves are added to a second set of depth gauges for training purposes to indicate the depth to the instructor who is sitting behind the pilot. These are removed for a war run.

Center

Hatches: There are an upper and a lower hatch, the upper being the main one. This is situated immediately above the pilot. Behind the pilot in the deck is a small hatch for telephone and battery charging leads. Behind this is the main lower hatch, through which the pilot enters the KAITEN when the weapon is carried on the deck of a submarine.

Lighting: There is one overhead light aft of the main hatch and one forward, together with an external light to indicate the position of the KAITEN during training.

Stop valves: In the rear part, aft of the manhole, there are large valves not needed for control during running but which must be opened before starting.

(1) Main sea water overflow
(2) Diluent water delivery from pump to main engine control unit
(3) Delivery from sea water diluent pump to buffer chamber
(4) Cooling water to engine

These valves are shut until the start of the run.

There is also a small valve for exhausting water from the engine crankcase. If the submarine which carries the torpedo dives deep enough, water will get into the engine crankcase and must be exhausted before starting.

"B" liquid containers: In the after part of the control room are the two "B" liquid containers placed one on each side of the center line. They are connected at the forward end by a four-way piece.

The connections are:

(1) Filling
(2) Draining
(3) Connecting the two together

Buffer chamber: This is situated at the extreme rear of the compartment. It is similar to and operates on the same principle as that of Type 93.

Water meters: Beside the "B" liquid chambers are two small water meters for measuring the quantity of:

(1) "B" liquid used
(2) Diluent pumped to generator

So that the ratios can be obtained, there are, in all, four meters:

(1) "A" liquid
(2) "B" liquid
(3) Fuel
(4) Diluent

Engine Room

The engine room is of standard steel plate, welded, open to the sea water. (See Figures 181 and 182.) It contains the generator, control unit, pumps, oil cooler, engine and lubrication oil tanks, the latter being situated on the port side.

The control unit, generator, and main engine are dealt with in separate sections.

After Body and Propellers

The afterbody is of standard ship's plate and is welded together. (See Figure 183.) The plate is 5-6mm (.197"-.236") thick. The design is similar to that of the torpedo except that the angle of the cone is steep due to a limit of length; therefore, it does not have a good streamlined shape.

It contains only the standard mitre reversing gear. The thrust is taken on the forward bulkhead.

Low down on the starboard side is a hatch for assembly of the gearing.

The fins are an enlarged form of the torpedo design. There are extensions of the angle irons to protect the propeller blades.

The propellers are similar in design to those of the Type 93 torpedo except that there are only three blades, because the engine power is small for the size of the hull.

From the results of model tank tests the value of the effective horsepower was calculated and from this the propellers were designed.

MAIN ENGINE CONTROL

The control of the main engine is in two parts:

(1) Pilot's control (See Figure 184)
(2) Automatic engine control unit (See Figure 185)

PILOT'S CONTROL

This consists of a disc valve operated by a single lever which is rotated by the pilot.

The control body is a bronze casting with six nipples, one for the high pressure (30 kg/cm^2, 426 lbs/in^2) oil inlet, one to each of the three valve units in the engine control, one to the reducer and one for oil release.

The disc is held against its working face by a spring held in by a cover screwed into the body. A spindle connects the handle to the center of the disc.

Oil enters from the side of the casting and the pressure holds the disc against the face.

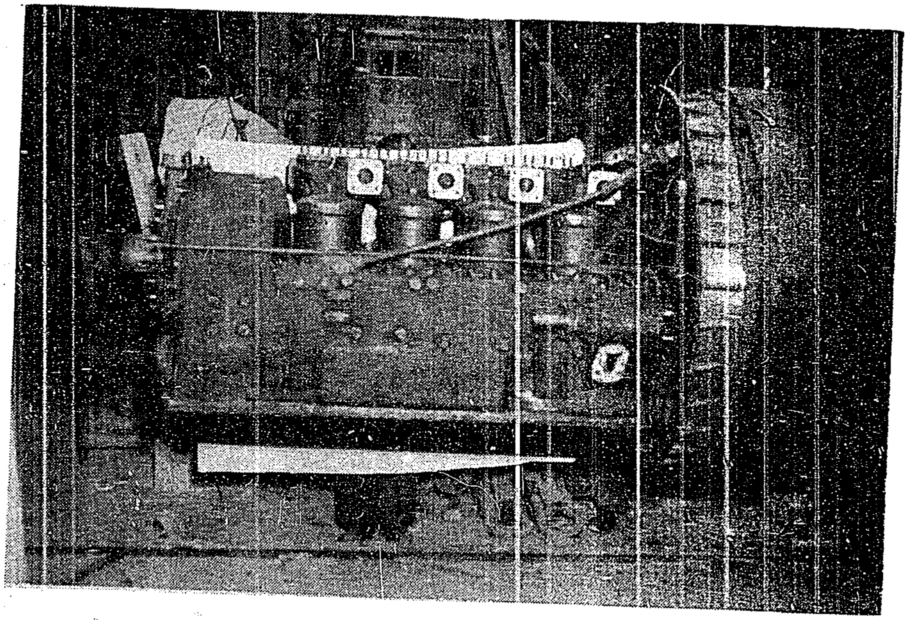


FIGURE 181
ENGINE NO 6 IN POSITION, KAITEN TYPE 2

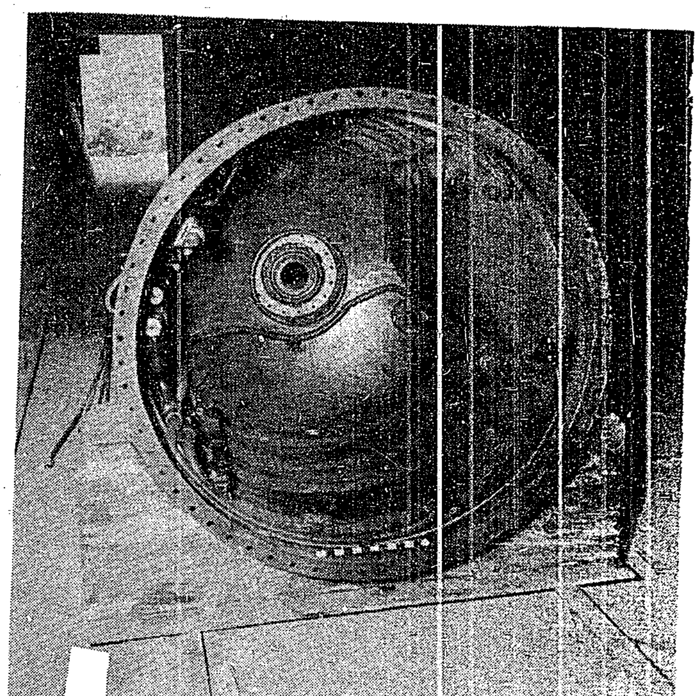


FIGURE 182
INTERIOR OF ENGINE ROOM, KAITEN TYPE 2

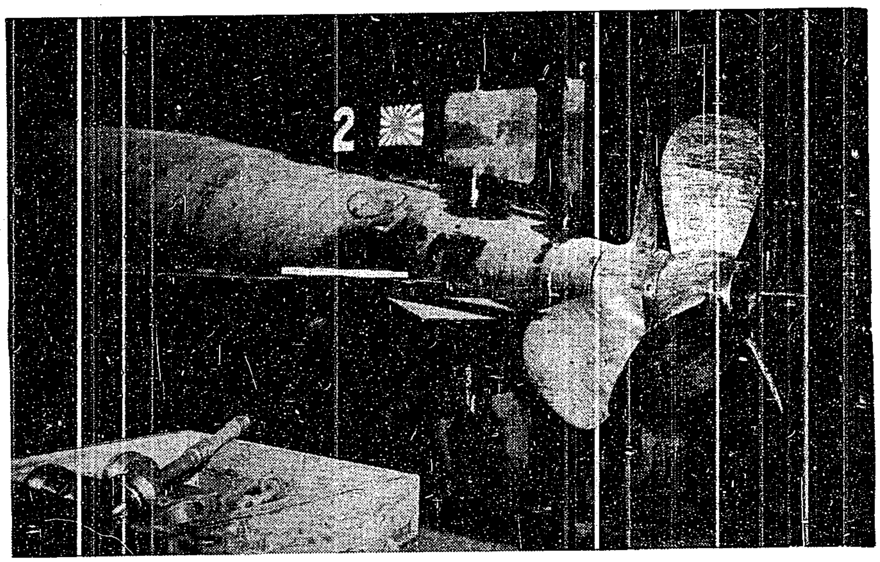


FIGURE 183
AFTER BODY AND PROPELLERS, KAITEN TYPE 2

The oil passes through a hole in the disc into an arc-shaped recess in its working face.

A similar recess diametrically opposite is connected by a milled channel to the center of the disc. There is a drilling for exhaust in the center of the valve body to correspond. The dimensions of the recesses are such that all four control nipples can be connected to high pressure oil or to release. As the disc is rotated first one and then another is connected to the oil circuit, the remainder still being open to exhaust.

ENGINE CONTROL UNIT

This unit controls "A" liquid, "B" liquid, fuel and water supplies to the engine. It is composed of three sets of valves and plungers identical in design. Each group consists of a spring loaded non-return valve opened by a plunger which is operated by the oil pressure.

The body is a phosphor-bronze casting with the valve, nipples and plugs of stainless steel. The oil plungers are of forged bronze.

The three valve groups are arranged in one plane. On one side of the body there are:

Inlet for "A" liquid

Three outlets for "A" liquid having bores to suit the quantities

Inlet for fuel

Three outlets for fuel
Three outlets for "B" liquid

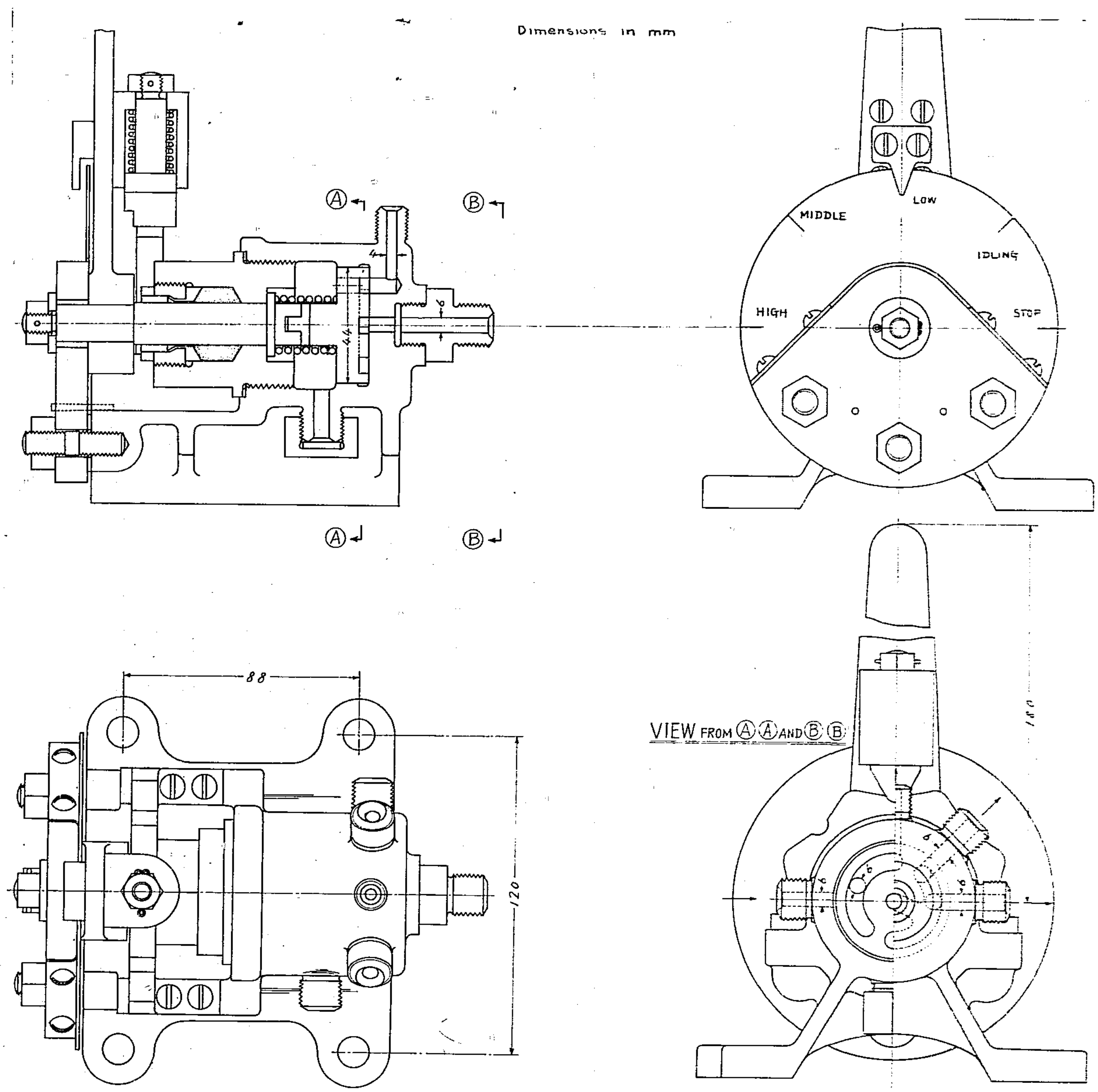


FIGURE 184
PILOTS CONTROL OF ENGINE, KAITEN TYPE 2

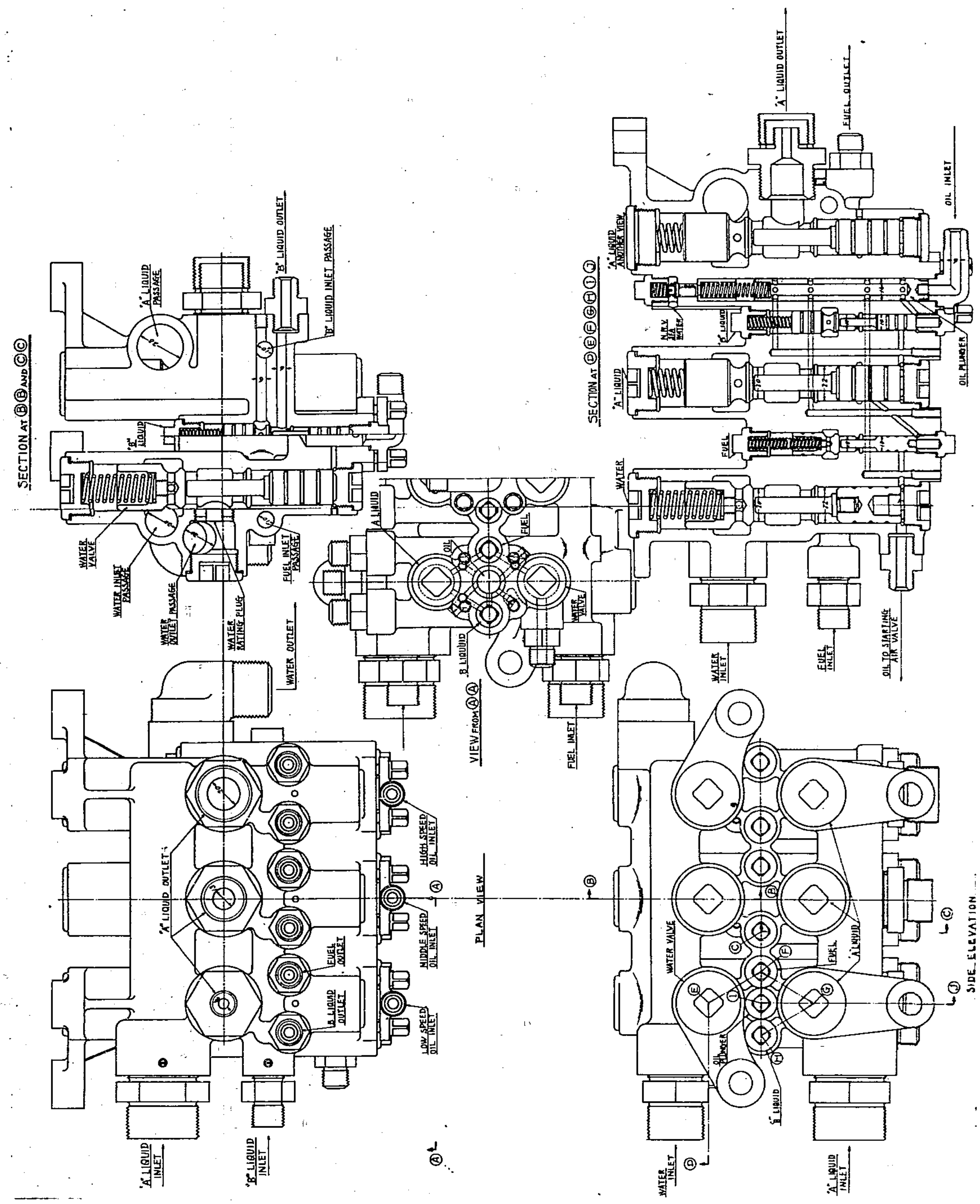


FIGURE 185
AUTOMATIC ENGINE CONTROL UNIT, KAITEN TYPE 2

On the other side are:

Water inlet and outlet

"B" liquid inlet

Oil outlet to air starting valve

On the top there are the three elbow pieces for the oil inlet.

ENGINE OPERATION

To start the engine the pilot first opens the starting air valve and admits compressed air to the bottom of the generator. The engine then rotates slowly.

When the control handle is moved into the lowest speed position, oil is admitted to the base of the low speed group and lifts the valves in that group in the following order:

"B" liquid
"A" liquid
Fuel
Water
Oil to starting air stop valve

The starting air stop valve under the oil pressure closes against the steering air pressure. The engine is now fed with fluids and runs at the lowest speed output. For the next speed the control handle is moved to the next position and the reduced air pressure to the buffer chamber is increased.

For the higher speed settings the second and third sets of valves are opened.

Now, since the port arrangement is such that oil can only reach the two subsequent groups through the first, for the middle speed two groups are in operation and for the high all three are open.

Only the metering of the water is carried out in the engine control unit; there are three chokes, each one governing the quantity from the particular unit. The delivery from the first is correct for the low speed, from the first and second for the medium and from all three for the high speed.

Upon reversing the motion of the handle from high to medium, the high speed group oil circuit is connected to release and the pressure vented, allowing the valves to close. The same occurs to the middle group for the next stage.

In the stop position all oil circuits are vented and all valves are closed no liquids flowing.

FLOW OF REACTANTS

A diagram of the KAITEN 2 circuits is shown in Figures 186(a) and (b).

SEA WATER

The sea water pump for displacing the reacting fluids and for supplying diluent water to the generator is attached to the engine casing. It takes in water from the engine room and pumps

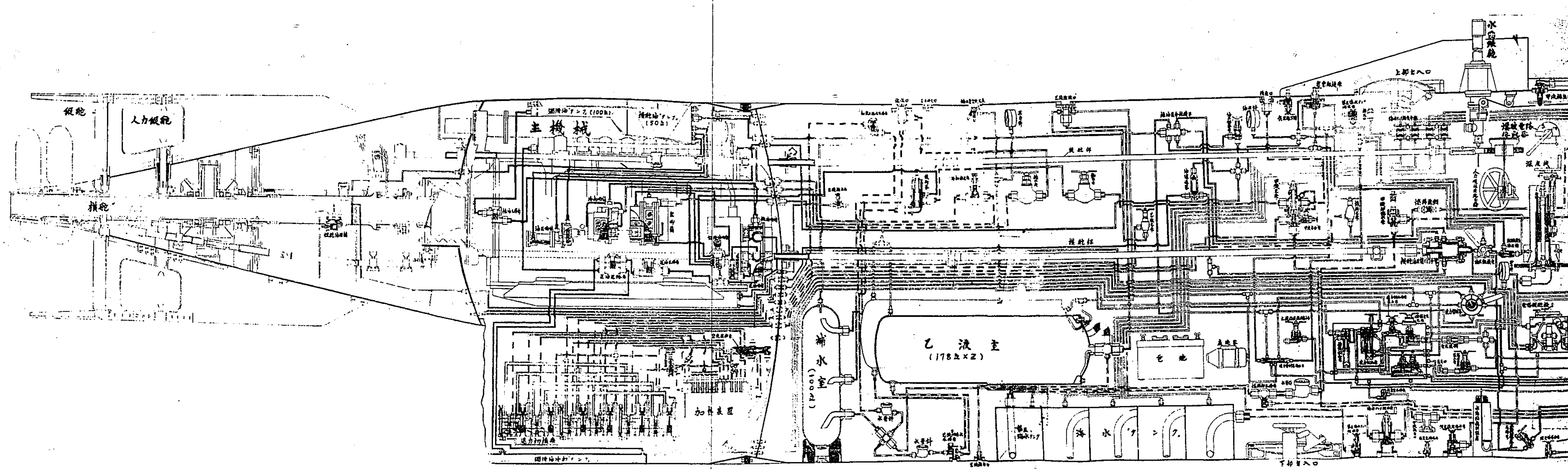


FIGURE 186(a)
CIRCUIT DIAGRAM, KAITEN TYPE 2

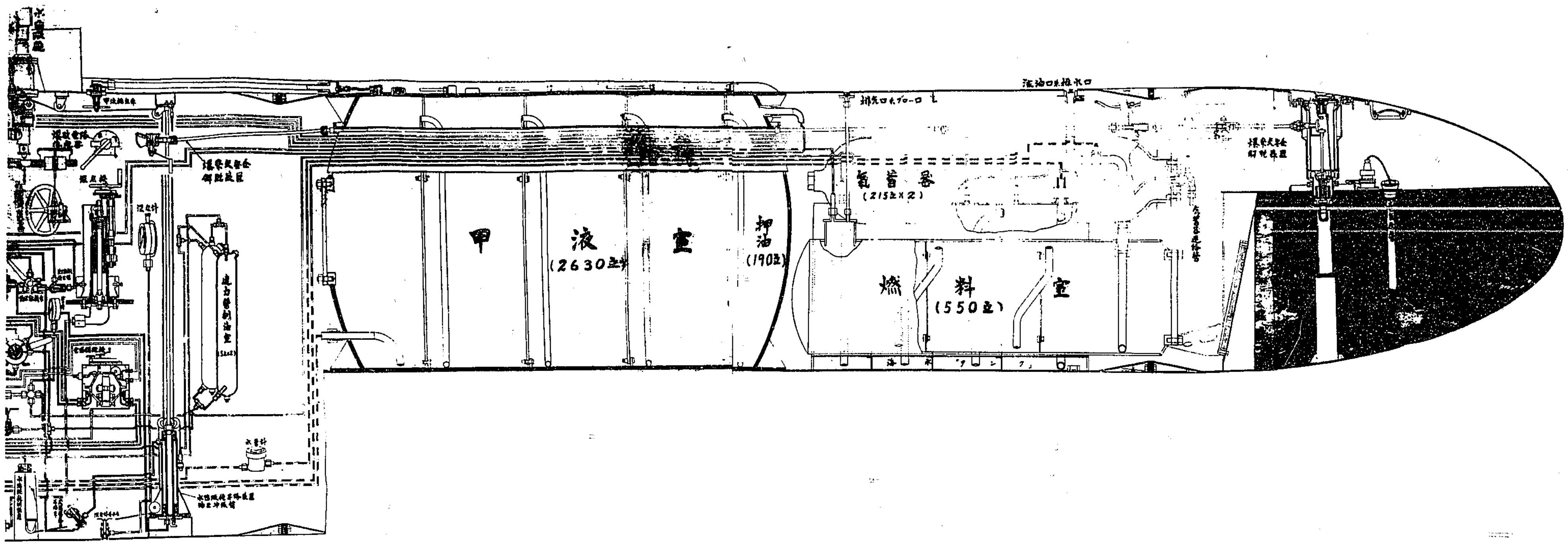


FIGURE 186(b)
CIRCUIT DIAGRAM, KAITEN TYPE 2

it through a stop valve in the pilot's cockpit to the buffer chamber; the water enters the latter near the middle of the chamber. In this water supply line is a filling valve fixed on the upper side of the hull. Through this valve the buffer chamber can be filled with water.

Two water pipes lead from the buffer chamber, one from the upper side and one from the lower side. The upper pipe passes to the regulating valve, from which the overflow of the buffer chamber goes through a stop valve, through the hydrogen peroxide stop valve and then to the sea, via a non-return valve on the upper side of the hull. The lower pipe goes to a three-way junction. One way passes through a flow meter and a non-return valve to the automatic control unit and hence to generator. One way goes forward to a two-way junction which sends a feed pipe to the vessel and a feed pipe to the forward compartment of the peroxide vessel. Both of these pipes pass through flow meters. The third pipe from the three-way junction goes through a flow meter and then divides into two pipes, one for each of the two hydrazine hydrate vessels.

The cooling pump for the engine has already been dealt with in the engine section.

HYDROGEN PEROXIDE

The peroxide passes, by sea water displacement, from the after compartment of the "A" liquid vessel. It goes through the main peroxide stop valve to the automatic control unit and hence to the generator. The peroxide stop valve is made of 18/8 stainless steel and across the top of the valve passes the overflow from the buffer chamber. A relief valve connects the peroxide line with this overflow. Thus, if serious decomposition of the peroxide (due to rust or other dangerous contamination) takes place in the valve, a pressure build-up will be prevented by the relief valve. Futhermore, if the stop valve should leak, the concentrated peroxide will be diluted and carried to the sea by the buffer overflow.

HYDRAZINE HYDRATE

The two "B" liquid bottles are connected in parallel and the hydrazine hydrate passes, by sea water displacement, through the "B" liquid filling valve on the upper side of the hull. From here, the hydrazine goes through the "B" liquid stop valve, then to the automatic control unit and hence to the generator.

FUEL

The fuel, displaced by water, goes aft through the "A" liquid vessel, through the fuel filter and fuel stop valve to the automatic control unit and then to the generator.

AIR

The two compressed air bottles are connected in parallel. An air lead runs from the forward ends of the bottles through the "A" liquid bottle to a three-way junction. From the junction one pipe leads to a pressure gauge, one to the main reducing unit, and one to an exhaust stop valve. This reducing unit incorporates the main reducer, the disc reducers for the gyroscope and the reducer for the starting air.

From the main reducing unit pipes run:

(1) To the oil-controlled starting air valve and then to the bottom of generator.

(2) To a non-return valve on the upper side of the hull, to a pressure gauge, and then by two leads to the air nozzles in the top of the buffer chamber and the regulating valve.

(3) To trimming tanks. These are dealt with in the section on KAITEN control.

DESIGN OF GENERATOR

For a general view of the generator see Figures 187 (a) and (b). The body and head are made of 18/8 stainless steel. The products of combustion are led to a welded T-piece at the bottom of the generator whence they pass to the engine via two induction manifolds.

HEAD

The head consists of an 18/8 stainless steel forging with a mild steel plate screwed to the underside (See Figure 188). Holes, for fitting nozzles, are drilled through the head at right angles to its face. Using special nozzles, "A" liquid, "B" liquid and fuel are supplied to the generator through these holes. (Diluent water is supplied through the generator wall).

For the "A" and "B" liquids 10 holes, 46.7mm (1.84 in) in diameter, are drilled. Of these, one is drilled through the center of the head and the remaining nine are drilled symmetrically around the circumference.

For the introduction of fuel, three holes, 16mm (0.63 in) in diameter, are drilled symmetrically around the central hole. The fuel nozzles are screwed into these holes and project into the body of the generator.

UNDERSIDE

To the mild steel plate, on the underside of the head, are welded 10 skirts of mild steel. These skirts surround the holes through which liquids "A" and "B" are introduced, and, on the inner surface of these skirts, the reaction between "A" and "B" liquids takes place. (These skirts were cooled by jets of water from the walls of the water jacket, in later designs. This is not shown in Figure 188).

Dimensions of skirt:

	mm	inches
Internal diameter	40.6	1.6
External diameter	46.0	1.81
Length	76.0	3.0
Thickness of mild steel plate	5.9	0.23

NOZZLES

"A" and "B" liquids: This nozzle has three main sections: the outer holder, the inner "A" liquid duct and swirler, and the central "B" liquid duct and swirler (See Figure 189).

The outer holder of the nozzle is screwed into the hole provided

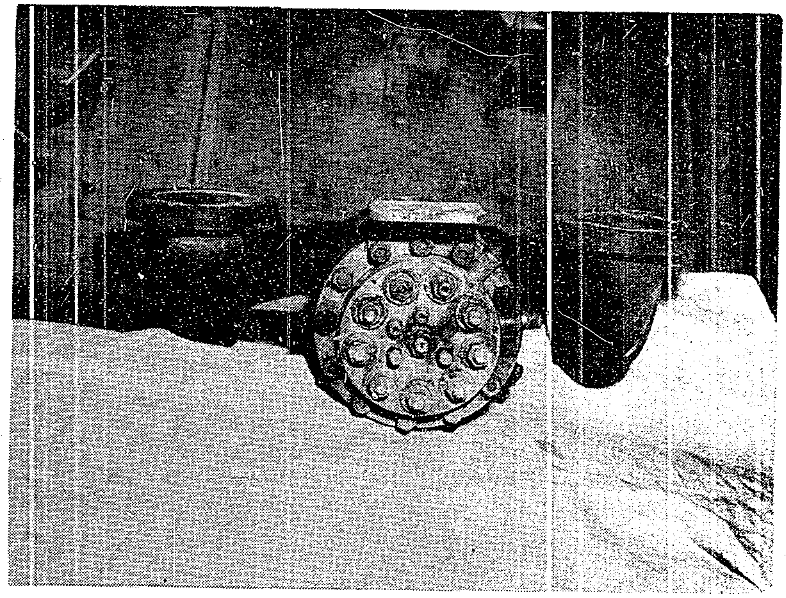


FIGURE 187(a)
GENERAL VIEW OF GENERATOR, KAITEN TYPE 2

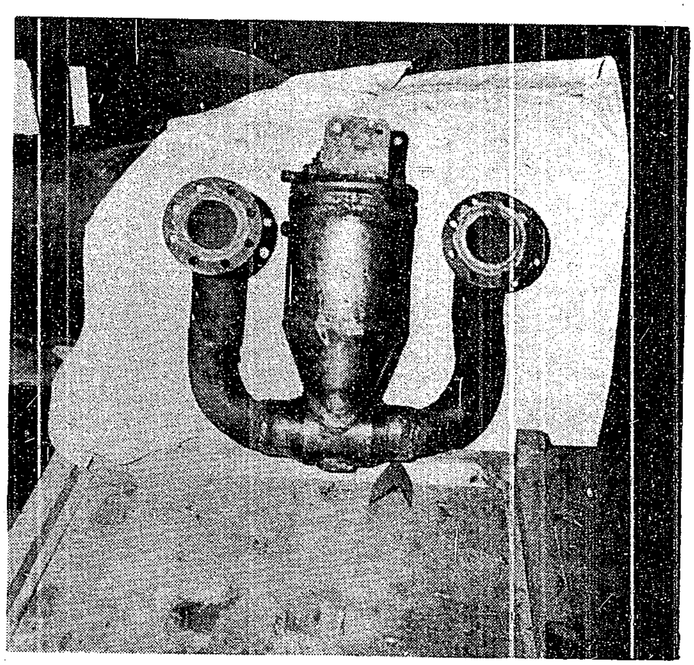


FIGURE 187(b)
GENERAL VIEW OF GENERATOR, KAITEN TYPE 2

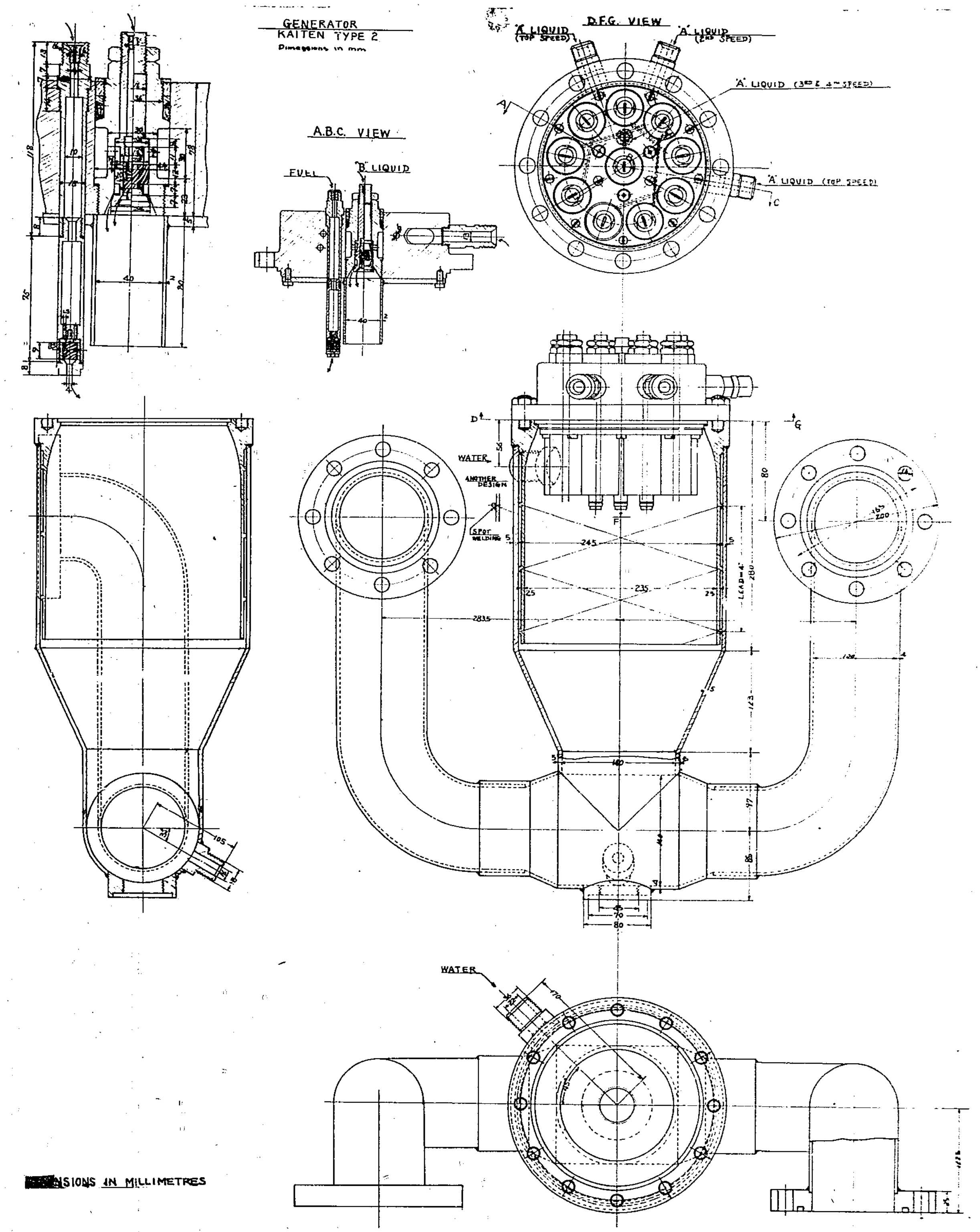
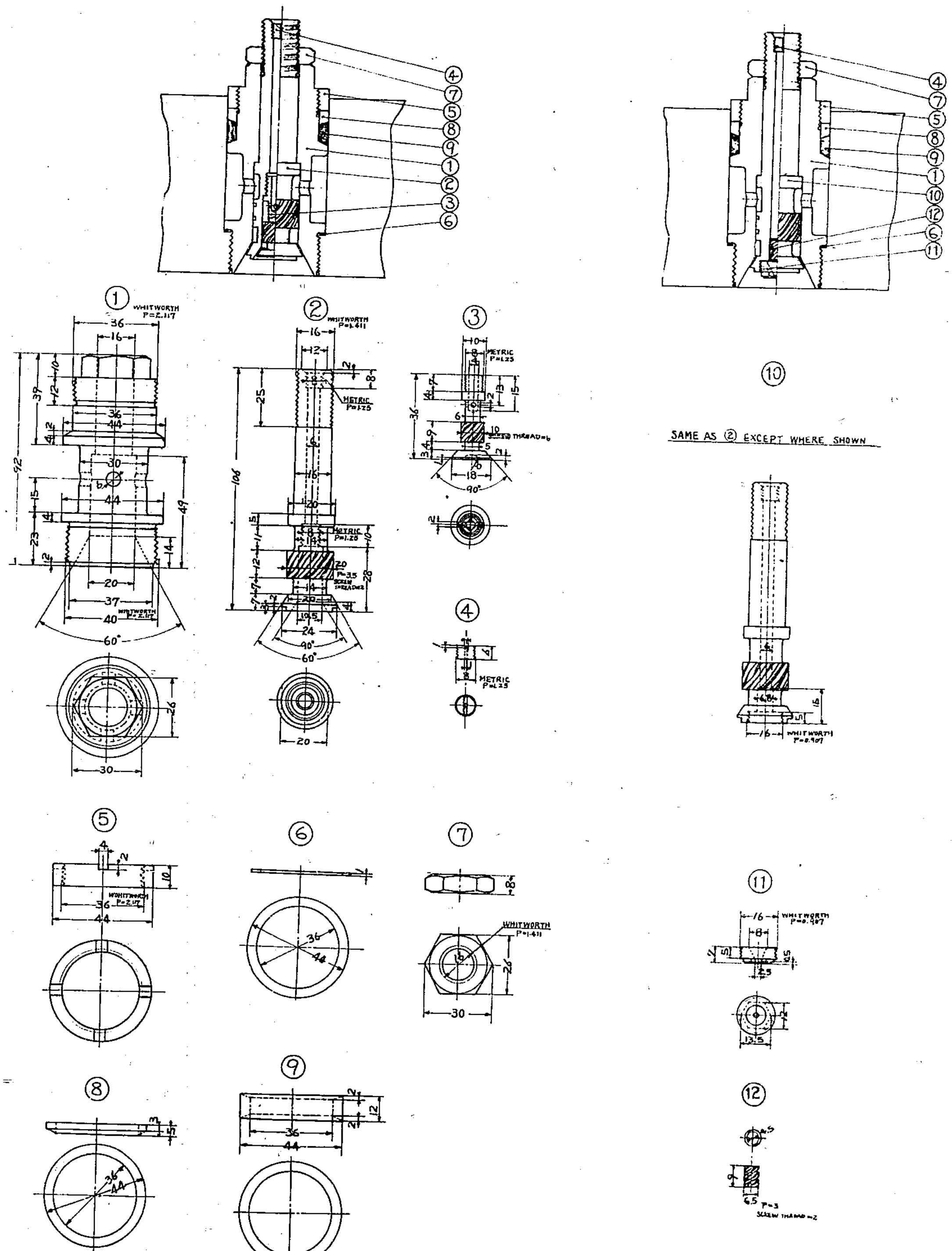


FIGURE 188
DESIGN OF GENERATOR, KAITEN TYPE 2



DIMENSIONS IN MILLIMETRES

FIGURE 189
DETAILS OF "A" AND "B" LIQUID NOZZLE, KAITEN TYPE 2

in the generator head. It is so designed, that an annular space is left between the holder and the generator head casing. The lower part of this space is sealed with a tin washer, and the upper part, by asb stos cord wound in a special groove machined in the upper portion of the holder. The holder is made of 18/8 stainless steel.

The "A" liquid passes through holes drilled in the side of the head into the annular space around the holder. From here, it passes through four holes into the annular space in the "A" liquid section, above the "A" liquid swirler. It then passes through the latter and out into the generator through a conical aperture formed by the mouth of the holder and the face of the "A" liquid section. The annular space above the "A" liquid swirler is sealed on the upper side by a tin washer. The thickness of the washer determines the position of the "A" liquid section face relative to the mouth of the holder. The "A" liquid section is integral and is machined from 18/8 stainless steel.

The "B" liquid section is fitted inside the "A" liquid section. Thus, the "B" liquid, introduced from the top of the generator head, passed down the central axis of the nozzle, through four holes into the annular space above the "B" liquid swirler, through the latter and into the generator via the conical aperture formed by the face of the "B" liquid section and the face of the "A" liquid section. As in the case of the latter section, the annular space above the "B" liquid swirler is sealed on the upper side with a tin washer. The thickness of this washer determines the size of the aperture through which "B" liquid has to pass to the generator. The "B" liquid section is integral and is machined from 18/8 stainless steel.

The faces of these nozzles for the introduction of "A" and "B" liquids are in the same plane as the underside of the generator head.

Fuel: The fuel nozzle consists of a pipe of 18/8 stainless with a length of 83.5mm (3.29 in) and an external diameter of 16mm (0.63 in). This is screwed into the underside of the generator head. The fuel is supplied through the head, down the fuel nozzle, past the fuel swirler and into the generator through a hole 4.1mm (0.16 in) in diameter. The swirler can be removed by unscrewing a section 7.3mm (0.288 in) in length from the end of the nozzle. The fuel nozzle projects into the body of the generator.

SUPPLY OF REACTANTS

"A" liquid: This is supplied to the nine nozzles on the circumference of the head through three drillings in the side of the head. Two of these drillings supply three pairs of nozzles, each pair being symmetrically placed on the circumference. The third drilling supplies the remaining three nozzles on the circumference. Connecting ducts between the nozzles are made by drillings through the head forging as required.

The tenth, and central, nozzles is supplied with "A" liquid through a special drilling made between two of the fuel inlets of the head, from the underside of the head.

"B" liquid: This is fed with 10 pipes to each of the "B" liquid inlets on the top of the generator head.

Fuel: This is supplied with three pipes through the top of the generator head to each of the three fuel nozzles.

SPEED CONTROL AND RATING

Unlike the usual torpedo, in which only one speed setting can be used in one run, the KAITEN pilot can vary his speed settings at will. For the low speed setting only the central nozzle in the head is used for supplying liquids "A" and "B" and only one fuel nozzle. For the middle speed setting, three further nozzles on the circumference can be switched in, and one more fuel nozzle. For the top speed setting all the liquids "A" and "B" nozzles are used and all three fuel nozzles. In addition the supplying pressure can be varied, giving an intermediate speed between the first speed and the middle speed.

Rating: Thus, it will be seen that the rating of each nozzle is kept constant, but the number of nozzles in operation is varied according to the performance required.

Control: To change the speed, the pilot operates one valve which in turn operates a master control valve. This latter, automatically increases or reduces the number of nozzles in use, as required by the pilot. It also alters the quantity of water flowing to the generator as required.

GENERATOR BODY

The upper section of the body is fitted with a skirt or double wall. Diluent water is introduced near the top of the body and passes along a spiral between the skirt and outer wall. This system is similar to the design of the British wet heater torpedo. By this method the diluent water is introduced low down in the generator body.

The head is bolted to the body with 12 half-inch bolts. The seal is made with a stainless steel washer.

GENERAL

It will be seen that in this design the peroxide reacts with the hydrazine hydrate and is decomposed on the steel skirts placed around the nozzles. Then the liberated oxygen, heated to a high temperature by this reaction, meets the fuel which is injected into the chamber slightly lower than the bottom of the skirt, and combustion of the fuel and oxygen ensues.

The design of the "B" liquid section in the nozzle was slightly altered just before the end of the war. The new design of "B" liquid duct was rather similar to the fuel nozzle, in that the conical aperture in the "B" liquid section was replaced by a small hole (diameter 2.5mm; 0.1 in). This design was claimed to be less critical in adjustment and easier to manufacture.

Figure 189 is a drawing of the two most recent nozzle designs.

NO. 6 ENGINE FOR KAITEN

HISTORICAL

At the beginning of 1944 when the construction of the KAITEN torpedo was decided upon, the manufacturers of torpedoes, both naval and civilian, were so overloaded that it was impossible to begin the production of KAITEN torpedoes until special steps were taken.

A committee was therefore set up, to expedite the work which was allocated as follows:

Torpedo body and fittings	Naval Ship Construction Department
Main engine and shafting	Naval Engine Construction Department
Energy source, control and final erection	Naval Torpedo Department

DESIGN

The main engine was considered to be similar to a diesel engine but operating on steam and the design of the engine and shafting was entrusted to Commander NAGANO the chief designer of the diesel engine section of the Navy Technical Department, TOKYO.

His instructions were to:

(1) Design a reliable engine capable of propelling the KAITEN torpedo at the required speed for the stipulated range.

(2) Design an engine capable of production with the machining facilities and knowledge available in the Engine Construction Department.

The chief designer went to the Kure Naval Yard with 12 assistants and designed and completed all production drawings in the month of August, working 18 hours a day. In all important matters he consulted with the chief torpedo designer, who was appointed chief inspector of KAITEN production in Kure Naval Yard. Specialists in propeller and pump design from the Navy Technical Department were also consulted.

MANUFACTURE AND TESTING

The production of the first engine was carried out in the Hiro Naval Arsenal and was ready for test by the first of October.

The first engine was used for water tightness tests under an external pressure of 13 atmospheres (191 lbs/in^2).

The second engine completed at the beginning of November was used for performance tests. For these tests boiler steam was used and the unit was submerged in a water tank.

From these tests a number of defects were found and remedied so that about the middle of December one or two engines were handed over to the torpedo department at KURE for full power trials on H_2O_2 and 100% oxygen.

At the beginning of 1945, about the middle of January, the first torpedo carried out its basin trials at the wharf at KABURASAKI.

Parallel with these tests a complete torpedo was water pressure tested to 10 atmospheres in a big tank.

Since the war situation had become worse, there was no time for further development work, so a compromise was arrived at in which both the maximum power and numbers to be produced were reduced. The strategic value and use in action were also modified.

In March 1945 the production of this engine was stopped.

REASONS FOR FAILURE

The chief designer gave the following reasons for the failure of the production program of the KAITEN torpedo.

(1) The initial standard was set upon too high a plane.

(2) The time allowed for research and development was too short for the technical ability available.

(3) The original plan was correct but was not systematically carried out.

SPECIFICATION

The specification for the design of the propulsion unit was as undernoted:

Cycle	Wet heater, 100% oxygen or H_2O_2 (80%); sea water diluent
Maximum output BHP	1500
RPM at maximum output: Crankshaft	1500
Propellers	750
Cylinder diameter	185mm (7.28 in)
Piston stroke	200mm (7.88 in)
Number of cylinders	8
Swept volume	4302.5 cm^3 (262.4 in^3)
Engine weight with pumps	1500 kg (3300 lbs)
Inlet pressure	23 atm (338 lbs/in^2)
Inlet temperature	540°C 1000°F
Exhaust pressure	3 atm (43 lbs/in^2)
Diluent pump	30 atm (427 lbs/in^2)

The engine must be water-tight and rigid enough to withstand 13 atmospheres (185 lbs/in^2) external water pressure.

The profile of the engine must be less than 1300mm diameter. The life of the engine must be about two hours at full load. An overload test is not necessary.

Full power must be developed in as short a time as possible. The engine must be vibrationless. Peroxide or oxygen, fuel and oil consumption to be small as possible. The materials used must be easily obtainable in Japan. The design of the engine to be as simple as possible to enable it to be manufactured in the Engine Construction Department of a Japanese dockyard.

CONSTRUCTION

LEADING PARTICULARS

The engine, to comply with the foregoing specification, has eight cylinders, single-acting, arranged vertically in two banks of four. There are two crankshafts, one for each bank, geared at the rear end to the main shaft. Slide valves are used and are driven from an eight-throw shaft housed above and between the main shafts. There are two combustion manifolds, one for each bank of cylinders. An exhaust manifold is mounted at the top of the engine and is connected to all eight cylinders.

(See Figures 190 (a) to (d)).

COMBUSTION MANIFOLD

The combustion manifolds are of welded construction, each supplying the bank of cylinders on the opposite side. They are bolted to the valve chests using spigotted joints with copper washers. (See Figure 191).

Since the connections to the cylinders are rigid, unequal expansion of the parts will cause failure. To prevent this the manifolds are water jacketted, sea water circulation being maintained by a gear type pump. In addition to the jacket, the manifolds are fitted with a stainless steel inner tube secured only at the forward end. The object of this tube is to reduce further the temperature of the manifold by the interposition of a layer of stationary gas. The heat losses from the manifold have not been measured without the sleeve, so the efficacy of the latter is unknown.

The manifold was tested to a water pressure of about 40 kg/cm^2 (568 lbs/in^2) for a working pressure of about 25 kg/cm^2 (355 lbs/in^2).

External diameter	124mm (4.88 in)
Internal diameter	92.5mm (3.64 in)
Bore of cylinder inlets	60mm (2.36 in)

EXHAUST MANIFOLD

This is also made of welded steel pipe, but it is not jacketted nor has it the insulating sleeve. (See Figure 192). It is fitted with a sea water spray into the valve chest of each cylinder, i.e. against the gas flow, to cool the valves. The flanges are welded to it, and the outlet is bolted to the extension of the splined drive casing. A non-return valve is fitted at the junction.

To obtain a gas-tight joint round the splined drive a corrugated steel casing is used to connect the engine gear casing to the after bulkhead.

CYLINDER BLOCKS AND VALVE CHESTS

The cylinder barrels, heads and valve chests are integral and are secured with ten half-inch bolts using a silk fiber washer. (See Figures 193 (a)(b) and 194). They were originally of bronze but this was abandoned on account of skirt deformation. To overcome this a shrunk-on steel ring was tried but was not found effective. Cast iron was next used; no cracking occurred but the wear was great. Finally chromium plating was found to be satisfactory but was not adopted in all engines.

No water jackets are fitted, cooling being effected by sea water circulating through the engine room.

External diameter of barrel	199mm (7.84 in)
Internal diameter of barrel	185mm (7.28 in)
Thickness of wall	7mm (0.275 in)

SLIDE VALVES

These are cylindrical and hollow, are of silchrome steel and operate in the cast iron body. (See Figure 195). They are secured to the crosshead by a bronze nut which screws onto the

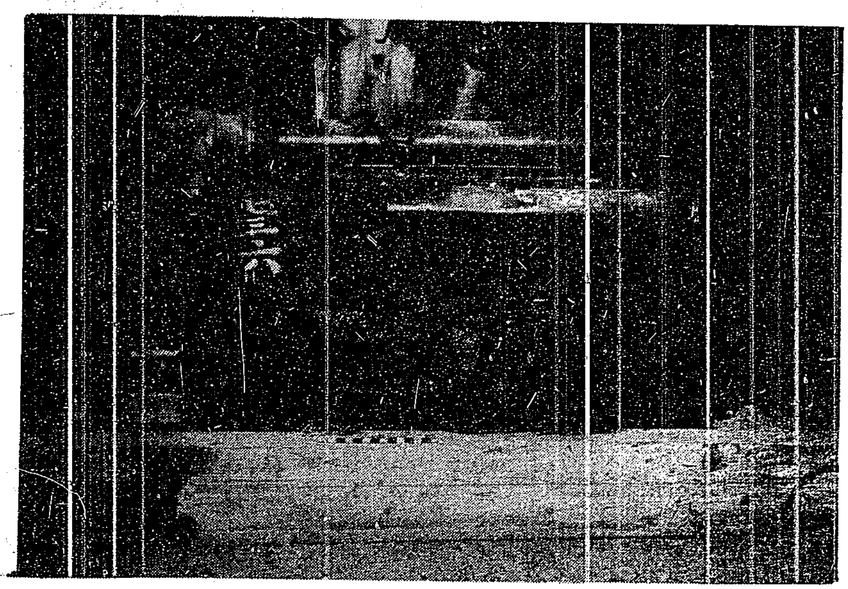


FIGURE 190(a)
GENERAL VIEW OF NO 6 ENGINE

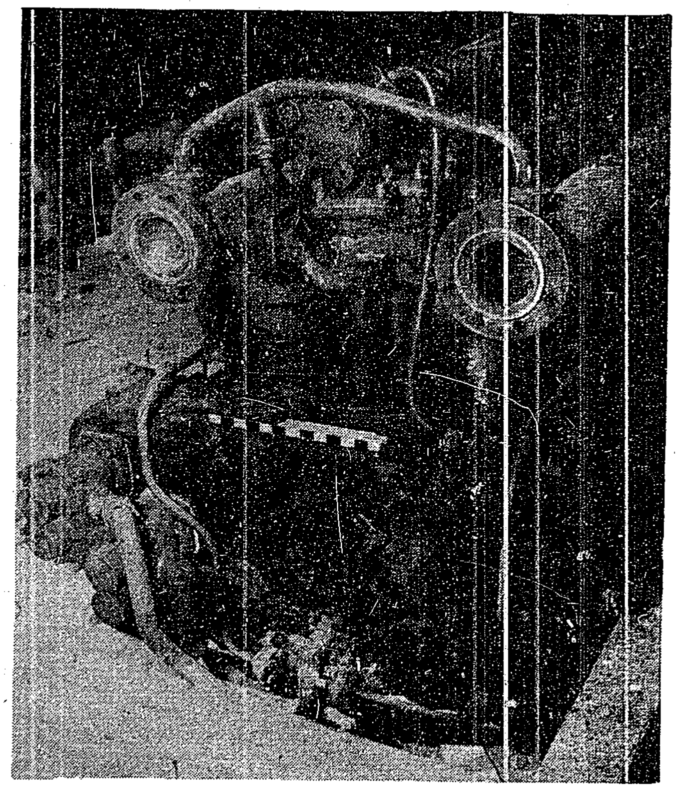


FIGURE 190(b)
GENERAL VIEW OF NO 6 ENGINE

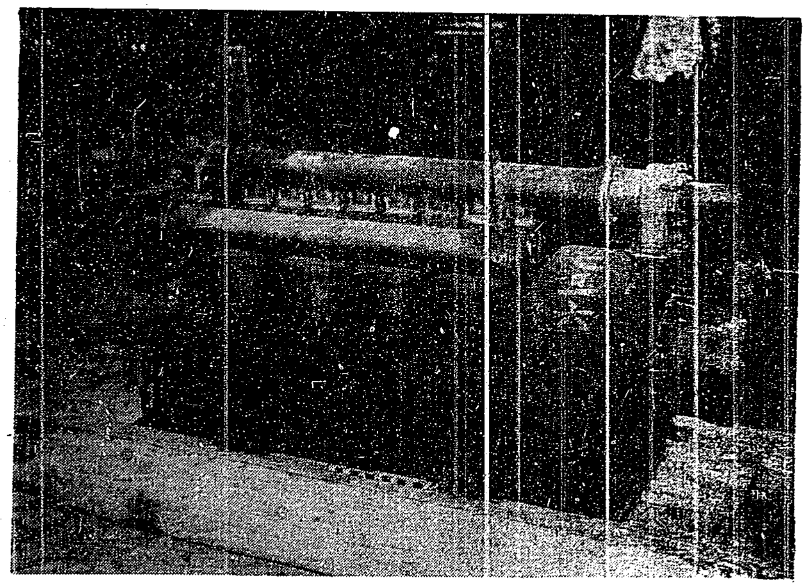


FIGURE 190(c)
GENERAL VIEW OF NO 6 ENGINE

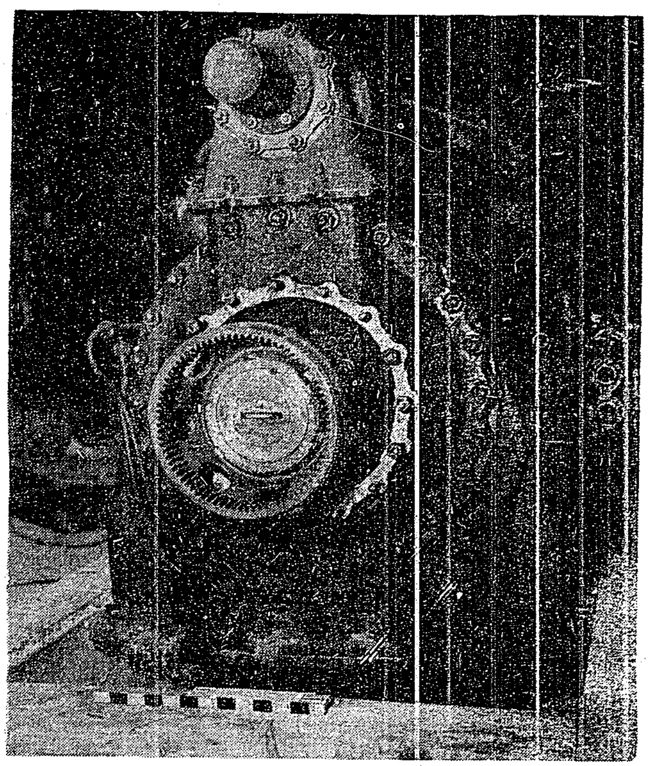


FIGURE 190(d)
GENERAL VIEW OF NO 6 ENGINE

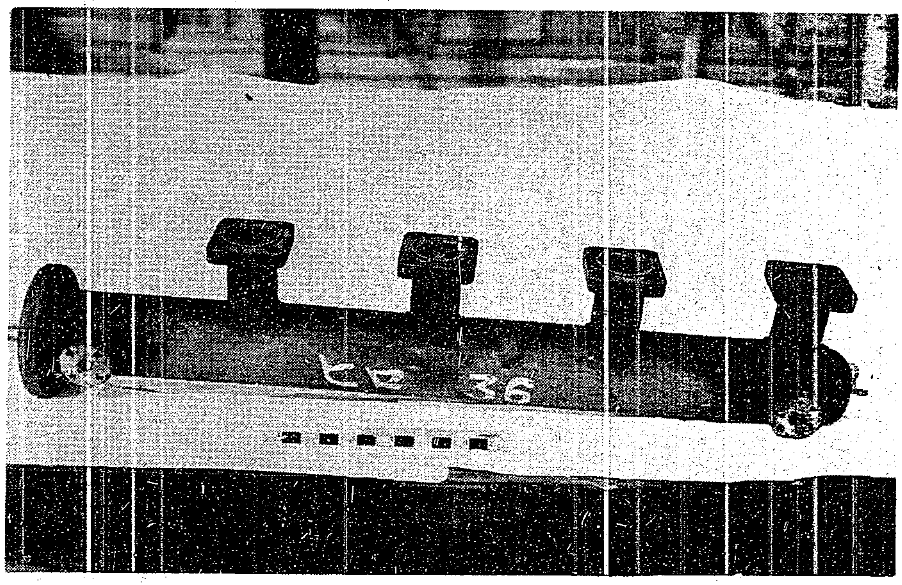


FIGURE 191
COMBUSTION MANIFOLD, NO 6 ENGINE

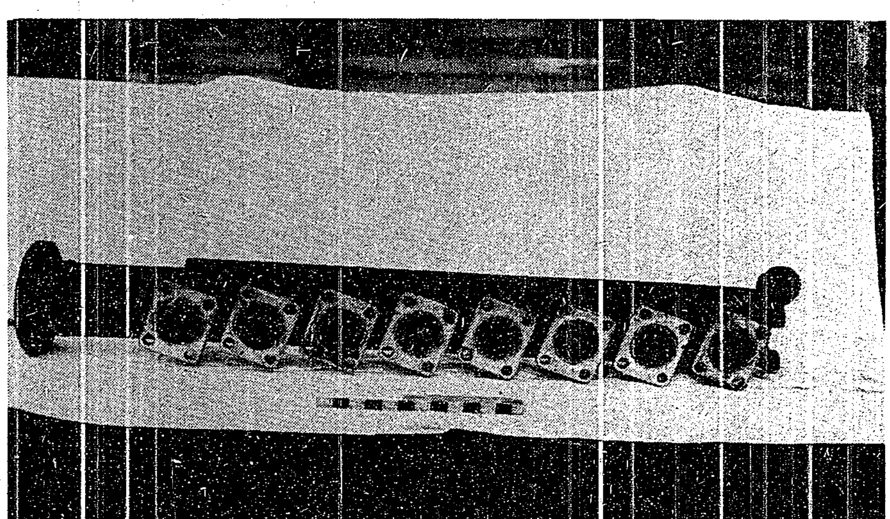


FIGURE 192
EXHAUST MANIFOLD, NO 6 ENGINE

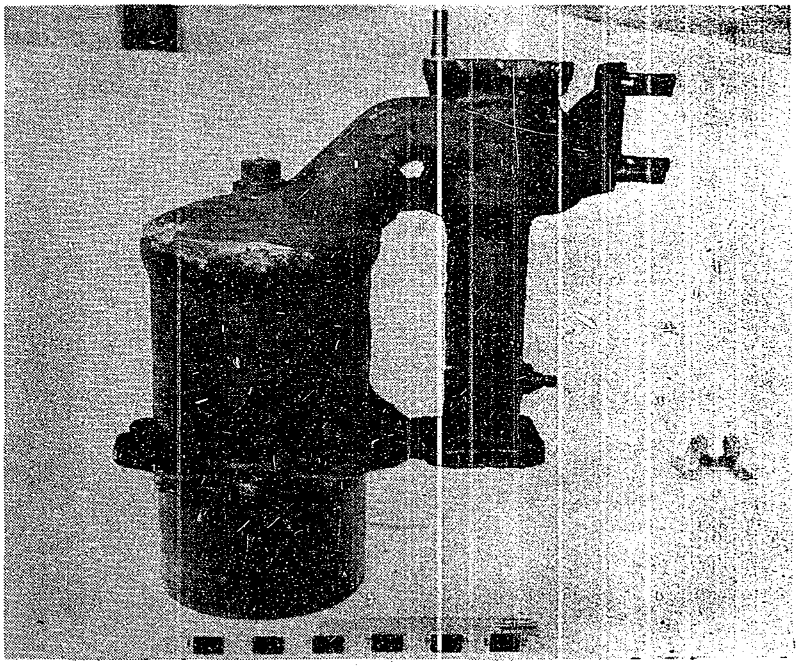


FIGURE 193(a)
CYLINDER BLOCKS AND VALVE CHESTS, NO 6 ENGINE

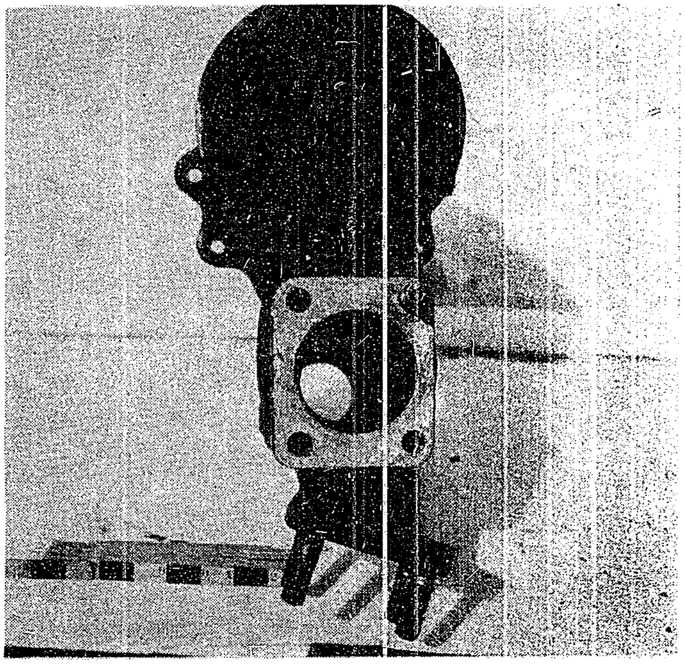


FIGURE 193(b)
CYLINDER BLOCKS AND VALVE CHESTS, NO 6 ENGINE

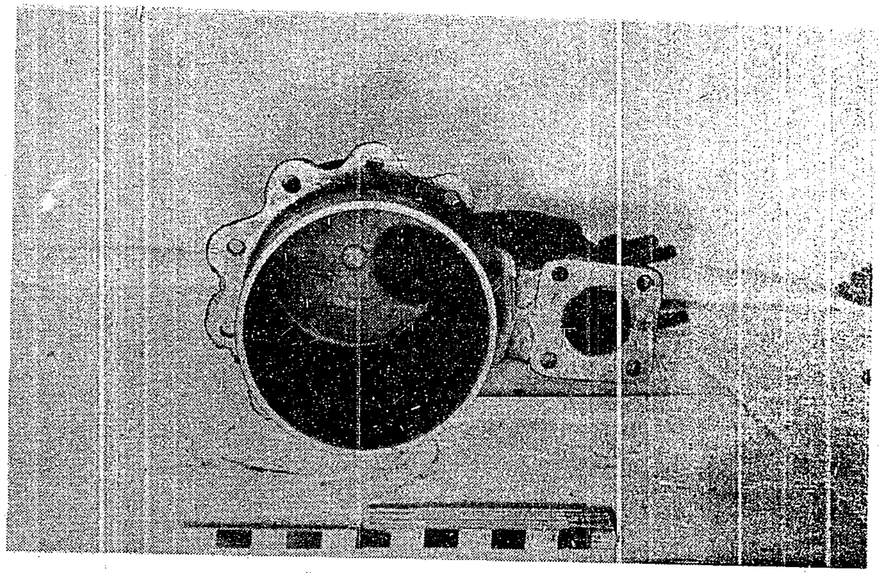


FIGURE 194
CYLINDER BARREL

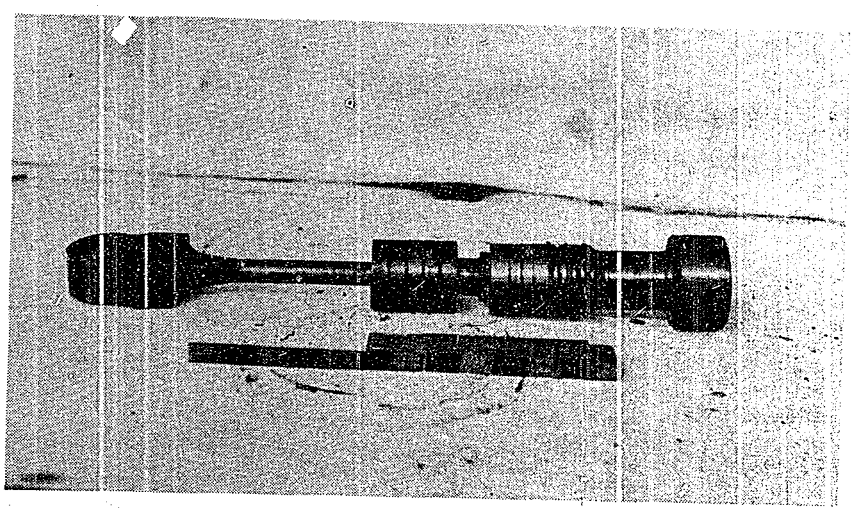


FIGURE 195
SLIDE VALVE, NO 6 ENGINE

split end of the rod; locking is effected by a tapered steel pin which is screwed down, expanding the rod end.

At the base of the valve are five pressure rings and three lubricating grooves. In the lowest ring groove but one, eight holes 3mm (0.118 in) in diameter are drilled into the hollow center of the valve. The object of this is to prevent condensate from draining down into the crankcase and mixing with the lubricating oil.

There are also two holes, 3mm in diameter, in the upper wall of the valve to allow water condensed in the cylinder to flow into the exhaust.

The main dimensions are:

Diameter of exhaust side	80mm (3.15 in)
Diameter of inlet side	50mm (1.97 in)
Clearance	0.1mm (0.00394 in)
Valve rings	
Width	3mm (0.118 in)
Thickness	2mm (0.079 in)
Free gap	8mm (0.315 in)

VALVE GEAR

The crosshead is cylindrical with a plain gudgeon pin retained by a spring clip ring. (See Figure 196).

Crosshead diameter	60mm (2.36 in)
Crosshead pin diameter	21.5mm (0.85 in)
Crosshead bush diameter	22mm (0.87 in)

The big end is of the same design as that of the Type 93 torpedo, i.e. with a horseshoe-shaped cap screwed onto the rod end and secured by a locking pin. The bearing is a split bronze type.

Effective width of bearing	40mm (1.58 in)
Projected length	45mm (1.77 in)

The valve shaft is an eight-throw crankshaft carried in main bearings on transverse members.

ENGINE FRAME AND OIL SUMP

The engine casing is built up around the four transverse members. (See Figures 197 (a)(b)(c)). The members are of cast steel and to them are welded the top, sides, and ends. All electric welding is used with coated electrodes.

This frame carries:

At the forward end	2 lubricating oil pumps
At the after end	gear casing
At the top	8 cylinders
At the bottom	oil sump

The main bearings are housed in the transverse members and are assembled from the bottom.

When assembling the engine in the KAITEN it is first pinned to the forward section and hung on a stay in its approximate position. The after section is then slid into place and the bolt

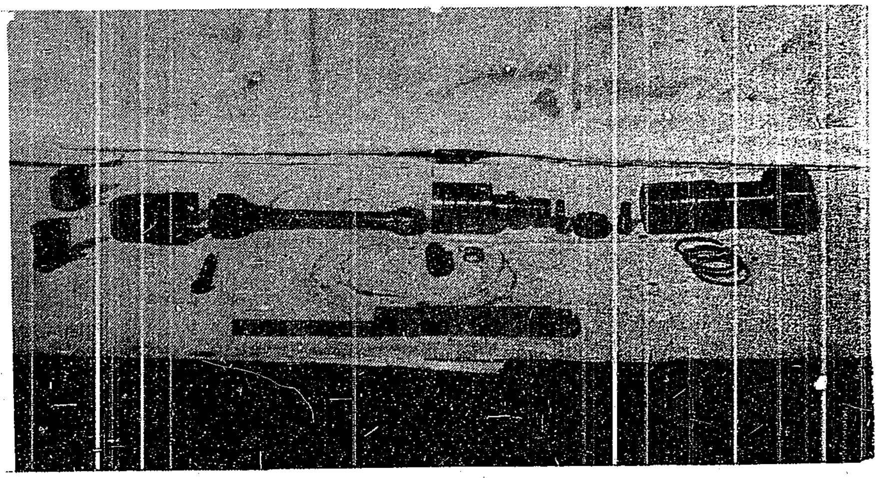


FIGURE 196
VALVE GEAR, NO 6 ENGINE

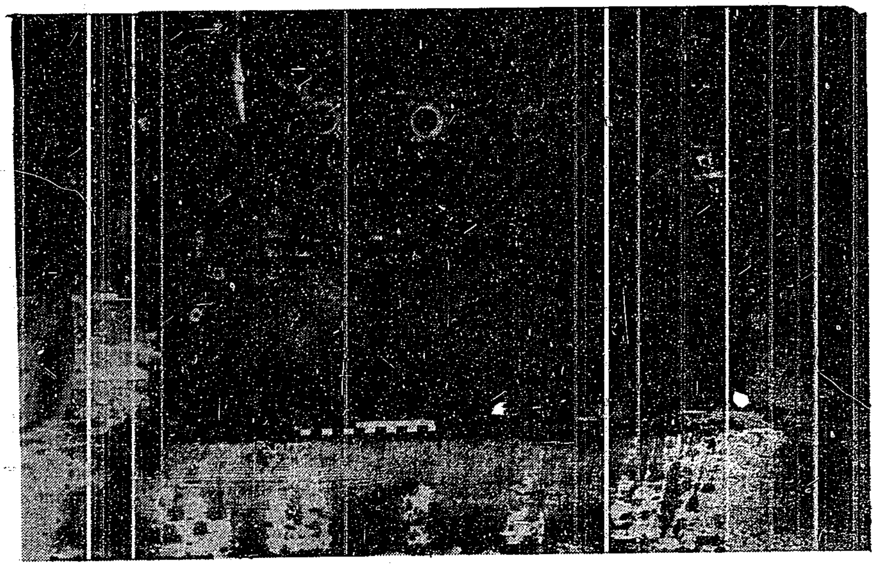


FIGURE 197(a)
ENGINE FRAME AND OIL SUMP

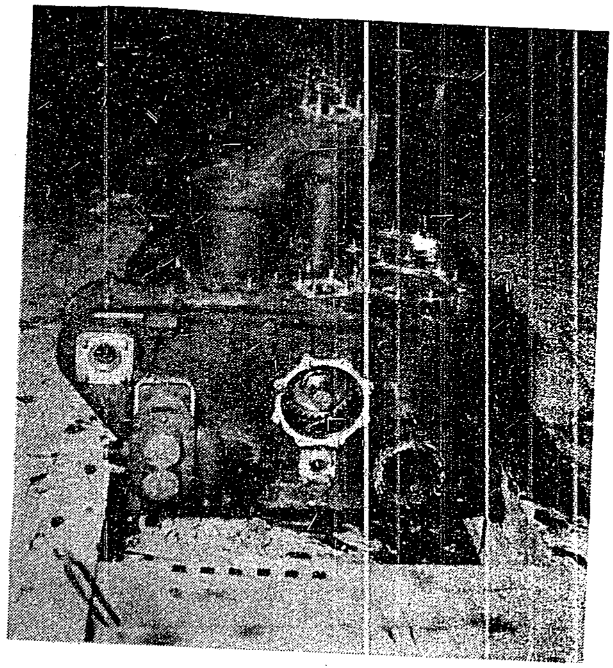


FIGURE 197(b)
ENGINE FRAME AND OIL SUMP

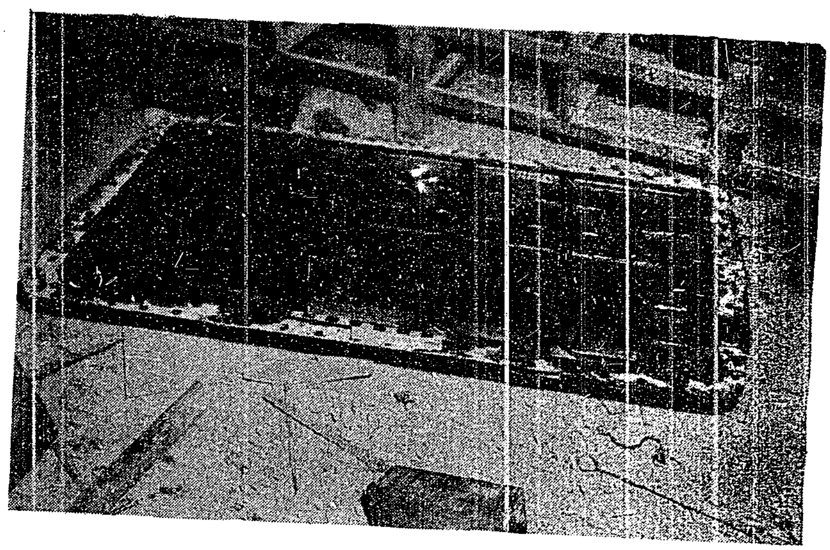


FIGURE 197(c)
ENGINE FRAME AND OIL SUMP

holes in the holding-down flanges are reamed with the engine in place.

Along the lower side of the transverse members is the main oil supply pipe. This is of heavy section and is bolted rigidly at the ends to give additional stiffening to the casing.

At the rear end of the engine frame is the main shaft gear pinion which meshes with the two crankshaft pinions.

The oil sump is of all-welded construction with steel pedestals under each transverse member. A considerable number of stiffeners are included.

The end bearings of all shafts are of a special design, being cap-shaped to prevent water from entering the crankcase

The great difficulty in the design of the engine was to comply with the external water pressure test of 13 atm (191 lbs/in^2) without distortion and yet for the engine to come within the weight limit. In the initial stages, distortion occurred and the stiffeners had to be added.

Overall dimensions:

Width	865mm (34.08 in)
Length	1565mm (61.66 in)
Thickness of casing	18mm (0.710 in)

CRANKSHAFTS

Each crankshaft is a single forging having four throws, two at 180° and two also at 180° but set at 90° to the other pair. The angle between the two shafts is 90°. (See Figure 198).

They are made of 0.35% carbon steel and have only a 20% margin on the fatigue limit.

The crank angles are such that the primary and secondary forces and couples are balanced and, therefore, the vibration is slight. Crank pin and main bearings are of 86% tin white metal 1.5mm (0.059 in) thick, backed by steel.

The leading dimensions are:

Cylinder spacing	270mm (10.64 in)
Main bearing	
Diameter	90mm (3.54 in)
Length	100mm (3.94 in)
Clearance	0.1mm (0.004 in)
Big end bearing	
Diameter	90mm (3.54 in)
Length	98mm (3.86 in)
Thickness of web	36mm (1.42 in)
Width of web	135mm (5.32 in)

REDUCTION GEAR AND SPLINED DRIVE

The crankshaft and intermediate main shaft pinions are bolted to their respective shafts by reamered bolts. Owing to the need for weight saving, the tooth pressure is comparatively high so that the margin for pitting fatigue is only 13%. Pitting was found to some extent after running at maximum output. The

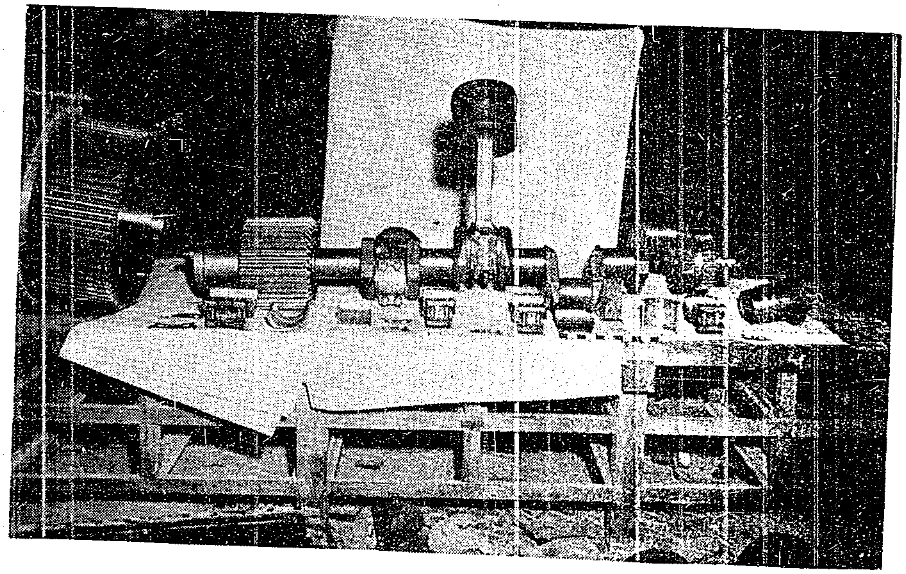


FIGURE 198
ENGINE CRANK SHAFT

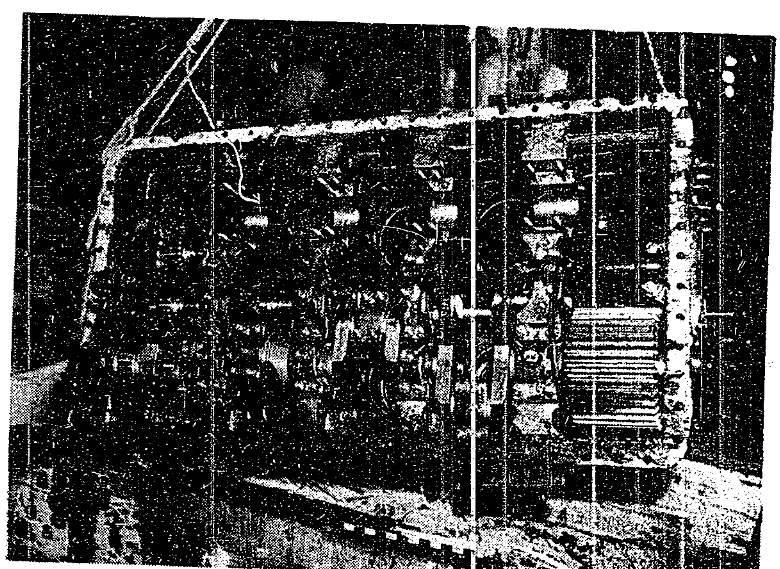


FIGURE 199(a)
REDUCTION GEAR AND SPLINED DRIVE

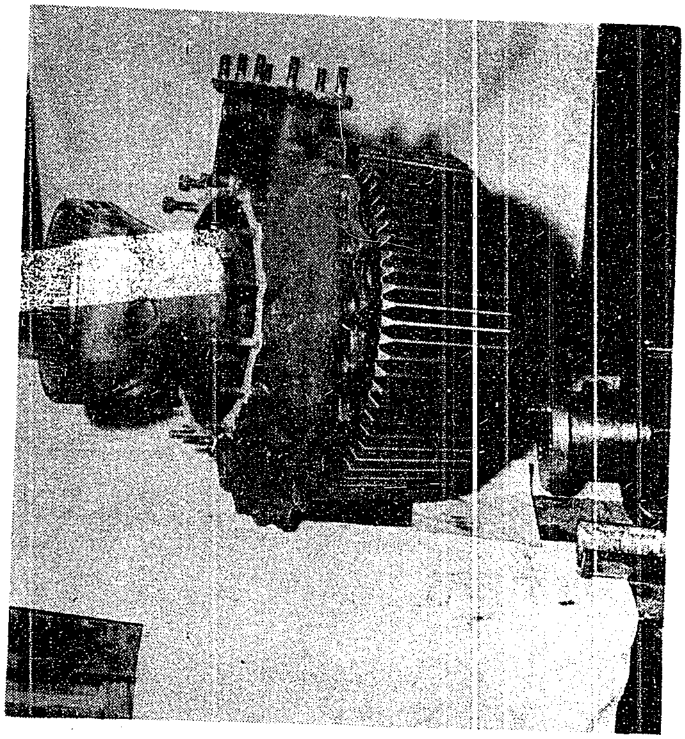


FIGURE 199(b)
REDUCTION GEAR AND SPLINED DRIVE

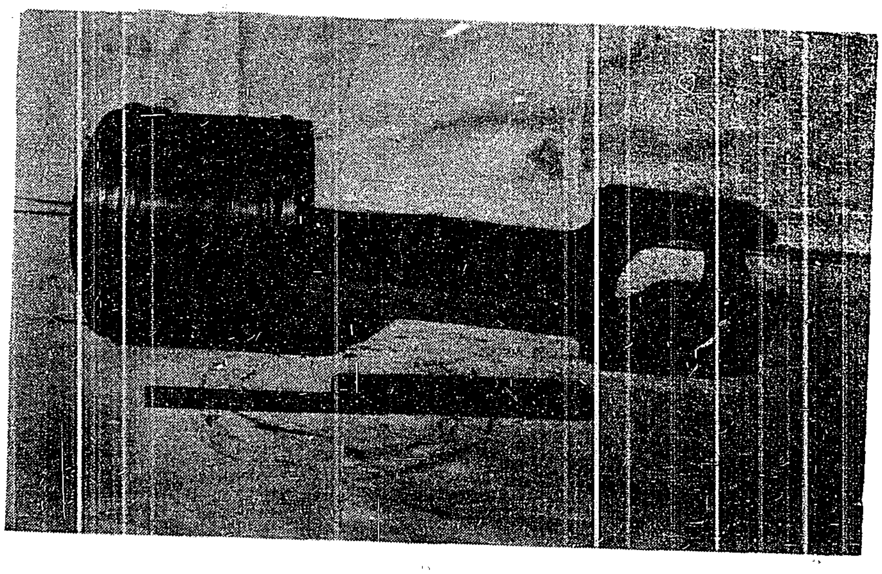


FIGURE 200(a)
PISTON AND CONNECTING ROD

machining must be as accurate as possible. (See Figures 199 (a) and (b)).

Through the center of the splined drive the exhaust from the engine passes. The exhaust holes must be as large as possible since the exhaust pressure tends to be high.

The valve gear shaft is driven through an intermediate wheel from the forward end of the port crankshaft.

At the forward end of the starboard crankshaft is the drive for the pumps. In the train is first the oil pressure pump, then the scavenge oil pump, the diluent pump and finally the cooling water pump. For the last three the rate of revolution is stepped up in the ratio of 1.37:1.

MATERIALS

Crankshaft pinions	0.35-0.4% carbon steel, heat-treated
Main pinion	3% nickel 0.8% chromium 0.3% carbon heat-treated steel
Splined drive	0.3% carbon steel

TOOTH DIMENSIONS

Crankshaft pinions	
Length of tooth	200mm (7.88 in)
Pitch	21.5mm (0.847 in)
Number of teeth	38
Main pinion	
Length of tooth	200mm (7.88 in)
Pitch	21.5mm (0.847 in)
Number of teeth	75
Pressure angle	14.5°
Main pinion bearing (hollow)	
Diameter	185mm (2.18 in)
Length	93mm (1.37 in)
Thickness	11mm (0.433 in)

PISTON AND CONNECTING ROD

The pistons are of pearlite cast iron and have a convex head. (See Figures 200 (a) and (b)). They have three pressure rings and one scraper ring. The most difficult part in the design is to overcome seizures from the high side thrust due to maximum gas pressure being maintained on the piston until 100° after top dead center. In addition the lubrication may be insufficient because the condensate flows down past the rings and mixes with the lubricating oil.

The gudgeon pin is of the standard diesel design with a spring retaining ring.

The connecting rod is made of 0.3% plain carbon steel stamped to H-section.

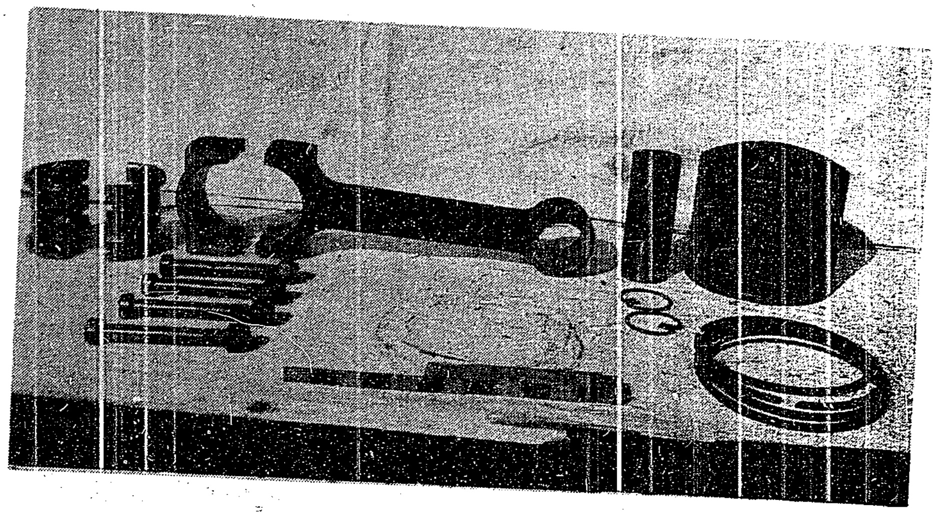
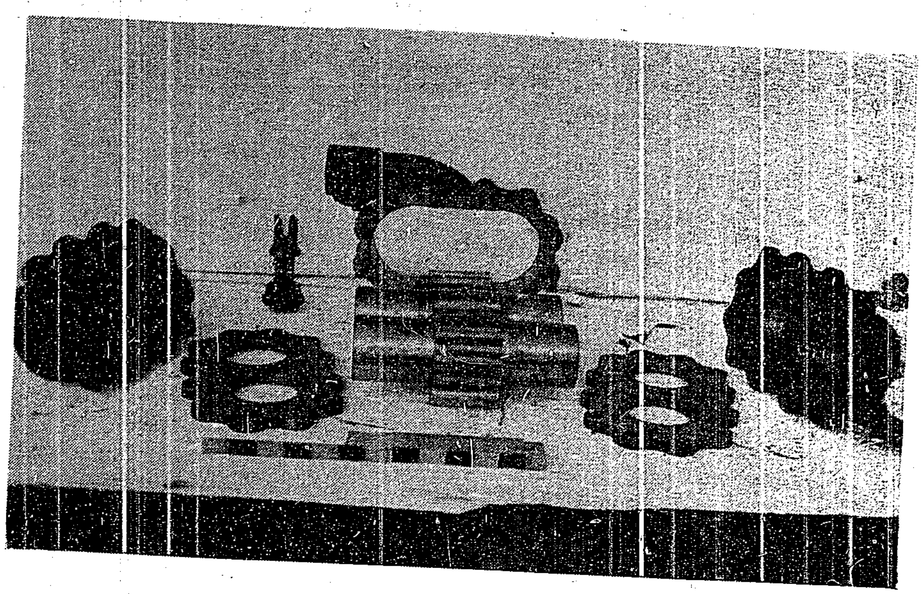


FIGURE 200(b)
PISTON AND CONNECTING ROD



FIGURL 201
DILUENT SEA WATER PUMP

PISTON

Diameter	1845mm (7.27 in)
Length	155mm (6.10 in)
Bearing surface length	115mm (4.53 in)
Thickness of crown	12mm (0.473 in)

PISTON RINGS

Pressure Width	5mm (0.197 in)
Thickness	6mm (0.236 in)
Free gap	18mm (0.709 in)
Scraper	
Width	6mm (0.236 in)
Thickness	6mm (0.236 in)
Free gap	17mm (0.670 in)

This ring has slotted vents to remove surplus oil.

GUDGEON PIN

Diameter	60mm (2.36 in)
Length	160mm (6.30 in)

CONNECTING ROD

Length	370mm (14.58 in)
Outside diameter of bearing	70mm (2.76 in)

DILUENT SEA WATER PUMP

This is a gear pump of the "Fulnagg" type; it supplies water as diluent to the generator and for displacing hydrogen peroxide, hydrazine hydrate and fuel. (See Figure 201). It is mounted on the outside of the engine casing on the starboard side, being driven by gears from the starboard crankshaft through the oil pump drive.

Difficulty was experienced with the lubrication of the bearings due to the presence of sea water. To overcome this a false cover was fitted to each end of the pump; this was drilled with a series of drain holes. Sea water could only escape from the pump through the clearance between the shaft and this cover, and then drain out through the holes. The pump bearings were fed with lubricant, at high pressure, by a small reciprocating pump mounted on and driven by the unit. (See Figure 202). One wheel of the pump was of bronze material and the other of steel to reduce the wear.

Delivery pressure	30 kg/cm^2 (426 lbs/in^2)
Teeth-involute form	
Overall diameter of teeth	115mm (4.53 in)
Diameter at root of tooth	90mm (3.54 in)
Length of tooth	70mm (2.76 in)
Number of teeth	14
Shaft	
Length	85mm (3.35 in)
Diameter	70mm (2.76 in)

CONFIDENTIAL

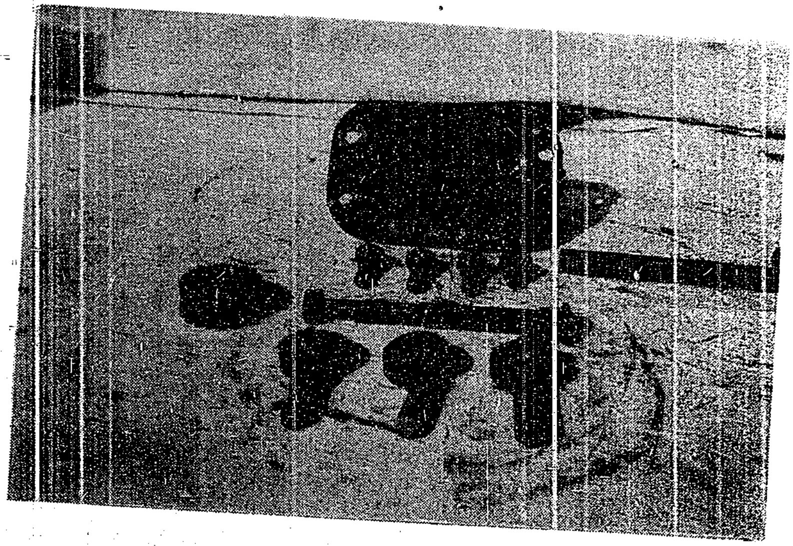


FIGURE 202
RECIPROCATING OIL PUMP

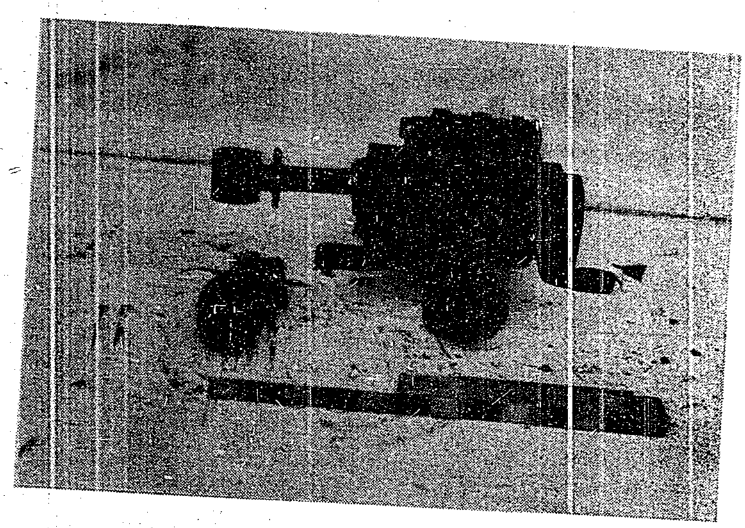


FIGURE 203
ENGINE COOLING PUMP

ENGINE LUBRICATION

The engine has the dry sump system of lubrication, feed and scavenge pumps being used. These pumps are of the same dimensions; both are of the standard gear type with no special features. The feed pump runs at engine speed and the scavenge pump at 1.36 times engine speed. The diluent, and engine cooling pumps also run at this speed.

Details of the pumps are:

Deliver pressure dependent on engine RPM	21-70 lbs/in^2
Tooth length	80mm (3.15 in)
Tip diameter	84mm (3.31 in)
Root diameter	65mm (2.56 in)
Number of teeth	14

The circulation is from the oil sump in the crankcase to the following units in series:

Wire gauze filter	
Scavenge pump	
Oil tank	
Pressure pump	
Oil cooler	
Engine	--(attached to torpedo shell)
Back to crankcase	--(crankshaft and reduction gear)

The actual circuit through the engine itself is of a standard pattern. From the oil rail in the crankcase each main shaft bearing is supplied by pipes. The big end bearings and gudgeon pins are fed through drillings in the shaft for the former and oil is piped up the rod for the latter.

Separation of the sea water is attempted in the oil cooler and depends upon the difference in the specific gravity of the liquids. Initially the tank is three-quarters full of oil; during the run the tank fills up with sea water. When it is full there is a rise in pressure in the tank; this pressure lifts a non-return valve and discharges sea water overboard through a pipe leading up from the bottom.

Lubrication of the gears is by splash in the case of the main gear wheels, an open-ended pipe discharging oil over the teeth. In each case the oil drains back into the sump.

ENGINE COOLING

The crankcase, cylinder head and valve chests are not water-jacketted, cooling is effected by sea water caused to circulate in the engine room by a scoop attached to the torpedo shell.

The special measures taken to cool the combustion and exhaust manifolds have already been described.

The cooling water pump is of the standard gear type. (See Figure 203).

SHAFTING AND BEVEL GEARS

The forward end of the propeller shaft is splined to fit the spline on the end of the gear shaft.

The reversing gear is of the standard torpedo design of four inter-meshed bevel wheels; the forward one being attached to the propeller shaft and the after one to the sleeve shaft. The side wheels transmit the drive from one shaft to the other and reverse the direction of rotation.

The thrust from the engine is taken on the after bulkhead, directly in the case of the propeller shaft and indirectly through the crosshead arm in the case of the sleeve shaft. Ball-races are used.

For lubrication the gears were dipped in lubricating oil mixed with grease.

Exhaust gases pass through the center of the inner shaft.

The bearings between the two shafts are of white metal, dove-tailed in position, having a clearance of 0.03mm (0.012 in) and are lubricated from the crosshead.

Material

Shafts
- 0.35% carbon steel solid drawn tube

Bevel wheels
- 3% nickel, 0.8% chromium
- 0.3% carbon heat-treated alloy steel

PROPELLERS

These are manufactured of manganese bronze or are steel castings. They were designed by Captain S. NAKAYAMA, a propeller specialist in the Navy Technical Department, TOKYO.

	Forward	Aft
Diameter	1060mm (41.8 in)	970mm (38.2 in)
Maximum blade width	314mm (12.4 in)	296mm (11.7 in)

They are similar in design to those of the Type 93 torpedo except that there are only three blades because the engine power is small for the size of the hull.

From the results of model tank tests the value of the effective horsepower was calculated and from this the propellers were designed. The design was checked by Commander HORI by an alternate method.

ENGINE TIMING

The engine timing is similar to that of the engine of the Type 93 torpedo.

Admission	Top dead center
Cut-off	110° A.T.C.
Release	135° A.T.C.
Recompression	315° A.T.C.

The method used to adjust the timing is by means of depth gauges fitted into the cylinder head and valve chest, piston displacement figures from top dead center being obtained from the drawing.

The valve position is adjusted by slacking back the taper locking screw in the center of the valve and screwing or unscrewing the valve as required before relocking it.

Since no valve seat is fitted the edge of the valve port is accurately machined to give the correct height specified on the drawing.

TEST

WATER PRESSURE TEST

Initially this was carried out in the Hiro Naval Arsenal at a pressure of 13 atmospheres (191 lbs/in^2). This is equivalent to a dead load of 100 tons in a vertical direction and 70 tons in the horizontal direction.

The magnitude of the requirements will be clearly realized from these figures when it is considered that the engine must operate satisfactorily under full load at this pressure. It would have appeared to be much easier to jacket the hot units and make the hull pressure-resisting. Commander HORI confessed that the torpedo practice of admitting sea water to the engine room was followed blindly.

Deformation occurred at the ends and sides of the crankcase and in the bottom and corners of the oil sump. Welded stiffeners were added at the weak points but although deformation was prevented, water leakage occurred at the joints which depended largely upon their finish for tightness. Finally a special paint was found to prevent these leaks, the engine being painted after final erection.

Later, when the specification was drawn up for general manufacture, the builder was obliged to carry out this test but no measurements were made, inspection for deformation and water leakage being by eye only.

STARTING TEST

Starting trials of the engine were carried out with boiler steam. It was found that the engine could be started in any position with a steam pressure varying from 10 to 50 lbs/in^2 depending upon the crank angle. It was found necessary to ensure that no condensate remained in the cylinder. This was considered to be due to the special conditions of the test and would not occur in the KAITEN under normal running conditions.

TORSIONAL VIBRATION TEST

Absence of vibration was essential so that the pilot could see accurately through his periscope. A torsional vibration test was carried out at HIRO using boiler steam. Vibration was measured by a Geiger torsiograph but the amplitude was small. By calculation the frequency was very high so that the measurements of frequency could not be relied upon.

TEST UNDER LOAD

For the normal maker's test only low pressure steam from Lancashire boilers was available and it was not possible to test out the engine fully.

LAND TEST

At the Hiro Arsenal, tests more nearly approximating to KAITEN conditions were made. The engine was mounted in a water tank and connected to a dynamometer outside, steam being supplied from the boiler, and exhausted to atmosphere.

The results of the test were:

Duration of test	30 minutes
Inlet steam	
Pressure	300 lbs/in^2
Temperature	370°C
Output	1500 hp
RPM	750
Exhaust pressure	atmosphere

The tests showed that with the engine properly aligned the power output could be obtained.

The defects revealed by these tests were:

(1) Fracture of cylinder head at starting by condensate in the cylinder

(2) Fracture of cylinder skirt and piston siezures at high loads

Alterations to overcome these defects have already been enumerated.

The data of two tests carried out on No. 2 engines are given in tabular form.

The test were made on two consecutive days, 23 and 24 December 1944.

From the results it will be seen that the engine developed more than the specified horsepower and in the final test ran for over thirty minutes.

It is considered that the inlet gas temperatures are inaccurate, the figures recorded being too low. This is probably due to the thermocouple junction being enclosed in a steel sheath.

The circumstances governing the gas analyses are not known, and therefore these data are shown without comment.

DYNAMOMETER TEST OF NO. 6 ENGINE FOR KAITEN TYPE 2 RUNNING ON HYDROGEN PEROXIDE

ENGINE NUMBER 2

Date	23 Dec. 1944		24 Dec. 1944	
Number of test	7		8	
Duration; min-sec	15-13		30-15	
Mean pressure	kg/cm^2	lbs/in^2	kg/cm^2	lbs/in^2
Air vessel	25.7	364.9	25.6	363.5
H_2O_2 chamber	25.0	355.5	24.7	351.2
$N_2H_4.H_2O$ chamber	24.6	349.8	26.3	374
Fuel chamber	27.6	392.5	27.4	389.6
Water supply chamber	28.1	399.6	27.9	396.7

	TEST 7		TEST 8	
Generator	22.3	317.1	22.0	312.8
Inlet gases	21.7	308.6	21.7	308.6
Exhaust gases	0.5	7.1	0.9	13.0
Crankcase	0-4.4	0-62.5	0-2.1	0-30.0
Lub oil	5.4	76.8	5.9	83.9
Lub oil chamber	4.0	56.9	4.6	65.4
Lub oil for main pump	9.1	129.4	6.1	86.7
Diluent pump	28.5	405.3	28.5	405.3
Cooling water pump	6.3	89.6	5.5	78.2
	liters	ft^3	liters	ft^3
Quantity of excess water	0	0	48.4	1.71

Mean temperatures °C

	TEST 7	TEST 8
Right side	240	230
Left side	-	-

Exhaust gas analysis %vol	Inlet	Exh	Inlet	Exh
CO_2	37.6	39.6	22.6	40.8
O_2	24.0	3.6	1.2	1.8
CO	17.0	20.6	28.6	3.6
H_2	11.6	13.0	16.6	19.8
C_mH_n	1.8	1.6	7.6	3.2
CH_4	3.8	8.4	6.0	14.0
N_2 and C	4.6	13.4	7.6	12.8

Consumptions per minute	kg	lbs	kg	lbs
H_2O_2	105.0	231.0	108.1	237.8
$N_2H_4 \cdot H_2O$	10.15	22.3	11.1	24.4
Kerosene	14.3	31.5	15.7	34.5
Water	91.5	201.3	88.6	194.9

Ratios by weight

	TEST 7	TEST 8
B/A liquid	0.097	0.102
Fuel/A liquid	0.136	0.145
Water/A liquid	0.837	0.87

Output

	TEST 7	TEST 8
Total revolutions	20,100	41,300
Mean RPM	1383	1388
RPM of main shaft	624	759
Mean horsepower	1570	1625

	hp sec/kg	lbs/BHP/hr	hp sec/hp	lbs/BHP/hr
Consumption of H_2O_2	899	8.8	902	8.8

TEST IN TORPEDO

Tests in a KAITEN under actual operating conditions indicated that the back pressure could not be reduced to 2-3 atmospheres, the lowest value being 7-8. To obtain the required output the inlet pressure would need to be increased to a value above that permissible in the torpedo so it was stated that the output was reduced to 1000 hp.

EXHAUST GAS FLOW TESTS

As a result of the torpedo trials, tests were made to measure the resistance to flow in the exhaust system. The drop in pressure along the system was measured by applying air pressure to the inlet.

PRODUCTION

No accurate information on the production figures could be obtained but it was estimated:

Initial order	1000
At end of 1944 changed to	200
March 1945	Production stopped

The principal makers of the engine were:

Hiro Naval Arsenal
Kure Navy Yard
Yokosuka Navy Yard
Sasebo Navy Yard
Maizuru Navy Yard
Hikari Naval Arsenal
Kobe Steel Works
Kobe Mitsubishi Dockyard
Nagasaki Mitsubishi Dockyard
Kawasaki Dockyard

WEIGHTS OF COMPONENTS	kg	lbs
Combustion manifold (one)	32.4	71.3
Exhaust manifold (one)	35.2	77.4
Cylinder barrels and valve chest (one)	29.6	65.1
Slide valve (one)	1.5	3.3
Valve gear (one)	4.8	10.6
Crankshaft (one)	132.4	291.3
Piston	8.9	19.6
Connecting rod and big end	20.7	45.5
Diluent sea water pump	45.0	99.0
Oil sump case	104.7	230.3
Crankcase	936.3	2059.9
Main gear pinion and casing	186.5	300.3

KAITEN TYPE 4

HISTORICAL

With an adequate supply of hydrogen peroxide for KAITEN 2 in doubt, the successful operational use of the latter weapon was no longer assured, despite the high promise shown in its development. The Japanese Naval Staff, therefore, decided that work should proceed on alternative lines. Requirements were put forward for a new KAITEN which would operate on 100% oxygen, like KAITEN 1, but which would use the No. 6 Engine and have the same hull dimensions as the KAITEN 2. It was hoped that the high speed of 40 knots envisaged for KAITEN 2 would be attained in this way.

Many of the Japanese torpedo engineers were opposed to this plan. They held the point of view that KAITEN 1 using oxygen was an operational success, and that further effort should be expended on speeding up the production of this KAITEN, rather than on embarking on new designs. They further believed that the high oxygen consumption of the No. 6 Engine in attaining 40 knots would make the range so short that the value of the weapon in combat would be very limited.

Despite these objections, work went forward on the new oxygen KAITEN, which was to be known as KAITEN 4, in accordance with a Naval Staff directive.

Land tests with the KAITEN 4 showed very high oxygen consumption (low efficiencies) and therefore confirmed the views of the engineers who were opposed to the original plan.

GENERAL PARTICULARS

Additional particulars of this torpedo are:

Date of production		1945
Number produced (approx)		50
Reserve buoyancy	kg	730
	lbs	1606
Trim		not known
Oxygen vessels		
Volume	liters	3340
	ft^3	118
Weight	kg	3804
	lbs	8369
Weight of charge		
	kg	1704
	lbs	2648
Fuel chamber		
Volume	liters	550
	ft^3	19.4
Steering air bottles		
Volume	liters	80
	ft^3	2.8
Pressure	kg/cm^2	215
	lbs/in^2	3053

Trimming tanks					
Volume	Fore tank	150	Total	liters	1100
	Middle tank	750		ft^3	39
	After tank	200			

Main engine	
Type No. 6	Two-row, vertical
Maximum hp	1500

DESCRIPTION

The KAITEN torpedoes were made in both the gun and torpedo departments, those from one being numbered with the odd and those from the other with the even numbers. The specimen examined was No. 33, which was the seventeenth made in the gun department.

An outline diagram of the weapon is shown in Figure 204.

For an actual war shot the KAITEN was operated by one man. For training purposes, up to four were carried, by the omission of some of the oxygen vessels. A certain number of other details were also omitted in the training weapons of which No. 33 was one.

The KAITEN is built up in five sections:

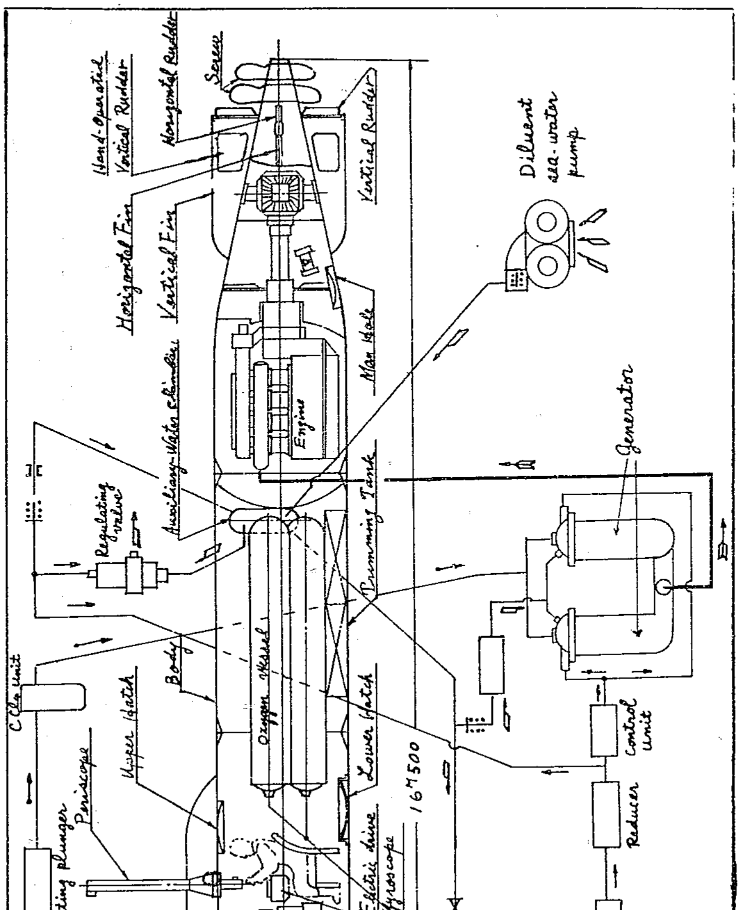


FIGURE 204
OUTLINE DIAGRAM. KAITEN TYPE 4

1- Head
2- Forward vessel compartment
3- Pilot's cockpit
4- After vessel compartment
5- Afterbody

The seal between each section is made with rubber gaskets and the end flanges of each adjacent section are bolted together.

HEAD

Both the war and exercise heads are the same as those for the Type 2 except that in this case two air bottles for blowing purposes are carried in the head, together with a recorder. (See Figure 205).

The pilot has a control lever geared to the head by means of which the recorder can be started and stopped or the head can be blown. The first few revolutions of the lever operate the recorder, while continued revolving of the lever operates the blowing mechanism.

The recorder, which records speed, depth and roll, works on the same principles as the recorder used in torpedoes.

The head can be entered through a manhole in the after end. (See Figure 206).

FORWARD VESSEL COMPARTMENT

In the forward end are four oxygen containers. The lowest one is the largest and is similar to that of the vessel of the 24" Type 93 except for the capacity which is larger. (See Figures 207 and 208).

Above it are three more oxygen vessels; these are similar to the high pressure air bottles used in submarines except that the rear end has a steel packing ring. This packing ring is as shown in Figure 215. The square threads are a slack fit so that the pressure in the vessel makes the joint by forcing the knife edges of the rings into the steel body and end. Much development work was carried out before this design was finally adopted. For training purposes the center one of the three is removed, suitable ballast being added.

The vessels are of steel, the large one to the same specification as that of the Type 93 vessels while the smaller ones were made of steel called SK (proprietary brand Sumitomo Kamzoku Co., OSAKA) which is a manganese silicon alloy without nickel but has the same tensile strength as the steel to the other specification. No attempt was made to coat the insides of the vessel to prevent corrosion.

The forward end of the vessel is fitted with a cover plate with a vent to the outside of the shell. The vessels rest on supports from the shell and are held in place longitudinally by one angle iron and wooden packing pieces.

Wood is placed round the shell in the upper half and lead ballast in the lower half.

The outer shell is of welded plate with a junction angle ring welded to it. The head is bolted to the compartment.

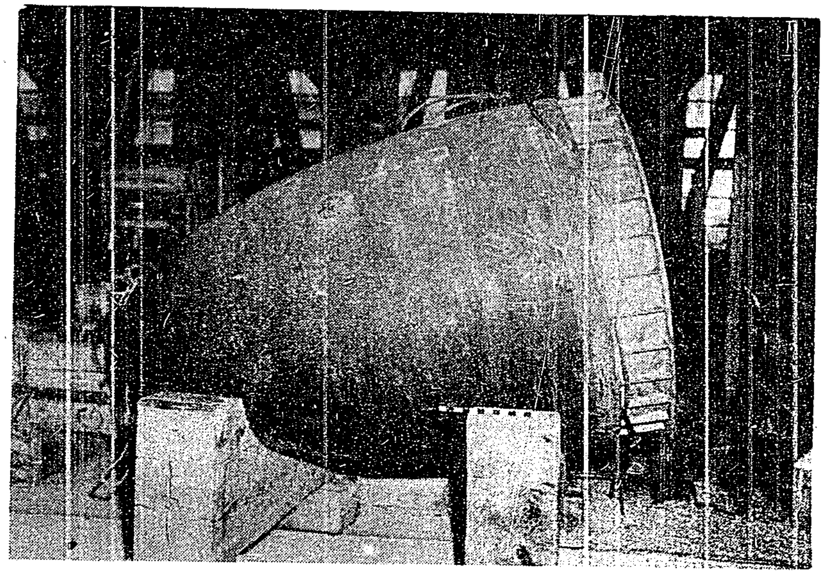


FIGURE 205
HEAD, KAITEN TYPE 4

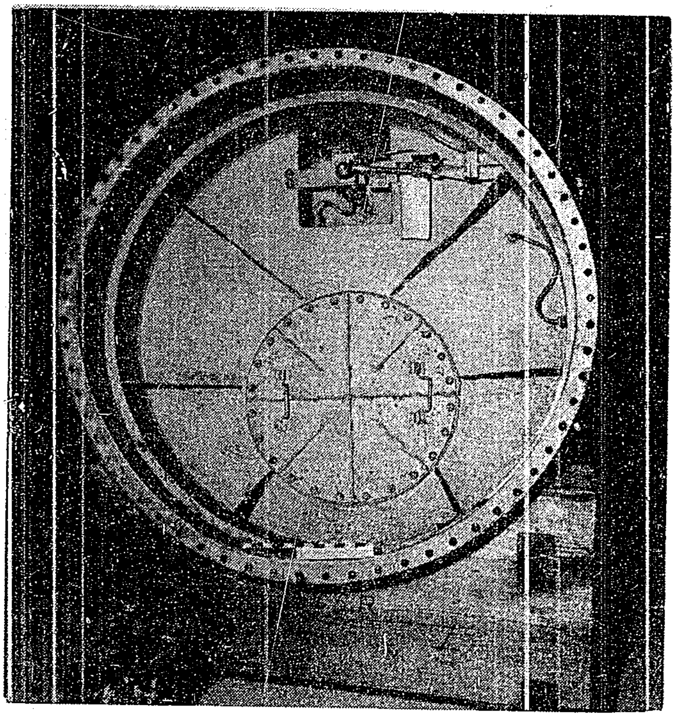


FIGURE 206
AFTER END OF HEAD, KAITEN TYPE 4

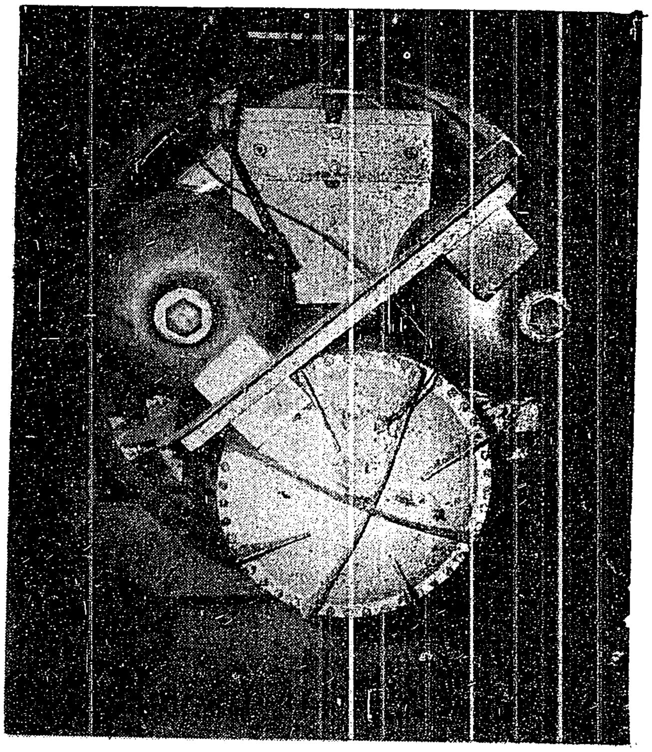


FIGURE 207
FORWARD END OF FORWARD OXYGEN VESSELS. KAITEN TYPE 4

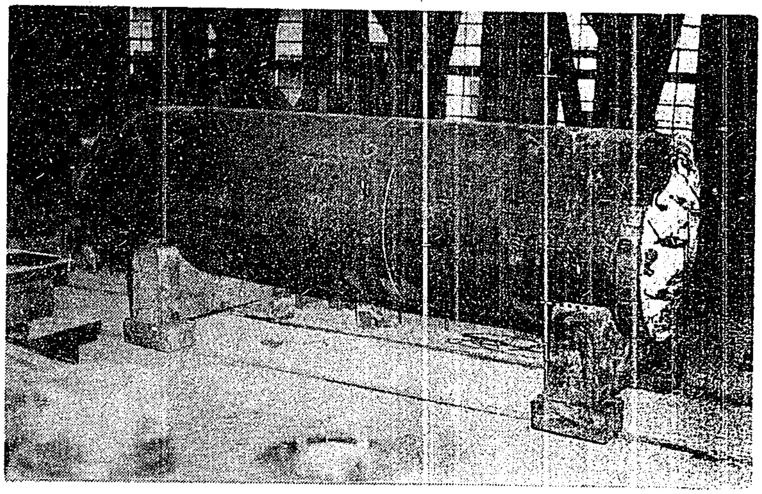


FIGURE 208
SIDE VIEW OF FORWARD COMPARTMENT. KAITEN TYPE 4

On both sides of the large oxygen vessel are trimming tanks. In the after end of the compartment is the fuel tank. This is fabricated from welded mild steel plates. This construction is acceptable because the tank has to stand up to a pressure only slightly above that at which the engine operates. There are baffle plates to stop surging.

An annular trimming tank surrounds the fuel tank.

Immediately aft of the fuel tank are four steering air bottles placed vertically. (See Figure 209).

PILOT'S COCKPIT

The control circuits and operating levers are the same as those of Type 2 and need not be described again in detail. (See Figures 210 and 211).

The power circuits are similar to those of the 24" Type 93 except for the speed controller. This is circular in shape, of welded steel plate.

On the outside of the casing are the rating plungers for water and fuel. They are controlled by a handle on the top, which is geared to the plugs so that the correct ratings are obtained. All are on the same principle as shown in Figure 216.

Initially, starting and stopping were done by means of the oxygen delivery stop valve. This was not satisfactory so a torpedo-type group valve was introduced.

The shell has a flange welded on to it for bolting to the after vessel compartment.

AFTER VESSEL COMPARTMENT

This normally contains another three oxygen vessels but for training purposes these were removed and two men substituted. Directly aft are two buffer chambers.

The batteries and the rotary convertor for the gyroscope are on the starboard side along the oxygen vessels.

The shell is made of steel plate ribbed at 12" intervals with ballast in the bottom half. (See Figure 212).

The engine Type No. 6 is bolted to the end of the after compartment in the same way as the Type 2.

AFTERBODY

Between the after bulkhead and the engine are two Type 93 generators supplying the inlet manifolds.

The igniters are fired by a geared drive operated from the main shaft of the diluent sea water pump. The ignition delay can be set from the upper side of the engine room. This is done as in the case of Type 93 torpedo by using a bevel gear and a special spanner.

The bottom of the shell of the afterbody forms the oil cooler. The oil storage tanks are in the port side, 50 liters for the oil hydraulic system and 100 liters for lubrication. Tail and

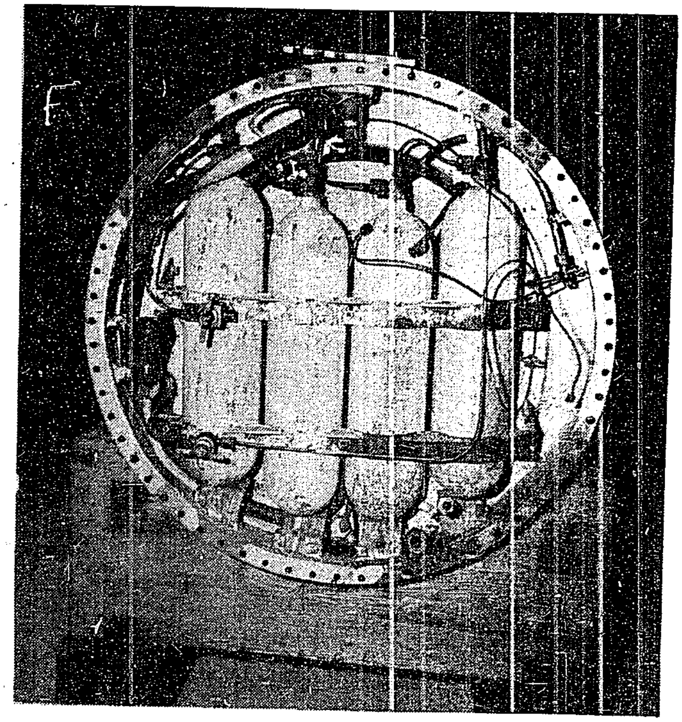


FIGURE 209
REAR OF FORWARD COMPARTMENT, KAITEN TYPE 4

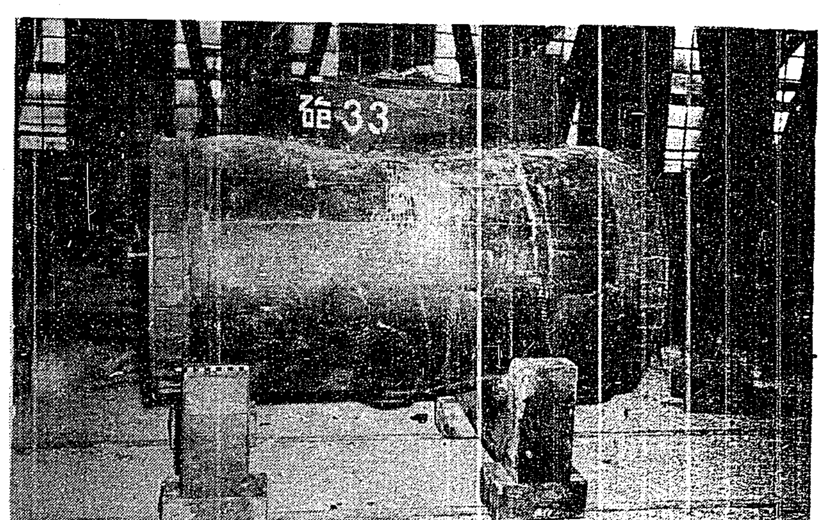


FIGURE 210
SIDE VIEW OF PILOTS CABIN, KAITEN TYPE 4

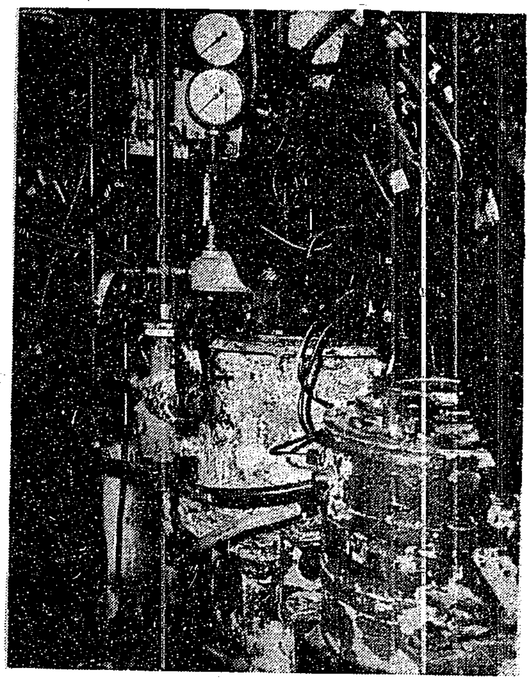


FIGURE 211
CONTROL UNIT AND GYROSCOPE, KAITEN TYPE 4

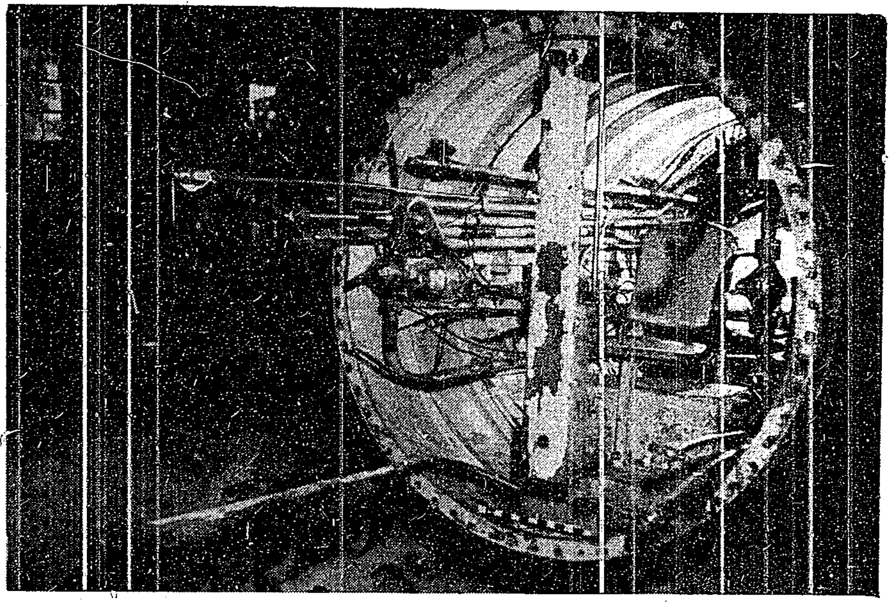


FIGURE 212
FORWARD END OF REAR COMPARTMENT, KAITEN TYPE 4

propellers are exactly the same as those of the Type 2. (See Figures 213 and 214).

CIRCUITS

The circuits are the same as those of the Type 93 torpedo, except for the inclusion of a CCl_4 bottle in the fuel circuit, as an additional starting precaution.

OXYGEN CIRCUIT

The forward three vessels have pipes leading to a common oxygen delivery valve. This valve is the same design as in the torpedo, only larger.

From the valve a pipe is led to a four-way piece, one to the after vessels, one to the charging connection and one to the speed controller.

Inside the speed controller are:

- Main oxygen delivery stop valve
- Carbon tetrachloride bottles
- Main rating plunger

This last consists of one standard choke giving constant delivery, together with three chokes, one for each speed, which can be opened as required by raising the plunger, i.e. one, two or three are brought into the circuit. (See Figure 216).

The gas next flows direct to the generators.

WATER CIRCUIT

The diluent sea water flows from the pump through a non-return valve on the pump casing to a stop valve, and then to two buffer chambers which are connected in series. The water is delivered to the bottom of the first and then from the top of the first to the bottom of the second.

There is one pressure regulating valve connected to the second chamber. Oxygen is supplied to the regulating valve and to the second buffer chamber.

Diluent to the generators via the speed controller and water to displace the fuel is taken from the bottom of the first bottle. There are non-return valves and stop valves in both these circuits.

Surplus water from the buffer chambers is discharged outboard via the speed controller.

FUEL CIRCUIT

The fuel is displaced by sea water. The tank is filled from the outside of the shell through a stop valve.

From the bottle the fuel goes to a stop valve, through a strainer and non-return valve, to the speed controller. In the engine room is a carbon tetrachloride bottle of 1.3 liters capacity. The stop valve in the circuit prevents the CCl_4 from being displaced.

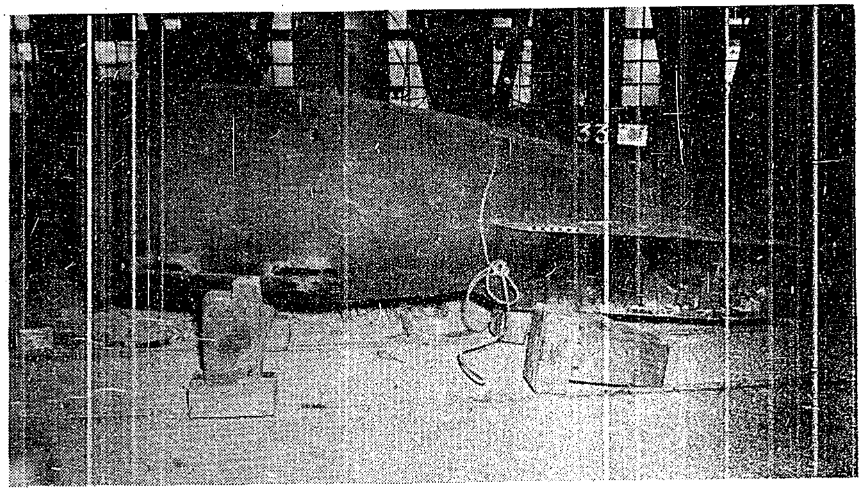


FIGURE 213
AFTER BODY, KAITEN TYPE 4

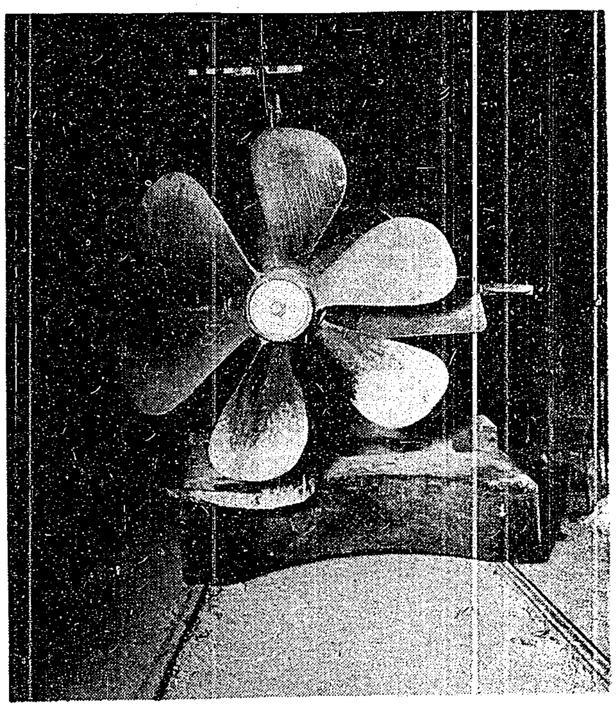


FIGURE 214
PROPELLERS, KAITEN TYPE 4

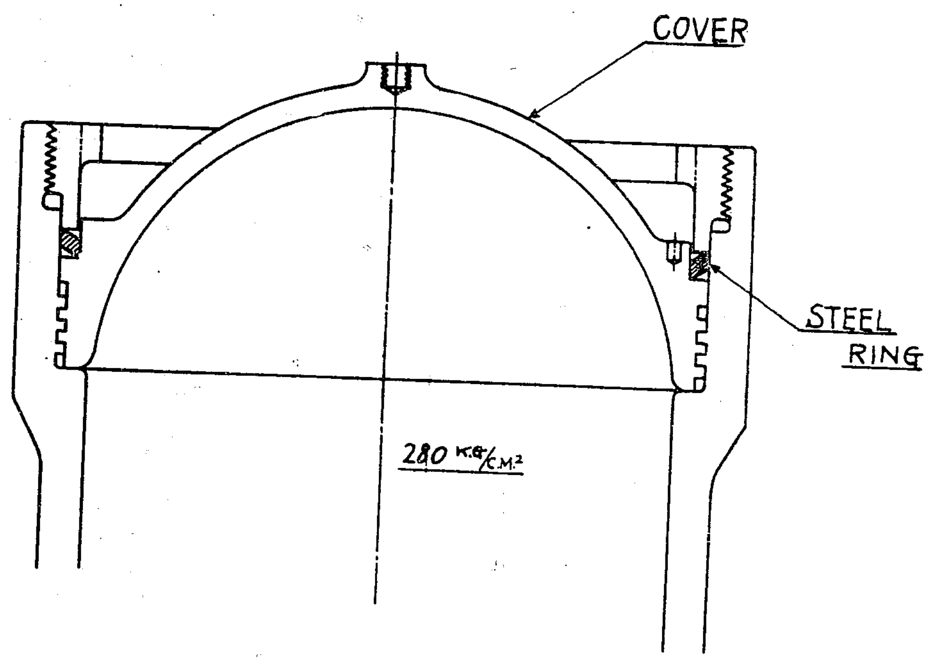


FIGURE 215
OXYGEN VESSEL END, KAITEN TYPE 4

From the CCl_4 bottle the fuel goes to the generator, i.e. it passes through the rating nozzles before passing to the CCl_4 bottle.

In the model examined, a CCl_4 bottle (similar to that in KAITEN 1) was also included in the oxygen circuit. Thus there was a double precaution to prevent an explosion at the instant of ignition.

GENERAL

About January 1945 two KAITEN 4 were completed. A sea-running test was made using automatic controls (no pilot) and a speed of only about 10 knots was realized for the low speed setting. Gas consumption was bad.

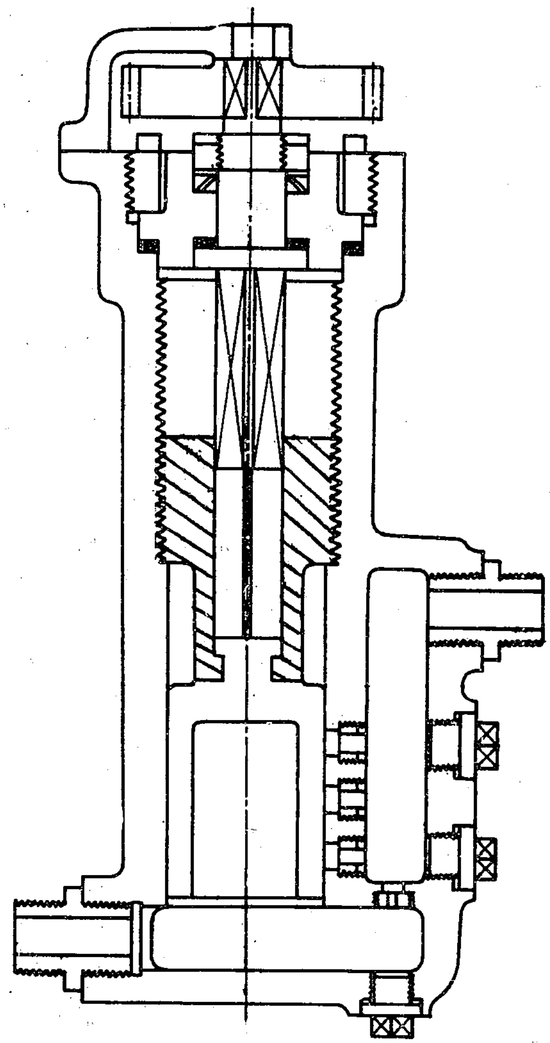
Trials, adjacent to the jetty, were then carried out with pilot. The nose of the KAITEN was fixed against the jetty. Gas efficiencies were again low. It was considered that the generators were not adequate and gas analyses showed a large percentage of unburnt oxygen in the exhaust.

At sea, greater speeds than 25 knots were never realized with the KAITEN 4. This design was therefore a failure.

KAITEN TYPE 10

DEVELOPMENT

This type of KAITEN was designed to meet a Naval Staff requirement for sufficient KAITEN torpedoes to defend the coastal waters from the Islands of KYUSHU and SHIKOKU.



Similar plungers are used for water and fuel.

FIGURE 216
OXYGEN RATING PLUNGER, KAITEN TYPE 4

Since there were surplus supplies of Type 92 torpedoes, they were converted to KAITEN Type 10.

A Type 92 torpedo was cut in half and the control chamber added as a center section.

Additional particulars of the KAITEN Type 10 are as follows:

Date of production		1945		
Number produced		less than 6		
Reserve buoyancy	kg	50		
	lbs	110		
Trim		level		
Steering air vessels (two)	liters	40	Total	80
	ft^3	1.46		2.92
Pressure	kg/cm^2	200		
	lbs/in^2	2840		
Trimming tanks		none		
Main engine		electric motor		

GENERAL DESCRIPTION

A view of the torpedo is shown in Figure 217.

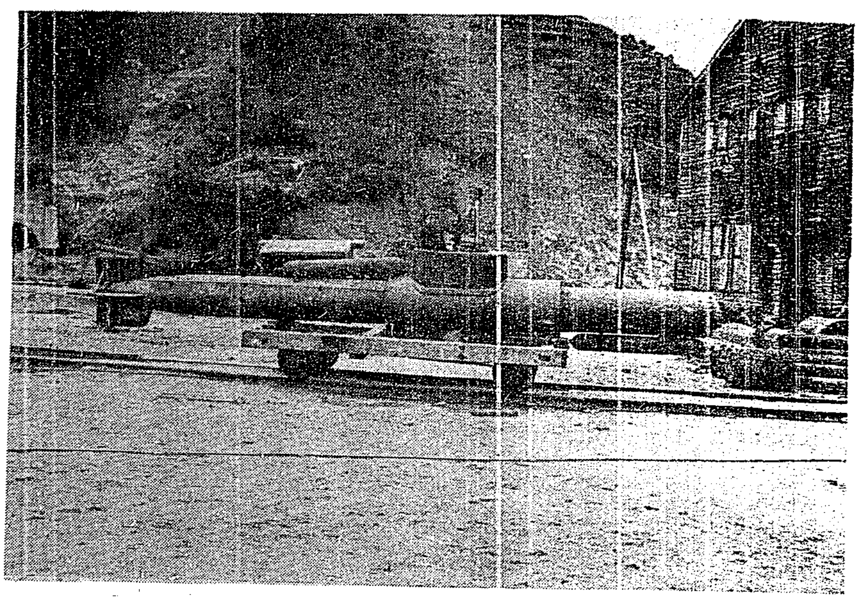


FIGURE 217
GENERAL VIEW, KAITEN TYPE 10

HEAD

Standard Type 92 excercise and war heads were used. In the case of the former the air from the steering air bottles was used to blow the head. This was controlled by the pilot. In the latter, one electric fuse was added which was also controlled by the pilot.

MIDSHIP SECTION

Below and outside the forward battery chamber a steering air bottle was attached to the underside.

The shell of the battery chamber was welded to the control cabin, a fairing being added to give streamlining.

CONTROL CABIN

In the cabin there were:

Periscope
Electric switch for detonators
Hand control of vertical rudders
Starter for main motor
Control device for depth gear
Starting valve for gyroscope
Upper hatch
Sodium peroxide tin
Lights
Inclination meter

PERISCOPE

This was of midget size and was fixed.

VERTICAL RUDDERS

A pair of balanced vertical rudders in the vertical fins were operated manually by the pilot. Normally he steered with these and started the gyroscope only when approaching the target.

STARTING AND STOPPING

A switch of the design used in the Type 92 torpedo, but slightly modified, was fitted in the cabin.

DEPTH GEAR

This is merely a handle, behind the pilot, which, through rods, increases or decreases the tension of the depth spring. Steering air is supplied to the servomotor throughout the run.

GYROSCOPE

Normally when the tube-operated starting lever is pushed aft, air is supplied to the gyroscope. In KAITEN 10 this air supply is controlled by the pilot. The air supply must be admitted as quickly as possible since the disengaging mechanism operates satisfactorily only when full pressure is applied suddenly.

UPPER HATCH

Since only the upper hatch is fitted the KAITEN 10 cannot be used for submarine entry. It was land-operated only.

REAR SECTION

This is the standard rear portion of the Type 92 torpedo, except for increased fin and rudder areas, and for a second steering air bottle outside the hull on the upper side. The propellers remained unchanged.

GENERAL

The speciality of this KAITEN is that it can be stopped and started with great ease. When stopped it comes to the surface and when started it can be submerged by use of the horizontal rudders.

It was first thought that the manufacture of this weapon would be easy. Actually great difficulty was experienced in the junction of the control cabin to the two halves of the torpedo. The initial defect in the torpedo of water leakage between the battery chamber and the afterbody was still present.

ENCLOSURE (A)

VIEWS OF CAPTAIN NAKAMURA, IJN, ON JAPANESE SHIP TORPEDOES IN SERVICE

Captain NAKAMURA was a Torpedo Officer. He gave the following particulars of his naval career:

1929 Trained at the Naval Academy on ETA JIMA, including torpedo instruction (Chiefly Type 44).

1930-31 As a prospective Torpedo Officer he took a special course in torpedoes at YOKOSUKA.

1938-40 As a Lieutenant-Commander, NAKAMURA captained the Second Class Destroyer ASAGAWA, which used "6th Year" torpedoes.

1940-42 Gave torpedo instruction at the Torpedo School in YOKOSUKA.

1942-43 Captain of the First Class Destroyer SAMIDARE which was fitted with two quadruple mountings for Type 93, Model 1, Modification 2.

Opinion of Oxygen Torpedoes

NAKAMURA considers that the disadvantages of the oxygen torpedo, as regards handling and preparation were outweighed by the excellence of the performance of the weapon in combat. He preferred to use oxygen torpedoes on his ship, rather than air torpedoes. NAKAMURA had not experienced any accidents with torpedoes, or oxygen plants, in the ships on which he had served.

Shell Splinters

Oxygen torpedoes behave differently from air torpedoes when struck by a shell or bomb splinter. In the case of an air torpedo the compressed gas escapes through the hole pierced by the splinter without endangering the warhead. In the case of an oxygen torpedo, when the oxygen vessel has been pierced, the local heat generated by the impact of the splinter on the vessel may be sufficient to cause the ignition of the metal with the high pressure oxygen. This local combustion evolves considerable heat and results in a larger hole than that made by the original splinter. The latter point is not important in itself, but if the vessel is pierced near the warhead, the heat generated by the combustion of the metal with the oxygen may result in the detonation of the warhead.

The Japanese were alive to this possibility, and took steps to obviate such an occurrence in action. Water hoses and an emergency water tank were installed besides the mounting. Four or five men were detailed to play water on the warhead, in the event of the oxygen vessel being pierced by a splinter. By this means the warhead remained cool until the heat resulting from the splinters was dissipated. If the situation appeared critical, the damaged torpedoes were fired from the tubes.

To reduce the probability of damage to the torpedoes by shell and bomb splinters, the sides of tubes on cruisers and destroyers were extended with side pieces of light armor. The thickness of this armor sheath was 5mm. The underside of the torpedo was necessarily unprotected (for successful launching), and when not in readiness for action, the mountings were trained fore and aft, thus making use of the cover given by the deck to this part of the torpedo.

Oxygen Plant

This has been operated in heavy seas and NAKAMURA has never known the purity of oxygen to drop below 94%. Under these circumstances, it was the responsibility of the captain of the ship to decide whether the reduced range resulting from the use of oxygen of this purity, was justified by the tactical situation.

The running of the oxygen plant was in the hands of two engineer officers who, in turn, were under the direction of the chief engineer. During a 'run', eight trained men controlled the plant under the personal supervision of one engineer officer.

To charge eight torpedoes, the plant had to be operated for about a week. Operation for this length of time was exceptional, since torpedoes were normally loaded on board with the oxygen vessels charged. Reserve oxygen bottles for charging were not used.

Effect of Temperature on Oxygen Vessels

In the Pacific campaign, the Japanese found the effects of temperature changes on the pressure of oxygen vessels very marked. NAKAMURA stated that in a cruise from Japan to the Solomons, the initial pressure of 220 kg/cm^2 might increase on the voyage, to as much as 260 kg/cm^2. Temperature at Solomons was circa 30°C. In such a voyage the pressure in the vessels would be measured periodically and reduced as necessary. In a cruise from the tropics to Japan, the circumstances would be reversed and 'topping up' of the vessel would be carried out.

Torpedo Attacks

On the night of 12 November 1942, the Japanese destroyers SAMIDARE and MURASAMI engaged an American light cruiser of the PORTLAND class off Guadalcanal. Gunfire ensued and MURASAMI was damaged; but she fired eight Type 93, Model 1 torpedoes from a range of 1000 yards. Two or three hits were obtained and the cruiser sank in three minutes. The torpedoes were fired from quadruple mountings. Two second intervals were used between each torpedo and a gyro spread of one degree. The speed of the cruiser was about 20 knots and the gyro angling used was 19°.

On the night of the 14 November 1942, the Japanese destroyers SAMIDARE, SHIRAYUKI and HATSUYUKI, in company with the light cruiser NAGARA, engaged an American heavy cruiser and two destroyers off Guadalcanal. The Japanese destroyers were fitted with Type 90 torpedoes, except SAMIDARE which had Type 93. NAGARA had 8th Year torpedoes. From a range of 4000 yards, SAMIDARE and NAGARA fired eight and four torpedoes respectively. SAMIDARE obtained two or three hits and the cruiser blew up.

The speed of the cruiser was 26 knots; the gyro angling 26°, the spread 1° and the time interval between each shot two seconds.

ENCLOSURE (B)

VIEWS OF LT. COMDR. ITAKURA, IJN, ON JAPANESE SUBMARINE TORPEDOES IN SERVICE

An outline of ITAKURA'S career in the Japanese Navy is as follows:

1936-39	Submarine Navigating or Gunnery Officer.
1939-40	Student at Advanced Torpedo School at YOKOSUKA.
1940-42	Senior Torpedo Officer of the Submarine I-169 (all the I-class were first line submarines).
1942-43	Student at submarine school for seven months.
1943	For two months captain of Submarine I-176 (completed in 1942).
1943	For seven months captain of I-2 (completed about 1923).
1944	For eight months captain of I-41 (completed in 1943).
1944-45	For about a year Commander of Suicide Torpedo (KAITEN) Corps at OTSUSHIMA, near TOKUYAMA.

ITAKURA drew attention to the low production numbers of the latest types of Japanese torpedoes. During the war, many first class submarines used Type 89 torpedoes (designed in 1929) or electric torpedoes (Type 92), the latter type being more easily produced in quantity than the higher performance Type 95 oxygen torpedoes.

Type 92 Torpedoes

Unlike most Japanese submarine captains, ITAKURA liked the Type 92 torpedo (with "kite" head) and appeared to rate it as highly as the Type 95. He did not consider the low speed of the Type 92 a serious disadvantage in view of the easy maintenance of the torpedo and its trackless running. He preferred the Type 92 to the Type 89, when the former was fitted with a "kite" head.

Type 95 Torpedoes

When Captain of the I-2, ITAKURA carried Type 95 Modification 1 torpedoes. He never made an attack with this type, but he fired six trial shots with good results. He considered the Type 95 much superior to the Type 89 air torpedo.

Maintenance troubles were experienced with the Type 95 due to rusting of valves. The general condition of the torpedo remained good for about two to three month. The pressure of the "first air vessel" was always measured before firing. If it had dropped due to leakage the torpedo was not run, but replaced in the tube by a spare. Similarly, if on examination the reducer or "group" valve was found to be corroded the torpedo often was not run.

Accidents

ITAKURA had experienced no accidents due to oxygen on board submarines, and he had not heard of any.

No oxygen bottles were carried aboard Japanese submarines. The torpedoes were charged at base and then loaded on to the submarine. Occasionally, torpedoes on a submarine were charged by a pipe line from a cruiser or destroyer.

ENCLOSURE (B), continued

Useful Range

ITAKURA considers 4000 yards to be the maximum useful range of the Type 95. He never used the Type 92 at long range but always fired within 1500 yards of his target.

Attacks

In 1942 when Captain of the I-169, ITAKURA made two attacks. (The I-169 carried Type 89 torpedoes).

(1) Without result, he attacked a destroyer about three miles from Pearl Harbor. He was subsequently depth-charged and had to remain submerged for 40 hours. He sustained no damage.

(2) Attacked an American merchant ship of about 12,000 tons (without escort) off the east coast of New Guinea. First he fired two torpedoes, with a three second interval, securing one hit near the bow. Range 1000 yards. The ship stopped.

Twelve minuted later, from 800 yards, he fired his third torpedo, which proved faulty and it turned away from the target.

Twenty minutes later, he fired his fourth torpedo from 500 yards and secured a hit near the stern. The merchantman sank in about one hour after the first hit.

Off the Aleutians, while transporting stores in the I-2, ITAKURA attacked an American transport of 10,000 tons escorted by one destroyer. The attack was made in heavy seas and the I-2 came to about 800 yards from the target without detection. From this position four Type 92 torpedoes (all fitted with "kite" heads) were fired. Two hits were obtained on the transport and she sank in two minutes. Depth setting of torpedoes was 14 feet.

The I-2 did not make a subsequent attack on the destroyer, for two reasons:

(1) Nine minutes were required to reload the rour tubes.

(2) The primary duty of the I-2 was the transport of stores.

Attack Strategy

Time Intervals:- When firing four torpedoes in "spread", ITAKURA fired at time intervals of three seconds.

Gyro Spread:- For a 'spread', $1\frac{1}{2}^{o}$ to 2^{o} was used between first and second, and between third and fourth. Three degrees was used between the second and third shot.

The 'gyro' spread was normally set at this value before loading in the tubes. if necessary, the spread could be altered when the torpedoes were in the tubes.

Attack Position:- The shaded portion of the diagrams in Figure 218 show the area within which ITAKURA considered that he must be, before pressing home an attack. In these areas, he claimed that he could get over 60% hits in training and 60% hits in action. The potential attack area is greater in case of the Type 95 than in the Type 92, because of the greater speed of the former.

ENCLOSURE (B), continued

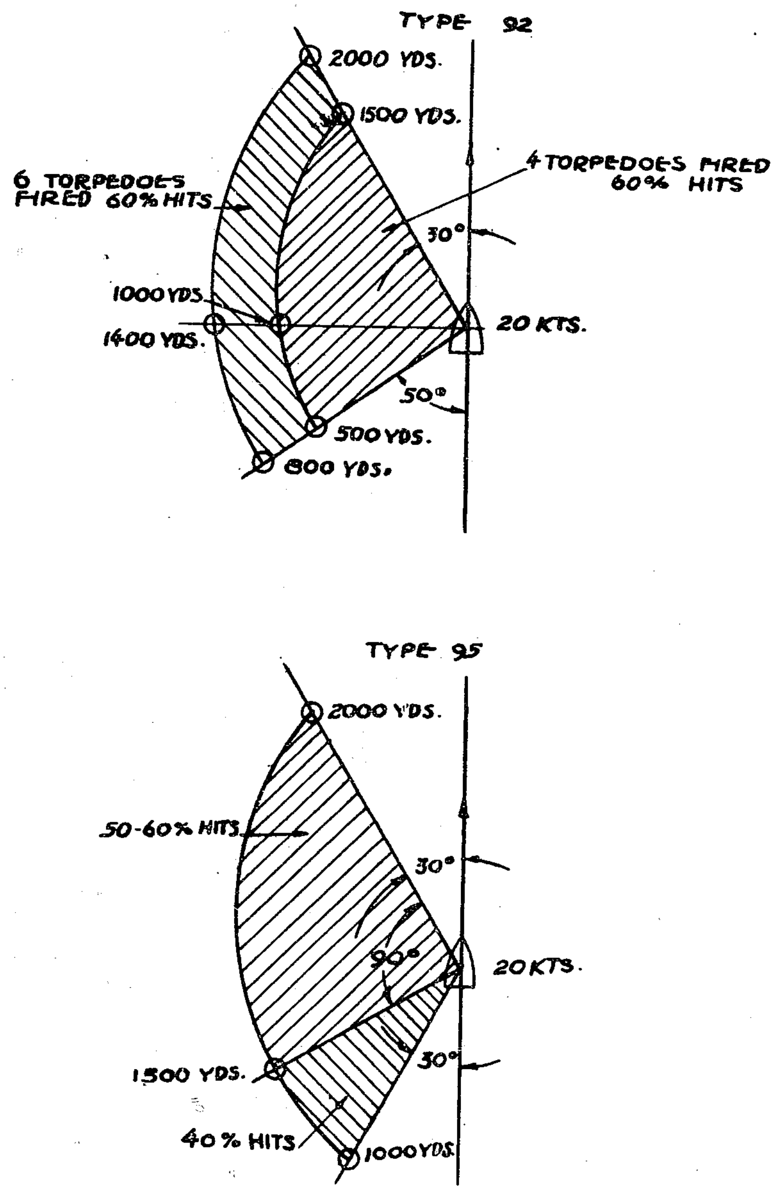


FIGURE 218
POTENTIAL ATTACK AREAS

General

The production of oxygen torpedoes during the war was insufficient for the requirements of the submarine service. (Thus, an accurate statistical survey of the effectiveness of Japanese torpedoes during the war cannot be compiled from Allied sources of information, unless the type of torpedo used in every attack is known.)

The striking power of Japanese submarines was greatly curtailed by the fact that many of them were forced to transport stores in forward areas.

KAITEN

While Commander of the Suicide Torpedo School at OTSUSHIMA, ITAKURA trained about 200 volunteers as KAITEN pilots. Each man made about 20 runs in a KAITEN over a period of three months.

Effectiveness of KAITEN:- ITAKURA could not offer accurate information on the effect of KAITEN attacks, but he thought that the following vessels had been sunk by these torpedoes:

2 or 3 aircraft carriers
2 battleships
25 or 30 merchant ships
4 or 6 destroyers

ENCLOSURE (C)

FUTURE DEVELOPMENT OF THE TORPEDO
COMDR. Y. HORI, IJN

The following views on the future developments of the torpedo were expressed by Commander HORI, the chief experimental designer, who was trained by Admirals OYAGI and NARUSE.

Since he has no information about the atomic bomb he has assumed that the conditions under which torpedoes would be used are similar to those during the war, prior to the bomb. The remarks are certainly applicable to the immediate future until atomic bomb research has been completed and tactics for its use at sea have been developed.

Tactics

He considers that the best weapon for sinking ships is the one which causes damage in the center of the bottom of the ship.

Of the two weapons available he prefers the torpedo to the mine, because it can be directed towards the target.

Development work on the torpedo will be divided into classes.

1 - Extreme range attack — Class A
2 - Short range attack — Class B

In both classes the torpedo should have only one speed setting to enable the mechanism to be both simple and thermodynamically efficient.

Extreme Range Attack

For this purpose the larger diameter (over 60 cm) torpedo, having a long range and moderate speed with external control will be used. The range should be at least 40,000 meters and the speed not less than 40 knots, not over 50 knots. The attack will be made using either a single torpedo or a group from a special cruiser-class of ship.

The torpedo will be developed from the 24" Type 93 torpedo using a power plant similar to that of the KAITEN Type 2, with concentrated energy partners, i.e. H_2O_2 or nitric acid, etc.

This torpedo will be carried by a special class of ship, carrying torpedoes only.

Short Range Attack

For this type of attack the diameter of the torpedo will be limited to 21", the speed will be increased to almost 55 knots (maximum) and the range limited to 5000 meters.

The torpedo will be used by aeroplanes, submarines and torpedo motor boats and will be propelled electrically or by the combustion of atmospheric air, condensed energy partners not being necessary.

Warheads

He considers that in the Class A there is no difficulty in carrying over 800 kg (1760 lbs) of explosive, but for Class B the maximum weight is 400 kg (880 lbs) in view of the smaller size of the torpedo. The actual weight carried is a matter for discussion with the ship designers.

ENCLOSURE (C), continued

For the greater weight no special type of detonating device is required but only a reliable inertia pistol.

For the smaller weight every means must be taken to increase the power of the explosion, such as special detonating devices, i.e. explosion should occur beneath the ship's bottom. He has experienced great difficulties with the mechanical method and considers that it is not worth further investigation.

As regards the magnetic pistol, adequate countermeasures can be taken.

He prefers a system in which the magnetic field is produced by the torpedo having one pole at each end. The design is simple but finally the two poles should be combined in the head.

With a torpedo salvo the inertia pistol has to be equipped with a safety device to prevent proximity explosion; because of the complexity of the mechanism he thinks that the simple lever type should be reconsidered.

To overcome the increased drag due to a whisker pistol, that for speeds over 50 knots, the nose of the torpedo should be fitted with a streamlined rubber cover in which the whiskers are buried.

To deal with torpedo nets explosive cutters must be used, but not in conjunction with an inertia pistol.

He considers that a streamlined head is not essential for the Class A torpedo but must be used for the Class B. The critical speed is about 45 knots. The present form is approaching the ideal and not much further gain can be expected.

Pressure Vessels

The modern method of making the joint of the detachable end is satisfactory. If forging methods can be improved he would forge the vessel with one integral end as in the Type 93 Model 3 and would close in the other end to reduce the size of the opening as much as possible, so that only a plug need be used to seal the end and to enable cleaning to be done.

For the future he considers that the problem of welding the vessel should be investigated.

For making the joint a softer material that copper should be used. If a suitable plastic on the lines of silicone resins could be found it would make a more satisfactory washer.

For the smaller vessels, (water, fuel, and oil bottles) a solid drawn tube with the ends welded in is the best.

Energy Source and Cycle

For the Class A torpedo, since range is the prime consideration, alternative energy carriers besides oxygen must be considered.

He considers that theoretically the use of H_2O_2 would increase the range to more than twice that of pure oxygen but that the design factors of the torpedo, i.e. negative buoyancy, etc., will limit the gain to 40 - 60%. Hydrogen peroxide and nitric acid and other condensed energy partners should be investigated

The wet heater cycle, because of the high exhaust losses, is not the best cycle. From the point of view of efficiency, the internal combustion cycle is best, the diesel cycle being the ideal. Commander HORI stated that the British semi-internal combustion cycle was in the right direction and half way towards it.

For the Class B torpedo the short range required permits the use of atmospheric air or electric battery. The main object is simplicity and ease of handling, in view of the small number of personnel available, the large numbers of torpedoes which must be carried and the short time in which attacks can be made.

Group and Reducer

The Whitehead type of group is very skillfully designed and requires no improvement.

Not much improvement can be obtained from the present type of reducer. The ideal is a single stage with oil damping device.

When large quantities of gas have to be dealt with the force on a single spindle is too great, so a balanced valve with a small pilot reducing valve, as is used in the turbine, is the most suitable. This has the additional advantage that the oil for lubrication is separated from oxygen by the diaphragm.

Circuits

Valves

He considers that all stop valves should be mechanically operated. The ideal valve design is one which employs a membrane which in the case of the subsidiary valve is pierced by the pressure.

Water

Commander HORI considers that taking the whole torpedo design into consideration the gear pump, even for high pressures (40 kg/cm^2; 568 lbs/in^2) is the most suitable on account of weight, space, simplicity, and absense of vibration.

Further development work to obtain the best tooth form, method of lubrication and optimum RPM should be carried out. With this type of pump a much smaller buffer chamber merely to control the pressure would only be needed.

He would continue to use sea water as diluent for Class A torpedoes but would employ fresh water for the Class B.

Fuel

As the calorific value is much the same for all hydrocarbon fuels, he would still use paraffin for the existing cycle.

For a diesel cycle he would use a reciprocating pump because of the high pressure and accurate metering. The maximum limit of pressure for a gear pump is 50 kg/cm^2 (710 lbs/in^2).

Lubrication

For Class A the lubricating oil must be circulated in order to minimize the track and to reduce the consumption. The use of different qualities of oil may be necessary to lubricate highly loaded parts. An oil should be developed with a flat viscosity temperature curve.

Investigation into ball, roller and oil impregnated bearings should be made.

Generator

He considers that the two most important points are:

1 - Complete combustion of the fuel with the minimum quantity of oxygen
2 - Rapid and complete evaporation of the water before leaving the generator

For Item 1, research must be carried out on the design of sprayer itself, on the number used and the arrangement.

For Item 2, intimate contact between the flame and the water must be ensured by getting the maximum area of contact between the two; for example, the use of two generators having half the capacity of a single one nearly doubles the area

As regards the heat losses, these can be reduced to almost zero by the use of an unbroken film of water covering the internal walls of the combustion chamber, as in the 24" Type 93 torpedo.

In view of the high gas velocities it is not necessary for the generator to be vertical.

Results of dynamometer tests had shown:

1 - That the evaporation of the water became bad when the generator pressure fell below 16-18 kg/cm^2 (227-256 lbs/in^2)

2 - That the maximum output in hp sec/kg of oxygen occurred at an oxygen fuel ratio of 2.8 - 3.0 when the percentage of CO and O_2 were not at a minimum.

Commander HORI considers the reason for this to be that combustion is delayed and occurs in the cylinders as well as in the generator and had a tendency towards the semi-internal combustion cycle.

He is much interested in the semi-internal combustion engine of the British Mark VIII torpedo and agrees with the principle of eliminating the cooling water and hence the loss due to its latent heat.

With regards to igniters he considers that two igniters are sufficient for the wet heater oxygen torpedo but that three are necessary for a semi-internal combustion cycle using air.

Power Unit

For the Class A the engine efficiency is most important and he considers that the reciprocating engine is the ideal prime mover.

A turbine operating on steam cannot be used because of its low efficiency, while a gas turbine is not practicable because of the high temperatures and the unsteady combustion.

To improve the efficiency he considers that there should be at least six cylinders and that a big expansion ratio should be used. In view of the size and weight of the whole torpedo, the engine weight can be considerably increased since it is a small fraction of the whole.

A cylinder arrangement of two rows of vertical cylinders or a V-type is not sufficiently compact unless the engine can be water-jacketted.

He is of the opinion that the swash plate type with horizontal cylinders is the best and if possible it should be double-acting to give a big output with small heat losses.

In addition, this type can be balanced so that the gyroscope, etc., are not affected by vibration.

Since the generator system is bad thermodynamically it should be made as small as possible and ulitmately disappear.

In the intermediate stages, development work on two-cycle engines with hot wire ignition should be carried out.

In general, for both classes, the poppet valve and cam system is desirable because any timing can be selected (slide valves must be used with sea water).

He further considers that the rotary valve is the ideal but presents many difficulties in its cooling, lubrication and prevention of leakage of gas.

For the Class B he prefers the electric motor or the turbine because simplicity and ease of manufacture is more important than performance. He considers that jet propulsion is bad both thermodynamically and hydrodynamicaly and is out of the question for torpedo propulsion except for very special short range purposes.

Fins and Rudders

For the higher speed torpedoes, i.e. over 50 knots, the Woolwich R.G.F. tail is much superior to the Fiume as regards propulsive efficiency. The latter has a very bad effect on the propellers but it does not disturb the water stream on the forward propeller and improves the operation of the rudders.

The fin area should be as large as possible provided rudder control is not affected. Research on this point should be carried out in wind tunnel tests.

In the case of the rudders the area should be as large as practicable since large area and small rudder angle is preferable to the reverse.

The form and area of the vertical fins and rudders have an important effect on rolling. Rolling may be reduced to a minimum by a suitable relation between the top and the bottom.

Commander HORI is of the opinion that it is better to overcome the tendency to roll rather than to design a universal controller to replace the depth gear and gyroscope.

Hull and Propellers

These have already been dealt with in another section of the report but the following are additional points which Comdr. HORI considers to be important. Intensive research on propellers should be carried out in a test tank with full-scale propellers. He is emphatic that the trials should be carried out using the afterbody.

The future torpedo will require a reduction gear between the engine and the propellers as the engine speed will be high.

The jet action of the exhaust gases is negligible at low speed but may have to be taken into account at high speed.

He considers that as a result of the turbine torpedo experiments a speed of 70 knots can be obtained without serious loss in propulsive efficiency. If the efficiency is allowed to fall below 50% a maximum speed of 100 knots is possible.

As far as manufacture is concerned he is of the opinion that each blade should be machined separately and welded to the boss.

Depth Gear

Comdr. HORI considers that the service depth gear with weight and hydrostatic valve is the best but prefers the American system of an air-tight depth gear casing so that the depth setting is not affected by air leaks in the balance chamber.

The position of the depth gear should be as nearly as possible at the center of gravity and the hydrostatic valve should be placed where there is no turbulence. This opinion is based on the results obtained with the Type 92 which had the depth gear in the afterbody.

The American system of adding pressure due to velocity to the static pressure so that the inclination of the torpedo is used to assist in correcting the depth, should be studied for high-speed torpedoes.

Attention must be paid to a second depth setting below the regular one for preventing break surfaces.

For higher speed torpedoes his experience with the Type F turbine torpedo is that the weight of the pendulum must be increased to obtain greater sensitivity to inclination and thus correct inclination more quickly.

As a general principle, near the set depth the torpedo should be controlled mainly by the pendulum but large deviations should be corrected mainly by the hydrostatic valve.

To obtain larger rudder angles as the torpedo inclination increases is desirable, and work on the lines of the German gear with clearance between the pendulum arm and the depth spring should be undertaken.

For the servomotor for the Class A torpedo, oil or water pressure should be used instead of air so that no wastage occurs, the pilot slide valve still being air operated. The standard arrangement is satisfactory for Class B.

Gyroscope

For Class A torpedo improved direction keeping is essential. Commander HORI considers that an electrically driven gyroscope wheel with air blast starting is the correct solution. The balanced diaphragm will be unchanged. Good vibration dampers will be needed.

The use of water or oil pressure for the steering engine should be adopted in the same way as for the depth gear servomotor.

For the Class B torpedo the standard gyroscope will be satisfactory provided better bearings and better mountings are fitted to withstand shock on entry into the water and engine vibration.

In general, he likes the American system of collecting into one unit both the depth gear and gyroscope.

If possible the vertical rudders should operate in the same way as the horizontal, i.e. the rudder angle should be directly proportional to the deviation of the torpedo from the true course. This has been partially realized in one of the German torpedoes.

"W" gear should be considered only for attack on convoys and not for use for attacks on warships.

ENCLOSURE (C), continued

Enemy-Seeking Torpedoes

The technical difficulties in developing an enemy-seeking device for Class B torpedoes does not justify the work involved except in the case of the electric torpedo where there is electricity available and the arrangement of connections between the two ends of the torpedo is easy.

For the air torpedo the best method is to develop suitable tactics and to press home the attack, i.e. methods of attack and numbers fired are more important.

For the electric torpedo an acoustic gear can be developed. In this system the receivers are installed in the tip of the head, partly to avoid interference from propeller noise and to avoid instability due to cavitation at high speeds. Development work on the material and form of the outside layer must be carried out and the frequency of the supersonic wave utilized must be carefully selected.

One idea is for the parent ship to emit sound waves which are reflected from the target to the torpedo. Alternatively the torpedo can be directed onto the target by the use of a supersonic beam emitted from and controlled by the parent ship. One difficulty, perhaps the main one, will be the effect of the torpedo propeller noise on the beam.

Remote Control

For Class A torpedoes, enemy-seeking devices are useless and some form of remote control must be devised. The lack of this control was the one defect of Type 93 torpedo.

Commander HORI considers that two methods might be realizable:

1 - The use of ultra-short electric waves to control a torpedo which rises to the surface at stated intervals.

2 - The use of long waves to control the torpedo when running at its set depth. (This type of wave can penetrate from air to water.) Actual control will be by means of a plane which will direct the parent ship on which the transmitter is erected.

ENCLOSURE (D)

STUDIES ON COLLOIDIAL TIN DIOXIDE AS A STABILIZER FOR HYDROGEN PEROXIDE

by
Fusao ISHIKAWA

(Chemical Institute, Faculty of Science,
Tohoku Imperial University)

It has already been determined that tin dioxide sol or gel is a very effective stabilizer for hydrogen peroxide. However, most of the previous experiments have been made with hydrogen peroxide of small or medium concentrations, and it is uncertain whether tin dioxide is still effective for concentrated hydrogen peroxide, such as 80% (by weight). This investigation was originally planned to find some inorganic stabilizers for concentrated hydrogen peroxide, and after several preliminary experiments, tin dioxide in a colloidal form was found to be satisfactory to the present purpose.

Experiments

a. Materials and Method of Experiment

Preparation of tin dioxide sol and gel - These colloids were prepared according to the prescription described in E on page 14 of Sauer's Kolloidchemisches Praktikum. Tin tetrachloride was dissolved in water and the clear solution was heated to boiling. The precipitate thus obtained was washed three or four times by decantation, and then peptized by adding a small quantity of ammonia. An excess of ammonia was expelled on the water bath and the sol diluted with water to the appropriate volume. By adjusting the quantity of ammonia, tin dioxide in a gel form was obtained.

Hydrogen peroxide - Most of the measurements were made with 80% hydrogen peroxide. Sixty per cent hydrogen peroxide of commercial quality which contains some stabilizers, such as oxine, pyrophosphate etc., was redistilled in vacuum, using Pyrex glass vessels in order to get rid of stabilizers, and a distillate of 80% concentration, which was free from any admixture, was collected and used.

Method of measurement - The comparative tests on stabilizing effect were made as follows:

Several glass bulbs, each of which has a water condenser and contains about 25 cc of the sample, that is, a mixture of hydrogen peroxide and a stabilizer, were kept at 96°C for 24 hours, during which a small quantity of the sample was taken out at regular intervals and the concentration decrease of the hydrogen peroxide determined by a permanganate method. Some measurements were made at 50°C for a longer period.

b. Results of Experiment

Experiment 1.

Stabilizer 1. SnO_2(gel) 0.3%, $Na_4P_2O_7$ 0.02%, H_3PO_4(90%) 0.015%

Stabilizer 2. SnO_2(sol) 0.03%

Stabilizer 3. SnO_2(gel) 0.03%

The above figures represent the percentage concentration of each stabilizer in hydrogen peroxide solution.

ENCLOSURE (D), continued

Table 1
Temperature 96°C

Time (hours)	Concentration of H_2O_2 (%)			
	No Stabilizer	Stabilizer 1	Stabilizer 2	Stabilizer 3
0	76.7	79.6	80.9	83.9
6	71.3	79.3	80.8	83.6
12	61.7	79.1	80.6	83.3
18	45.3	78.6	80.1	82.9
24	15.6	78.3	79.9	82.1
Concentration decrease after 24 hours	61.1%	1.3%	1.0%	1.8%

The above results show that SnO_2 sol or gel is a very excellent stabilizer for concentrated hydrogen peroxide.

Experiment 2.

The stabilizing effect of oxine may be improved by adding tin dioxide gel as shown in Table 2.

Stabilizer 1. Oxine 0.03%, $Na_4P_2O_7$ 0.02%, H_3PO_4 (90%) 0.015%

Stabilizer 2. Stabilizer 1 + SnO_2 (gel) 0.03%

Table 2
Temperature 96°C

Time (hours)	Concentration of H_2O_2 (%)	
	Stabilizer 1	Stabilizer 2
0	91.0	90.5
6	90.3	90.2
12	89.8	90.0
18	89.2	89.5
24	85.6	89.1
Concentration decrease after 24 hours	5.4%	1.4%

Experiment 3.

Similar experiment was conducted at 50° for 40 days, using the same stabilizers as mentioned above.

When SnO_2 gel was present, the decrease in concentration between 33 and 40 days was found to be less than in the case of Stabilizer 1 without SnO_2. If the experiment were continued for a longer period, the effect of SnO_2 would be expected to appear more prominently.

Experiment 4.

The stabilizing power of SnO_2 is considered to be due to its adsorptive power for heavy metal ions which may accelerate the decomposition of H_2O_2. The experiments, therefore, were carried out in the presence of Fe and Cu. The results are shown in the Tables 4 and 5.

Table 3.
Temperature 50°C

Time (days)	Concentration of H_2O_2 (%) Stabilizer 1	Stabilizer 2
0	90.5	90.5
5	90.4	90.4
10	90.3	90.3
26	89.8	90.3
33	89.8	90.4
40	88.5	89.7

Table 4
Temperature 50°C

Time (hours)	Concentration of H_2O_2 (%) Fe 10^{-4} mol/L	Fe 10^{-4} mol/L, SnO_2 (sol) 0.05%
0	80.3	83.5
5	78.9	
10	78.3	82.5
24	73.1	80.6
48	67.2	78.1
72	61.3	75.9
96	55.9	73.5

Table 5
Temperature 50°C

Time (hours)	Concentration of H_2O_2 (%) Cu 10^{-4} mol/L	Cu 10^{-4} mol/L, SnO_2 (sol) 0.05%
0	79.1	78.1
5	76.0	
10	75.8	
24		77.0
30	73.2	
48	70.2	76.2
72	65.3	75.0
96	59.8	73.3
120	47.5	73.3

The above results show that tin dioxide is able to reduce the injurious effects of Fe and Cu. Similar results were obtained in the experiments on Pb and Cr.

Conclusion

On the basis of the foregoing experiments, it can be concluded that colloidal tin dioxide is quite an effective stabilizer for concentrated hydrogen peroxide.

ENCLOSURE (E)

LIST OF JAPANESE DOCUMENTS FORWARDED TO THE WASHINGTON DOCUMENT CENTER

NavTechJap Document No.		ATIS No.
ND50-3050	Specifications of metals used in Japanese Navy - Sept. 1936	
ND50-3051	(a) Test data of throttling holes in generator of Type 95 torpedo	4688
	(b) Generator nozzle rating data	4689
	(c) Nozzle flame test data	
ND50-3056	(a) Rough plan of DAINYU installations	
	(b) Data of running test of Type 95 torpedo	4690
ND50-3053	(a) Torpedo instruction book - 1935 (2 copies)	
	(b) Torpedo instruction book; diagrams (1 copy)	4691
ND50-3054	Theory of Depth Mechanisms	
ND50-3055	Primary manual of torpedo instruction	4692
ND50-3056	Notes on No. 6 Engine	4693
ND50-3057	(a) Test data on Types 91, 95, 96, and 98 torpedoes	4694
	(b) List of various parts for Types 93 and 95 torpedoes	4695
ND50-3058	Oxygen generating agents	
ND50-3059	Test data of KAITEN 4 generators	4696
ND50-3060	Recorder for ranging measurements - 1937	4697
ND50-3061	Torpedo screw data - 1939	4698
		4699

ENCLOSURE (F)

TORPEDO EQUIPMENT SHIPPED TO ORDNANCE INVESTIGATION LABORATORY, INDIAN-HEAD, MARYLAND

NavTechJap Equipment No.	Quantity	Description of Items
JE10-4677, 4678, 4679	3	6th Year Type Torpedoes
JE10-4878	1	6th Year, Model 1, Torpedo
JE10-4680	1	6th Year, Modification 1, Torpedo
JE10-4681 4682, 4683	3	6th Year, Modification 2, Torpedoes
JE10-4865(1-2) -4866(1-3) -4867(1-2) -4877	8	8th Year, Model 2, Torpedoes
JE10-4699	1	8th Year, Mk 2, Torpedo
JE10-4693, 4694, 4695	3	8th Year, Mk 2, Modification 1, Torpedoes
JE10-4697, 4698, 4699	3	8th Year, Mk 2, Modification 2, Torpedoes
JE10-4876	1	8th Year, Model 2, Modification 2, Torpedo
JE10-4684, -4685	2	Type 44 Mk Torpedoes
JE10-4975(1-3)	3	Type 44, Model 2, Torpedoes
JE10-4976(1-2) -4883	3	Type 89 Torpedoes
JE10-4686 -4687 -4688 -4875(1-3)	6	Type 90 Torpedoes
JE10-4882	1	Type 91 Torpedo
JE10-4881	1	Type 91, Model 1, Torpedo
JE10-4880	1	Type 91, Model 2, Torpedo
JE10-4664 -4665 -4666	3	Type 91, Modification 3, Torpedoes
JE22-1062(1-4) JE21-4987	5	Type 91, Model 3, Torpedoes Type 91, Model 3, Torpedoes
JE21-4510 JE22-1063(1-4)	5	Type 91, Model 3, Strong Torpedoes Type 91, Model 3, Strong Torpedoes

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE10-4879(1-3) -4890	4	Type 91, Model 3, Special Torpedoes
JE10-4667 -4668 -4669	8	Type 92, Modification 1, Torpedoes (Electric)
JE22-3263 -3264 -3265 -3266 -3267		Type 92, Modification 1, Torpedoes (Electric)
JE10-4864 -4874(1-2)	3	Type 93, Model 1, Torpedoes
JE10-4670 -4671 -4672 -4862(1-3)	6	Type 93, Model 1, Modification 1, Torpedoes
JE10-4863(1-2) -4873	3	Type 93, Model 1, Modification 2, Torpedoes
JE10-4673 -4674 -4675 -4872(1-3)	6	Type 93, Model 1, Modification 3, Torpedoes
JE10-4676 -4871(1-3)	4	Type 93, Model 3, Torpedoes
JE10-4698	1	Type 94 Torpedo
JE10-4861(1-3)	3	Type 94, Model 1 (Temporary Designation) Torpedoes
JE10-4870(1-3)	7	Type 94, Model 2, Torpedoes
JE22-1506 -1507 -1508 -1509		Type 94, Model 2, Torpedoes
JE10-4658 -4659	2	Type 95, Modification 1, Torpedoes
JE10-4660 -4662(0-1) -4853 -4888(1-2)	6	Type 95, Model 2, Torpedoes
JE10-4663 -4889(1-2)	3	Type 96 Torpedoes
JE10-4653 -4654 -4655 -4891(1-3)	12	Type 2 Torpedoes
JE22-1510 -1511		Type 2 Torpedoes

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
-1512 -1513 -1514 -1515		
JE10-4884(1-2) -4885(1-3)	5	Type 2 (Temporary Designation) Torpedoes
JE10-4656 -4657 -4886 -4887(1-3)	6	Type 2 Special Torpedoes
JE21-4508 JE22-1061(1-8)	9	Type 4 Torpedoes Type 4 Torpedoes
JE10-4690 -4691 -4692	3	Type 4, Mk 1, Model 1, Aerial Torpedoes
JE21-4990(1-3)	3	Type 4, Modification 1, Model 1, Torpedoes
JE10-4499(1)	2	Type 5, Eleven Inch, Torpedoes
JE21-4991	1	Type 5 (Rocket) Torpedo
JE21-4511	1	Model 6 Aerial Torpedo Bomb
JE21-4988	1	Model 7 Aerial Torpedo Bomb
JE21-4518(1-2)	2	Model 8 Special Torpedo Bombs (Complete)
JE21-4505	1	Type 1 Aerial Torpedo (Jet Propelled)
JE21-4507	1	Type k Torpedo Engine - 220 HP
JE21-4965	1	Type M Torpedo (without Head)
JE22-1501 -1504	2	KAITEN Type 1 (Body)
JE22-1502 -1505	2	KAITEN Type 1 (Torpedoes)
JE22-1521	1	KAITEN Type 2 (Body)
JE22-1522 -1523	2	KAITEN Type 4 (Body)
JE21-4517	1	Buffer Aerial Torpedo Wing
		TORPEDO EXPLODERS
JE10-4768(1-6) -4769(1-26) -4770(1-13)	-	4th Year Type, Mk 1, Model 1, Exploders

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE10-4573(1-7) -4577(1-3) -4578(1-4) -4580(1-3)	-	Type 90 Exploders
JE10-4770(1-13)	-	Type 90, Model 2, Exploders
JE22-3414 -3415		Type 90, Model 2, Exploders
-3416	1 Bx	Type 90, Model 2, Strong Exploders
JE10-4571(1-4) -4572(1-4) -4573(1-7) -4574(1-11)	-	Type 91, Model 1, Exploders
JE10-4569(1-12) -4570(1-18)	-	Type 91, Model 2, Exploders
JE10-4570(1-18)	-	Type 91, Model 3, Exploders
JE22-3417	1 Bx	Type 91, Model 3, Exploders
JE10-4848	1 Bx	Type 98, Model 1, Exploders
JE10-4569(1-12) -4574(1-11) -4575(1-4) -4576(1-2) -4578(1-4) -4579(1-3) -4581(1-2) -4582(1-3) -4583(1-2) -4584(1-2) -4585(1-12)	-	Type 2 Exploders
JE22-3402	1	Type 2 Special Torpedo Exploders
JE10-4568(1-16) -4769(1-26) -847	-	Type 2, Modification 1, Exploders
JE22-3418	-	Type 2, Modification 1, Exploders
JE22-3258 -3259 -3260 -3261 -3262 -3411 -3412 -3413	-	Type 2, Model 2, Exploders
JE22-3410	1 Bx	Type 3 Exploders
JE21-4426	1 Bx	Type 4, Mk 1, Model 1, Exploders
JE22-3409	1 Bx	Type 4, Model 1, Modification 1, Exploders

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE10-4846	1 Bx	Type 10, Model 2, Exploders
JE10-4496	1 Bx	Whisker Type Exploders
JE10-4998	3	Torpedo Pistol (3) & Tool Kit (1)
JE21-4973	-	Assorted Torpedo Exploders
JE21-4075 -4338		Assorted Torpedo Exploders
JE23-0011(8-13)		Assorted Torpedo Exploders
		TORPEDO WARHEADS
JE10-4712(1-2)	2	4th Year Type Aerial Torpedo Warheads
JE10-4619 -4620 -4621 -4622 -4623 -4624 -4703(1-2)	8	6th Year Type Torpedo Warheads
JE10-4613 -4614 -4615 -4616 -4617 -4702(1-2)	7	8th Year Type Torpedo Warheads
JE10-4701	1	Type 44 Torpedo Warhead
JE10-4618	1	Type 89, Model 2, Torpedo Warhead
JE10-4708	1	Type 90 Torpedo Warhead
JE10-4705(1-2)	2	Type 91, Modification 2, Torpedo Warheads
JE10-4704(1-2)	2	Type 93, Model 1, Modification 1, Torpedo Warheads
JE10-4700(1-2) -4856(1-3)	5	Type 93 Torpedo Warheads
JE10-4706	1	Type 2 Torpedo Warhead
JE10-4707	1	Type 2 Special Torpedo Warhead
JE10-4625	5	Type 5, Model 2, Torpedo Warheads
JE22-1500 -1503	2	KAITEN Type 1 Torpedo Warheads
JE22-1520	1	KAITEN Type 2 Torpedo Warhead
JE22-1524 -1525	2	KAITEN Type 4 Torpedo Warheads

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE21-4986	1	'OR' -2 Torpedo Warhead (body only)
JE21-4985	13	Net Cutters for Torpedo Warheads
		TORPEDO EXERCISE WARHEADS
JE10-4869(1-9)	9	6th Year Type Exercise Heads
JE10-4594	4	6th Year Type, Model 2, Exercise Heads
JE10-4892 (20-22,25-30)	9	8th Year Type Exercise Heads
JE10-4598 -4600 -4601 -4610	4	8th Year Type, Model 2, Exercise Heads
JE10-4589 -4869(10) -4892(1)	3	Type 44 Exercise Heads
JE10-4586 -4892(13-19)	3	Type 89 Exercise Heads
JE10-4892 (23-24)	2	Type 90 Exercise Heads
JE10-4599	1	Type 90, Model 2, Exercise Head
JE10-4892 (16-17)	2	Type 91 Exercise Heads
JE10-4602 -4603 -4604 -4605 -4892(31-36)	10	Type 91, Model 2, Exercise Heads
JE22-1064(1-4)	4	Type 91, Model 3, Exercise Heads
JE22-1065(1-4)	4	Type 91, Model 3, Strong Exercise Heads
JE10-4892(4-11)	8	Type 93 Exercise Heads
JE10-4989(2)	1	Type 93 (Large) Exercise Head
JE10-4939(3-6)	4	Type 93 (Small) Exercise Heads
JE10-4590 -4591 -4592 -4593	4	Type 93, Model 1, Modification 1 and 2 Exercise Heads
JE10-4869(20-25)	6	Type 94, Model 2, Exercise Heads

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE10-4989(1) -4892(12-15)	5	Type 95 Exercise Heads
JE10-4606 -4607 -4608 -4609 -4869(11-17)	11	Type 95, Model 2, Exercise Heads
JE10-4869(18-19)	2	Type 96 Exercise Heads
JE10-4892(2-3) JE22-1516 -1517 -1518 -1519 -3255 -3256 -3257	9	Type 2 Exercise Heads Type 2 Exercise Heads
JE10-4587 -4588	2	Type 2, Model 2, Exercise Heads
JE10-4499(2)	2	Type 5 Eleven Inch Exercise Heads
JE10-4611 -4612	2	Radio Type Exercise Heads
JE10-4776 -4777	2	Type Z 2 Smoke Filled Torpedo Heads
JE10-4541(1-4) -4545(1-4) -4546(1-4) -4547(1-4) -4548(1-4) -4550(1-4) -4551(1-4) -4560(1-5) -4768(1-6) -4769(1-26)	-	4th Year Type Gyros
JE22-3423	-	4th Year Type Gyros
JE10-4542(1-4) -4543(1-4) -4545(1-4)	-	4th Year Type, Modification 2, Gyros
JE10-4851	1 Bx	4th Year Type, Model 2, Gyros
JE10-4849	1 Bx	6th Year and 8th Year Type Gyros
JE10-4544(1-4) -4549(1-4) -4552(1-3) -4553(1-4) -4556(1-5)	-	Type 91 Gyros

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE22-3403 -3404	-	Type 91 Gyros
JE21-4992	1 Bx	Type 91 Gyros Modified for Type 2 Torpedo
JE21-4993(2)	1 Bx	Type 91 Strong Gyros
JE21-4994(1-2)	2	Type 91 Gyros for Use in Midget Subs and PT Boats
JE10-4768(1-6) -4769(1-26)	-	Type 91, Modification 1, Gyros
JE21-4987(1-2)	2	Mk 91, Model 3, Gyros
JE21-4510(1-2)	2	Mk 91, Model 3, Strong Gyros
JE10-4548(1-4) -4567(1-4)	-	Type 92 Gyros
JE10-4557(1-4) JE21-4995(1-3)	7	Type 98 Gyros Type 98 Gyros
JE10-4554(1-4) -4555(1-4) -4556(1-5) -4558(1-4) -4559(1-4) -4561(1-4) -4562(1-4) -4563(1-4) -4564(1-4) -4565(1-4) -4566(1-4) -4850	-	Type 98, Modification 1, Gyros
JE22-3405 -3406	-	Type 98, Modification 1, Gyros
JE22-3425 -3428	4	Type 2 Gyros
JE21-4508(1-2)	2	Type 4 Gyros
JE21-4996(1-3)	3	Electric Gyros
JE10-4759(1-10)	10	Type 2, Modification 1, Gyro Compasses, Torpedo Practice Scuttling Clocks
JE21-4998(1-2)	-	Type 2 Recorder Mechanisms
JE21-4997(1-2)	-	Type 92 Recorder Mechanisms
JE21-4997(1-3)	-	Type 93 Recorder Mechanisms
JE10-4760(1-2)	-	Radio Recorder Mechanisms
JE10-4755(1-6)	-	Assorted Recorder Mechanisms

ENCLOSURE (F), continued

NavTechJap Equipment No.	Quantity	Description of Items
JE21-4971 -4972		Assorted Recorder Mechanisms
JE22-3507	-	Assorted Recorder Mechanisms
JE50-1256	1 Bx	Parts for Recording Depth Gauges
JE50-1261(1)	1	Recording Depth Gauge and Accessories
JE50-1239(1-7)	7	Assorted Depth Recorders
		TORPEDO TUBES
JE22-1052	1	Type 92, Model 4, Quad Mount Torpedo Tube
JE50-1143	1	Torpedo Tube, with Equipment