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INDEX NO. S-37

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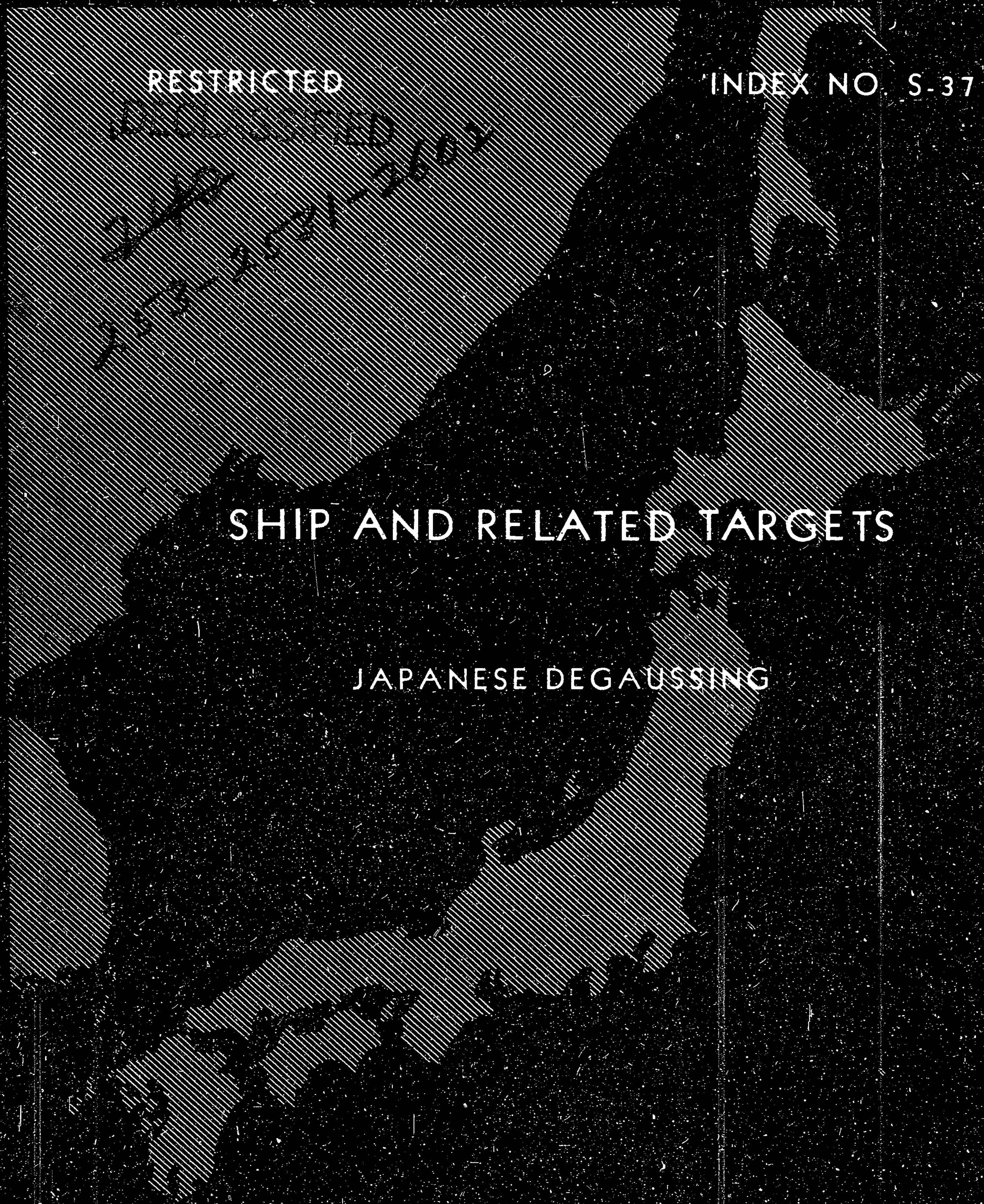

SHIP AND RELATED TARGETS

JAPANESE DEGAUSSING

U.S. NAVAL TECHNICAL MISSION TO JAPAN

NS/ccb

U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

25 December 1945

RESTRICTED

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

Subject: Target Report - Japanese Degaussing.

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

1. Subject report, dealing with Targets S-37 and S-39 of Fascicle S-1 and Target O-34 of Fascicle O-1 of reference (a), is submitted herewith.

2. The investigation of the target and the preparation of the report were accomplished by Dr. George Welch, Air Technical Intelligence Group, Advanced Echelon, Far East Air Forces, assisted by Lt. (jg) P.S. Gilman, USNR, and Capt. M. S. Zaslow, AUS, as interpreter and translator, respectively.

C. G. GRIMES
Captain, USN

JAPANESE DEGAUSSING

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

FASCICLE S-1, TARGET S-37, S-39

FASCICLE O-1, TARGET O-34

DECEMBER 1945

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

SHIP AND RELATED TARGETS

JAPANESE DEGAUSSING

The following are the principal policies which governed Japanese degaussing:

1. Only naval vessels were degaussed.
2. Ships were fitted with single-loop M-coils only, using submarine type cable on the outside of the hull.
3. Degaussing facilities existed only at the four principal naval bases of YOKOSUKA, KURE, SASEBO, and MAIZURU. There were no facilities at advanced bases.
4. After installation at one of the above bases, the M-coil was calibrated by means of magnetometers swung under the ship. Following this calibration, the magnetic condition of the ship was not checked again. The Japanese had no magnetic ranges.
5. Magnetic treatment was limited to submarines and a few destroyers and was done only at the Kure Arsenal.
6. Installation of coils was abandoned in favor of minesweeping in the early part of 1944.

Had the Japanese used multiple loop coils, deperming would have been nesessary for consistency, and the converse is also true to a lesser extent. Either or both would have required an extensive program of checking. Any consistent policy of improvement would have resulted in a very great expansion of their program which they were not prepared to undertake.

The number of engineers and officers engaged in degaussing, excluding men engaged in instrument research and degaussing coil installation, but including those engaged in primary research, administration, and all other phases of degaussing, was about eight. In addition, about twenty engineering assistants were engaged in degaussing. While Japanese degaussing was poor according to American standards, a great deal was accomplished in terms of the effort expended.

The decision in 1944, to abandon coil installation and concentrate on minesweeping, which had a greater potentiality of effectiveness, appears to have been based on good judgement.

No outstanding developments were noted in Japanese degaussing. Certain recommendations for further study are made in the report.

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LIST OF ENCLOSURES

REFERENCES

Targets Visited:

Ships in Yokohama and Kure harbors
Magnetic Treatment and Measuring Station at Kure Arsenal
Degaussing Laboratory at HIROSHIMA
Factories Supplying Degaussing Instruments and Equipment:
- Yokogawa Denki (Yokogawa Electric Works), KICHIJOJI, TOKYO
- Mitsubishi Electrical Manufacturing Company, TOKYO
- Nippon Musen (Japan Radio Company), TOKYO
- Nippon Denchi (Japan Battery Company), KYOTO

Japanese Personnel Who Assisted in Gathering or Locating Instruments and Documents:

Mr. Keizo SHIBATA
Mr. Tsugio KAWAI
Lt. Comdr. Giichi YOKOYAMA

Japanese Personnel Interrogated:

Mr. Tsugio KAWAI - Graduated from Kyoto University with a degree in electrical engineering in 1930 and entered the Electrical Experiment Department at the Kure Arsenal where he worked on materials and small current measurements until research on degaussing was begun. Under the supervision of Captain Junichiro OSHIMA (Ph. D. in E. E., Tokyo University, 1922), he was in charge of research on degaussing, which, until the middle of 1942, involved only coiling. At that time research on magnetic treatment was begun, and until this was terminated in the middle of 1943, Mr. KAWAI and Lt. Comdr. YOKOYAMA shared this responsibility. Mr. KAWAI was very well qualified to discuss essentially all phases of degaussing.

Lt. Comdr. Giichi YOKOYAMA - Graduated from Kyoto University with a degree in electrical engineering in 1934 and worked at the Yokosuka Arsenal until 1942 when he was put in charge of naval construction. Lt. Comdr. YOKOYAMA shared with Mr. KAWAI the responsibility of research on magnetic treatment and, under the supervision of Captain OSHIMA, was responsible for the installation and operation of the magnetic treatment station.

Mr. Keizo SHIBATA - Graduated with a degree in physics from Kyoto University 1930 and did research work there on theoretical electricity from 1930 to 1937. Worked at Yokosuka Mine Experiment Department, 1937-1943 and Naval Technical Research Laboratory 1943-1945. Mr. SHIBATA developed the YZ magnetometer and experimental model recording magnetometer.

Lt. Comdr. Saburo ABE - Graduated from Tokyo Imperial University with a degree in electrical engineering about 1933 after which he was commissioned a Lt. (jg) Engineering Officer. Was with Kure Electrical Department from 1933 to 1943 working on submarine propulsion motors except for three years when he studied in Germany. Was with the Navy Technical Department (Kanseihonbu) of the Navy Ministry since the beginning of 1944.

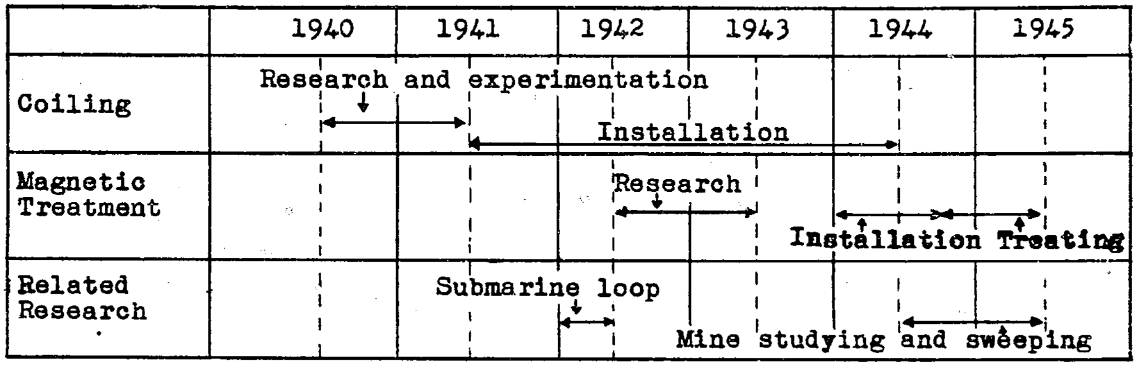
INTRODUCTION

The information for this report was obtained by interrogation of Japanese personnel, by examination of measuring instruments in the Tokyo area, by examination of degaussing installations, by examination of the magnetic treatment station and experimental laboratories of the Electrical Experiment Department at KURE, and from papers submitted by Japanese personnel. Most documents relating to degaussing were reported destroyed and it was necessary in some cases to have the pertinent points of the reports reproduced from memory. It is believed that the information in this report is accurate and comprehensive.

THE REPORT

Part I
HISTORY OF JAPANESE DEGAUSSING

A. The history of Japanese degaussing is illustrated in the following diagram. It is interesting to note that research and experimentation on coiling was terminated before the war began. Installation of coils was abandoned for minesweeping in the early part of 1944. The Japanese were not certain that we were using magnetic mines until 1943.



B. In the development of degaussing, the Japanese received considerable information on coiling from the British prior to 1941 through the Japanese Naval Attache in London. This information included the formula used by the British to calculate the ampere-turn capacities of degaussing coils in terms of the mean height of the ship (AT = 28 x height in feet).

C. In 1942 the Japanese captured a British 5000-ton cargo ship (probably VENNEBIS, re-named SHONAN MARU) which was equipped with M, F, and Q coils, They also captured an abandoned American submarine equipped with M, F, and Q coils. Except for information obtained from examination of this submarine, the men interrogated stated that they had no information on American degaussing. They were not aware of the U.S. range at Cavite at the time the Japanese invaded the Philippine Islands. The men interrogated stated that they had no information on Russian degaussing.

D. According to the Japanese, they knew that the Germans were using some form of magnetic treatment. The Japanese developed their method of treatment independently, though later in the war they received more detailed information on German methods.

E. The total cost of degaussing (not including loss of ships' time) was as follows:

Installation of degaussing coils	¥10,000,000
Magnetic treatment	1,500,000
Research	1,000,000
Testing, repair, etc.	1,000,000

(The pre-war (1941) value of the yen was about 15 cents.)

Part II
ORGANIZATION OF DEGAUSSING

A. Degaussing activities in Japan were limited to naval vessels. The organizations responsible for the various primary phases of degaussing are listed below:

1. Warfare Section of the Navy Ministry (Gummukyoku) - primarily responsible for policy regarding types of ships which were to be coiled and treated.

2. Navy Technical Department of the Navy Ministry (Kanseihonbu) - shared the above responsibility and was, in addition, responsible for engineering specifications of magnetic treatment apparatus. Lt. Comdr. ABE, who was interrogated, had been in charge of degaussing in the Navy Technical Department since the latter part of 1943.

3. Naval Arsenals at YOKOSUKA,KKURE, SASEBO, and MAIZURU - responsible, together with the Navy Technical Department of the Navy Ministry, for the installation of degaussing coils (including calibration with magnetometers swung under the ship after installation) and for the installation of compass compensating coils.

4. Electrical Experiment Department at the Kure Arsenal - responsible for all research work on degaussing. Mr. KAWAI and Lt. Comdr. YOKOYAMA were in charge of the research under the very general direction of Captain OSHIMA (Ph. D., Electrical Engineering) who was also charged with responsibilities other than degaussing. Magnetic treatment was limited to submarines and a few destroyers and was carried out only at the Electrical Experiment Department at KURE.

B. Measuring instruments were developed at the Experiment Department for Mines and the Experiment Department for Navigation, both located at YOKOSUKA. Research on compass compensation was done at the latter place.

C. General specifications to fit standardized cables and controls were furnished by the Navy Technical Department of the Navy Ministry and fundamental policies of degaussing were centrally established. Arsenals were allowed complete freedom of action in coil installation within the bounds of these limitations.

D. The number of men engaged in various degaussing activities was as follows:

	Officer or Chief Engineer	Assistant Engineer	Assistant
Administration	2		
Research	3	1	5
Installation	No special personnel		
Measuring			2 or 3 at each arsenal
Maintenance	No special personnel		
Treatment	1		5

These numbers include only those men whose sole function was degaussing. There was no special degaussing officer at each arsenal; the engineering officer was charged with the responsibility of degaussing installations and measurements together with his other duties.

E. Minesweeping policy and degaussing policy were not correlated particularly, though a number of men at different times worked in both fields, and there was said to be a high degree of cooperation. Logical policy was difficult to formulate because of inadequate knowledge of American mines and because of changes in these mines with the progress of the war.

Part III
RESEARCH AND DEVELOPMENT

A. Japanese research on degaussing was very limited according to American standards. All the research was done under the supervision of the Electrical Experiment Department, which, until December 1944, was located at the Kure Arsenal. At that time the Electrical Experiment Department was moved to HIROSHIMA to avoid bombing. The laboratory at HIROSHIMA, which consisted of four or five rooms in an engineering school, was badly damaged by the atomic bomb.

B. Research on models and coiling - Three or four models were constructed. One of these was a fairly accurate model of DD WAKATAKE with some superstructure but no compartmentation. This model was about four meters long, the scale being 1/20. The other models were only crude shells, having various values of beam, height, and length. The models were made of 0.5mm tin-plated steel (used because it was available, with little consideration to its permeability or thickness).

C. Experiments on models were conducted out-of-doors. The models were mounted on wooden tracks which could be oriented with respect to magnetic north. Magnetic shaking was accomplished by moving the model through a coil (60 cycle) fixed with respect to the track. A Z-loop was used, but there was no other provision for compensating the earth's field.

D. The measuring instruments were fixed with respect to the wooden tracks and measurements at different points were taken by moving the model over the tracks. In the beginning, two types of magnetometers were used. The first was a magnetic needle type. The second was an earth inductor type, the coil of which was rotated by means of an air turbine. In this latter type the coil rotated between two permalloy poles which were not magnetically connected. The poles were so constructed that the field between them was proportional to the component of the field in the direction of the common axis of these poles.

E. Later only the Mitsubishi magnetometer, which was much more satisfactory, was used. The same type magnetometer was used on full scale ships. (See paragraph E, Part V, and Enclosure (H).)

F. The models were fitted with simple M-coils, multiple loop M-coils, L-coils, and A-coils. All these coils, except for one case where the effect of placing a simple M-coil inside the hull was being studied, were on the outside of the hull. Satisfactory results were not obtained for the L-coils or A-coils. The models were used to study coil arrangements, and the magnetic effects of changing currents and headings. They were also used in connection with research on magnetic treatment. (See paragraphs M to O, incl., below.)

G. Model experiments indicated that inside coils required 50 percent more copper than outside coils. An attempt was made to verify this result on the captured British vessel, but the experiment was never completed. Based on this figure, a decision was made to use outside coils in order to conserve copper.

H. The full scale DD WAKATAKE (beam 8 meters, length 80 meters) was also fitted with simple and multiple loop M-coils, an L-coil, and an A-coil, all of which were installed on the outside of the vessel. It was stated that the experimental data on the WAKATAKE model were in fair agreement with full scale data on the same ship, but these data were not available for examination. On the full scale ship, as on the model, the L-coil and A-coil were not successful.

I. Experimental single loop M-coils were installed on the following ships:

BB YAMASHIRO	DD USUGUMO
CA AOBA	SS I-52
CL (none)	AM No. 13

From this a design formula was developed:

$$AT = 100\ H$$

where H is the mean height in meters.

This formula assumes compensation at Z = 500 milligauss. This formula is nearly identical with the British formula:

$$AT = 28\ H'$$

where H' is in feet.

J. No experiments were done by the Japanese on F and Q coils.

K. Latitude Cruise Experiments - DD WAKATAKE was available to the Electrical Experiment Department at KURE exclusively for degaussing research from December, 1940 to May, 1941. During two months of this time, a latitude cruise was conducted going from KURE to PALAU in southern magnetic latitude and to BAKO (in PESCADORES), KURE, OMINATO, MAOKA (in SAKHALIN), and WAKKANAI. Measurements were made below the ship and at points $\frac{1}{2}$H and H above the upper deck. A general formula was developed for the ampere-turns required in the M-coil:

$$AT = A + K\ H\ \frac{Z}{500}$$

where A is constant corresponding to permanent magnetization
K is constant to account for change in magnetic latitude
H is ship's height in meters
Z is earth's vertical field in milligauss.

The constant, K, was found to be 70 for WAKATAKE, and this was used at first for all ships. Later experience indicated that this figure was too low for submarines, and a value of 100 was adopted for underwater craft.

L. Variations of Permanent Longitudinal Magnetization with Building Yard - By field measurements of different ships of the same class, the permanent longitudinal magnetization was found to be correlated with the heading of construction at the following building yards:

KURE	south pole in bow	strong
SASEBO	north pole in bow	very strong
NAGASAKI	north pole in bow	very strong
YOKOSUKA	south pole in bow	weak
KOBE	south pole in bow	weak
MITSUBISHI	south pole in bow	rather weak
KAWASAKI	south pole in bow	rather weak

It was concluded from these and other data that the permanent magnetization (both vertical and horizontal) originated from mechanical shock such as riveting, bomb shock, or shock due to depth charges.

M. Theoretical Studies of Ship's Fields - Theoretical calculation of ship's fields were made assuming the ship's hull to have the shape of an ellipsoid. Similar calculations were made assuming the ship to approximate a finite circular cylinder. These latter calculations, in comparisons with full scale ship measurements, are given in Enclosure (I).

N. Research on Magnetic Treatment - The first experiments on magnetic treatment were done with models. The ship model was passed through a circular loop carrying alternating current using frequencies from 20 cycles per second to 60 cycles per second. A Z-loop was used to compensate the vertical component of the earth's field. From these experiments, quantitative information was obtained on the magnitude of field strengths required. Using this information, a full scale installation for submarines was designed and installed at KURE. The frequency used was 0.3 to 0.5 cycles per second (i.e., T= 2 to 3 seconds). The current was supplied by means of mercury vapor rectifiers whose grids were controlled by low frequency relaxation oscillators. It was recognized that lower frequencies would be more effective from the point of view of obtaining magnetic penetration but, if the frequency was too low, the number of effective cycles during the passage of the ship through the loop would be too small.

O. Difficulty was experienced in making the current from the power source the same magnitude on both halves of the cycle. As a result, large permanent longitudinal magnetization occurred, the use of alternating current in the loop was abandoned, and intermittent direct current was used in its place. The ship was passed through the loop a number of times. The magnetic field through the ship was decreased on successive passages, and each time the direction was changed.

P. The coil through which the ship passed had a diameter of about 10 meters. Only one submarine was treated with the circular loop. To allow larger ships to be treated, the loop was replaced by a saddle-shaped coil whose dimensions and capacity were based on model experiments. The installation, as it was used in practice, together with the procedure and method of measuring the ships' fields, are discussed in more detail in Part VI.

Part IV
COILING OF SHIPS

A. Almost all naval ships except coast defense ships were equipped with degaussing coils. Approximately 500 ships were so equipped. No merchant ships were degaussed in any manner. Coil design was based on the results of experiments on models and on actual ships of various classes. A formula for ampere-turn capacities in terms of the mean height was then developed and used. (See Paragraph K, Part III.)

B. The only type of coils which were used, except for a few experimental installations, were single loop M-coils mounted on the outside of the vessel at the level of the main deck. Inside coils were not used; horizontal magnetization was not compensated; heading adjustment was not used. The coils were proprotected by steel plates at critical points.

C. Six standard sizes of cable were used. These are shown in the accompanying table. These cables, known as "Cabtyer" cables, were submarine type and were covered with a heavy thickness of rubber. Cable loading of about two amperes per square millimeter was used. Specifications are in the table on the following page.

D. A wiring diagram for a representative degaussing installation is given in Enclosure (A). In this installation, there are nine identical circuits which car be switched on independently. A tenth circuit, which is used for fine adjustment, has resistors which can be shorted out by means of switches. Only one of the cables is shown in the diagram. All circuits are of the same number of turns so that the ammeter reading is proportional to the number of ampere-turns in the coil. The control is mounted in a box about 1 meter by 1.25 meters. The resistors are mounted in a separate box. The number of circuits was not the same on all installations as shown here, nor were the number of steps in the fine adjustment the same as shown, but the same principle of control was used on all installations. The electrical equipment was of high quality.

Cable	Number of Conductors	Number of Strands per Conductor	Diameter of Individual Strands (mm)
No. 1	7	7	1.6
No. 2	7	7	0.8
No. 3	12	1	1.2
No. 4	12	7	0.8
No. 5	12	30	0.8
No. 6	12	12	0.8

E. Enclosure (B) gives the voltages, size of cables, and number of cables used on typical installations on various size vessels.

F. The insulation resistance of the cables to ground was measured each month by the ship's crew, using a 500-volt megger. The circuit was repaired when the insulation resistance became less than 0.01 megohms. Ampere-turn meters were not used to check for possible shorts between conductors.

G. Submarines were coiled in the same way as surface craft. The cables ran above the wing buoyancy tanks passing through the superdeck at the bow and stern. The cables were protected by iron plating at critical points. Current control was by means of a rheostat of approximately 40 steps. The cables used were of the same type as for surface craft. The cables were said to stand up under use for about a year.

Part V
CALIBRATION OF DEGAUSSING INSTALLATIONS

A. Ships were calibrated only once. (An exception to this occurred in the case of ships re-treated at a magnetic station. See paragraphs J to L, incl., Part VI.) The calibration was usually done at the arsenal where the installation was made. In the case of new-construction ships the calibration was not done until after the shake-down cruise. There were no channel ranges or other type of checking. After the first calibration, there was no further check on the settings used. It was recognized that there was some change in the permanent vertical magnetization of ships but this was not considered important in view of the over-all degaussing policy.

B. The calibration was done by swinging an instrument under the ship. The instrument was hung from the center of a bamboo pole which was supported from ropes passing over each side of the hull. Ten to twenty men were used to move the magnetometer along under the ship. Usually two men were used for reading and recording the fields.

C. Usually about ten measurements were taken along the ship. The depth of measurement below the keel was normally taken as $\frac{1}{2}H$, where H is the height of the ship from the keel to the top deck. The current was adjusted to make positive and negative peaks on east-west heading equal in magnitude. The Japanese did not use fixed magnetometers.

D. Two types of magnetometers were used. Both utilized the reluctance change of permalloy with change of field intensity. The first type was the YZ instrument which was developed at the Experiment Department for Mines at YOKOSUKA. The theory, construction, and operation of this instrument are discussed in Enclosure (G) and (J). The accuracy of this instrument was about ±5 milligauss. About fifteen of these instruments were produced.

E. The second type magnetometer was the Mitsubishi type. Details of this instrument are contained in Enclosure (H). The accuracy of this instrument was about ±1 milligauss.

F. The overall accuracy of the measurements was limited by the condition of measurement rather than by the instruments. The accuracy of measurement was considered to be about ±20 milligauss under normal circumstances. Samples of both instruments were sent to the United States for examination.

G. An instrument was developed by the Experimental Department for Mines at YOKOSUKA for continuously recording the field under a ship. This instrument, which works on the same general principle as the other two instruments, is described in Enclosure (I). The instrument was designed for use on submarines in detecting other ships. It was considered for degaussing but was never developed to that point. A sample of this instrument was forwarded to the United States for examination.

H. No instruments of the fluxmeter type were used by the Japanese.

I. After calibration the ship was given a chart on which were written the various values of current to be used at various locations corresponding to different values of the earth's vertical field. The variation of current with vertical field was based on the following formula (See also Paragraph K, Part III):

$$AT = A + k H \frac{Z}{500}$$

where A is a constant determined from measurement of the field of the individual ship at the time of calibration.
where k is a constant taken as 70 for surface ships and 100 for submarines.
where H is the height of the ship from the keel to the upper deck, expressed in meters.
where Z is the value of the earth's vertical field in milligauss.

The boundary values of Z-zones corresponding to convenient values of current (e.g., 5, 10, 15, 20, 25, etc., amperes for destroyers) were determined from this formula and these boundaries were marked on the chart for each ship and the appropriate current values were entered on the chart. Enclosure (C) is a copy of such a chart drawn from memory by Mr. KAWAI. This chart is about one-fourth the size of the original chart. A similar chart was issued for southern latitudes.

Part VI
MAGNETIC TREATMENT

A. Magnetic treatment was done only at the Kure Arsenal. The station was originally designed for treatment of submarines but later was also used for treating a few destroyers. The research leading up to the particular design and procedure used is discussed in paragraphs N to P incl., Part III.

B. Enclosure (D) shows the general layout of the station. The ship was treated by passing it through a moored floating saddle coil and a measurement of its magnetic condition was taken after each run through the coil by means of two loops, lying on the bottom, connected to a galvanometer. The station was equipped with a Z-loop under the saddle coil, but this was never used because the power supply was never completed. The depth of water was 25 meters, and the tide was about 2.5 meters. The values of H and Z at KURE were 310 and 360 milligauss, respectively.

C. The leads from the two measuring loops and the saddle coil led into the treatment station building which was located on an island. The house was approximately 25 feet by 70 feet. Most of the building held the power supply and control for the saddle coil. The electrical equipment was of good quality.

D. The method of connecting the measuring loops is shown in Enclosure (E). The two loops are so connected as to compensate for local fluctuations in the earth's field. Measurement was done only at the outside ends of the loops away from the saddle coil. Ignoring end effects and assuming constant velocity of the ship, the reading of the galvanometer, which measures the rate of change of flux within the loop, is proportional to the average value of B taken along the end of the loop where the ship is passing. In the case of the type of loop used in American degaussing, the fluxmeter responds to the difference, ΔB, between the average values of B along two parallel lines separated by the width of the loop. But since the fluxmeter integrates the quantity to which it responds, it also measures B, since B is the integral of ΔB. Consequently the interpretation of loop signatures from a Japanese type loop using a galvanometer is identical with the interpretation of loop signatures from an American loop in which the sides of the loop are very close together. Bow or stern marks were not employed on the signatures.

E. The ship passed through the saddle coil at a speed of 6 to 8 knots in a magnetically east-west direction. The height of the saddle coil was 13 meters, 5 meters being above the water. Its length and breadth were 10 and 21 meters, respectively. The M-coil was not turned on during runs through the coil. It was not necessary to compensate for the athwartship field because of the small athwartship dimension of the vessels being treated and because the direction of the athwartship field with respect to the ship reversed on alternate runs.

F. The saddle coil was made up of 15 turns and was excited with pulsating direct current with a maximum value of 2000 amperes, resulting in 15,000 ampere-turns. This produced a horizontal field in air of approximately 15 gauss, the field being in opposite directions at each end of the coil. (See Enclosure (F).) The current built up exponentially and, upon being cut off, dropped off exponentially. The time between cycles was from 2 to 3.5 seconds, and the build-up period of the current occurred over a period of time somewhat less than one-fourth the period of one cycle. Direct current would have been used if the design of the equipment had not precluded its use. The manner of scheduling the current on the various runs is described in the following paragraphs.

G. Before any treatment, the ship passed over the east end of the eastern loop as shown in Enclosure (D), and its signature was taken. It was determined from the signature whether the ship had a north pole or a south pole in the bow, and the current in the saddle coil was set at its maximum value in such a direction that the ship's longitudinal magnetization would be reversed in the first complete passage through the coil. This is illustrated in Enclosure (F) in which the ship is passing from east to west and is assumed to have south pole in the bow before treatment. While the field at A tends to accentuate the south pole in the bow, the field at B, which acts last, produces a north pole in the bow, as shown, after the ship has gone through the coil.

H. On the next run, the current in the saddle coil is reversed and reduced in magnitude. The magnitude is based on experience and depends on the original permanent longitudinal magnetization. The current is usually 60 to 70 percent of the maximum value of 2000 amperes and is chosen so that it will reverse the direction of the longitudinal magnetization and will reduce it somewhat in magnitude, since it is desired to reduce the longitudinal field uniformly to zero in about six to eight runs through the loop. If a mistake was made early in the schedule, the entire schedule was repeated. If a mistake was made after a number of runs only a portion of the originally planned schedule was repeated. Sometimes as many as twenty total runs were made.

I. The permanent longitudinal magnetization was said to be reduced to 0.1 of the value of the induced longitudinal magnetization produced by a horizontal field of H = 310 milligauss. The treatment and measurement process required about one-half day of the ship's time.

J. An interesting consequence of this treatment was that the permanent vertical magnetization of ships which originally had a south pole in the bow was decreased, whereas the reverse was true for ships having a north pole in the bow. The reason for this can be seen from Enclosure (F) where it can be noted that on the first run through the coil, during which run the treatment field is the largest, the vessel is subjected to a strong vertical field (C) directed upward. Since the currents are biased in order to remove the permanent longitudinal magnetization, the treatment results in a decrease in permanent vertical magnetization.

K. The schedule for ships with a north pole in the bow results in a downward bias of the vertical field. The M-coil requirements for ships with a south pole in the bow were said to be reduced as much as 50 percent of the value before treatment in extreme cases. For ships with north pole in the bow the M-coil requirements were on occasions increased by as much as 30 percent. This was not considered serious by the Japanese because most of the submarine operations were in southern magnetic latitudes. In case of operation in the Aleutians the submarines frequently were undercompensated.

L. Following the treatment a report was made showing the field of the ship (1) before treatment with M-coil off, (2) after treatment with M-coil off, and (3) after treatment with the M-coil on at its proper value. Also included were data such as the ship's speed and draft during the runs. The ship was furnished a copy of such information together with a new M-coil chart.

M. All Japanese submarines (about 100) were treated except certain ones used for training (20 or 30). Of 100 to 120 destroyers only about 10 were treated. One coast defense ship was treated experimentally. Of the 80 or 90 ships treated about 20 were re-measured. The time between treatment and re-measurement ranged from 2 to 12 months. Of these there were only two or three submarines which showed appreciable decay of either longitudinal or vertical magnetization. These submarines had been severely depth-charged.

Part VII
DEGAUSSING OF MINESWEEPERS

Steel-hulled minesweepers were equipped with an ordinary single-loop M-coil, and they were not treated magnetically. Wooden-hulled minesweepers were not degaussed.

Part VIII
COMPENSATION OF MAGNETIC COMPASSES

A. Ships having gyro compasses (which included most naval ships) were not fitted with compass compensation on the magnetic compass so that the problem was not as important as in the case of American degaussing, which included merchant ships. The compensation was accomplished by the use of three mutually perpendicular coils mounted on the binnacle, using current shunted from the M-coil, as is done in American practice. Little hysteresis effect was observed, and no attempt was made to eliminate the effect by special securing of the coils.

B. Magnetic treatment greatly changed the compass, but the ship was thought to be magnetically more stable after the treatment than before. There was little evidence to support this, however.

Part IX
EFFECTIVENESS OF JAPANESE DEGAUSSING

A. The following factors contributed to poor quality in Japanese degaussing:

1. Merchant ships were not degaussed at all.

2. Permanent longitudinal magnetization was not removed except in the case of submarines and a few destroyers.

3. Induced longitudinal magnetization was not compensated in any ships.

4. M-coil misfit was probably very high considering the small amount of research done on degaussing and the fact that only simple M-coils were used.

5. M-coil setting was undoubtedly extremely poor because:

a. Very rough setting formula was used.

b. There was no check on change in permanent vertical magnetization after the first calibration.

c. There was no range check on proper use of degaussing equipment. (This was probably minimized by the simplicity of the installation and the discipline of the Japanese.)

d. Shorts between coils changing the effective number of turns were were not checked unless a short to the hull occurred at the same time.

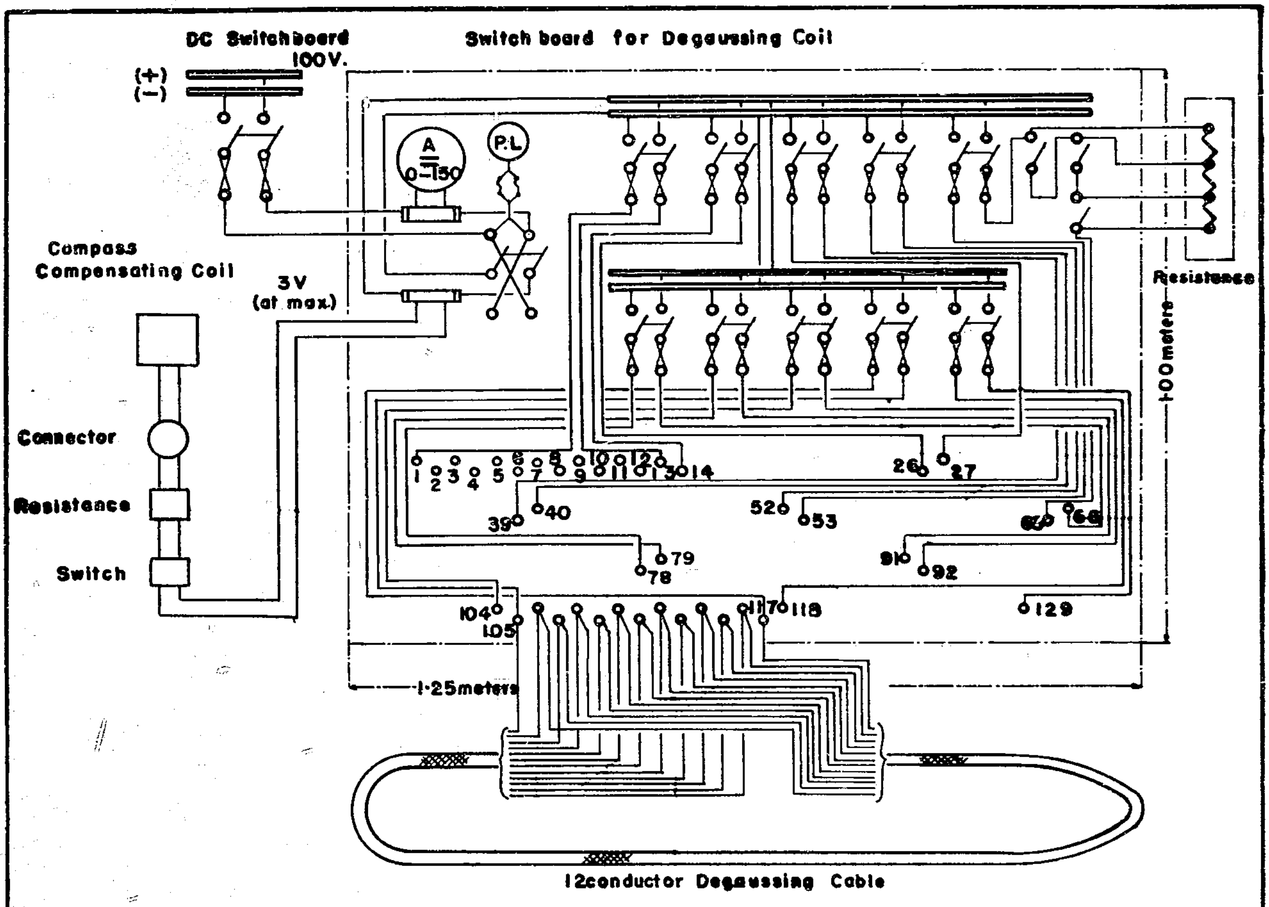
Lack of Japanese range data prevents an estimate of the overall effectiveness of Japanese degaussing. An upper limit of this effectiveness against specific mines can be made by ignoring (5) (c) and (5) (d) above, since the other factors can be estimated fairly accurately from a study of American range records. Target widths and area obtained from such data may be of value.

B. The Japanese recognized the inadequacy of their degaussing. The following are interpretations of comments made in this connection:

"We recognized the use of degaussing to be effective against magnetic mines responding to changes in vertical field, but it was believed to be almost impossible to degauss ships effectively against mines responding to changes in horizontal fields or rate of field change."

"Partial coils were recognized to be necessary, but they were not adopted due to difficulty in their design and use, and also because there was not time to design them. As a consequence, the effectiveness of an M-coil was doubtful, particularly in the case of ships with large permanent longitudinal magnetization."

ENCLOSURE (A)



Wiring Diagram of Typical Degaussing Installation.

Figure 1(A)

ENCLOSURE (B)

VOLTAGES, SIZES OF CABLES, AND NUMBER OF CABLES USED ON TYPICAL DEGAUSSING INSTALLATIONS ON VARIOUS SIZED VESSELS

	Battleship		Aircraft Carrier	Cruiser		Destroyer	
	YAMATO	NAGATO	SHOKAKU	CHIKUMA	KITAGAMI	KAGERO	HATSUHARU
Standard Displacement	69,900	32,700	20,000	8,500	5,100	2,000	1,400
Source Voltage	220	220	220	220	100	100	100
Kind of Cable*	7c $\frac{7}{1.6}$	7c $\frac{7}{1.6}$	7c $\frac{7}{1.6}$	7c $\frac{7}{1.6}$	12c $\frac{7}{1.2}$	12c $\frac{7}{1.2}$	12c $\frac{7}{1.2}$
Number of Cables	14	12	12	9	10	6	4

	Destroyer	Mine-Sweeper	Gun Boat		Submarine	
	HASU	No. 38	ATAKA	TOBA	Ro-104	I-364
Standard Displacement	770	630	725	210	500	1470
Source Voltage	100	100	100	100	Variable (about 240-250)	Variable (about 240-250)
Kind of Cable*	12c $\frac{7}{1.0}$	12c $\frac{7}{1.2}$	12c $\frac{7}{1.2}$	12c $\frac{7}{1.2}$	12c $\frac{30}{0.8}$	12c $\frac{30}{0.8}$
Number of Cables	4	3	3	1	2	4

*In this designation the first number is the number of conductors in the cable; the numerator is the number of strands in each conductor; and the denominator is the diameter of each strand in millimeters.

ENCLOSURE (C)

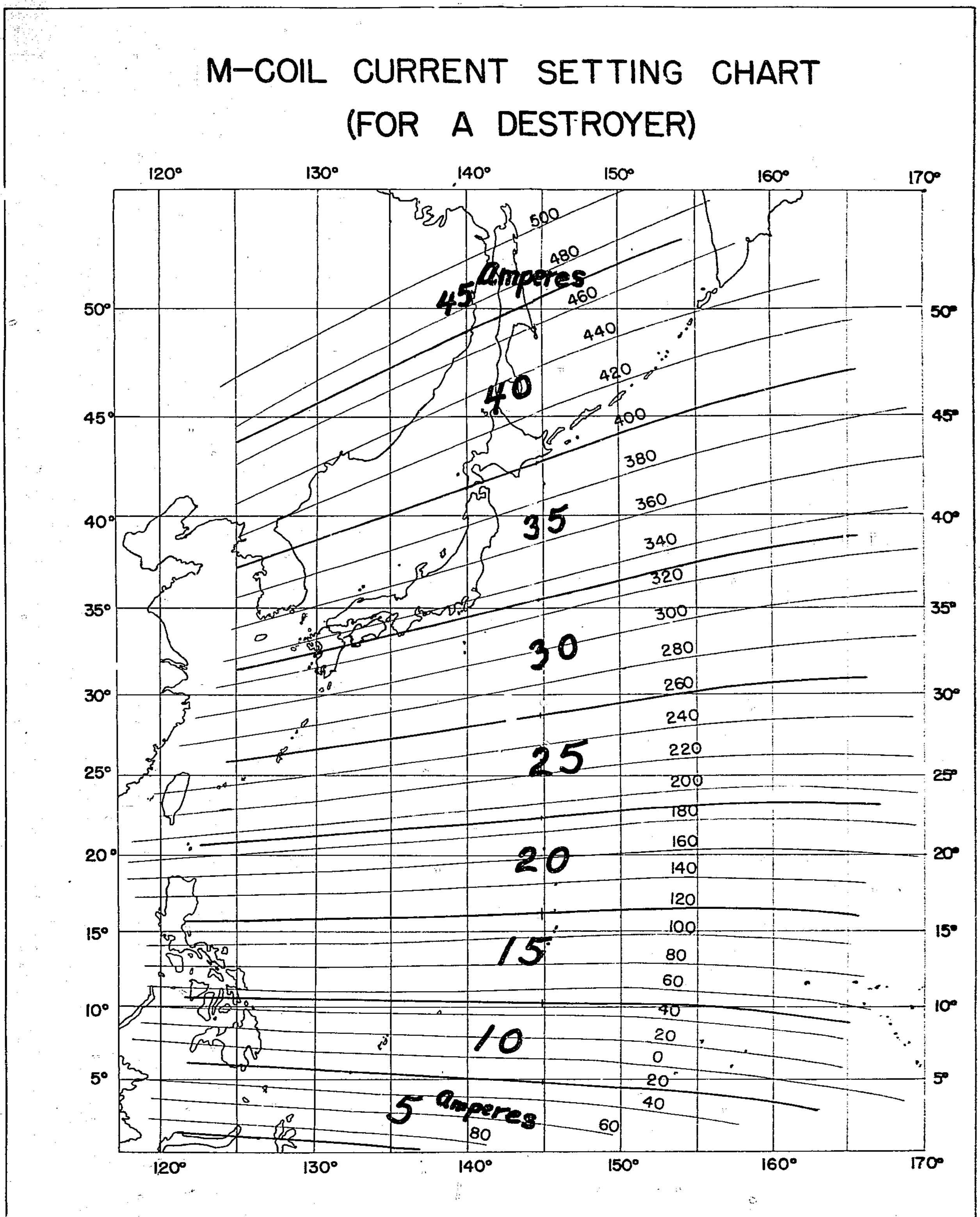
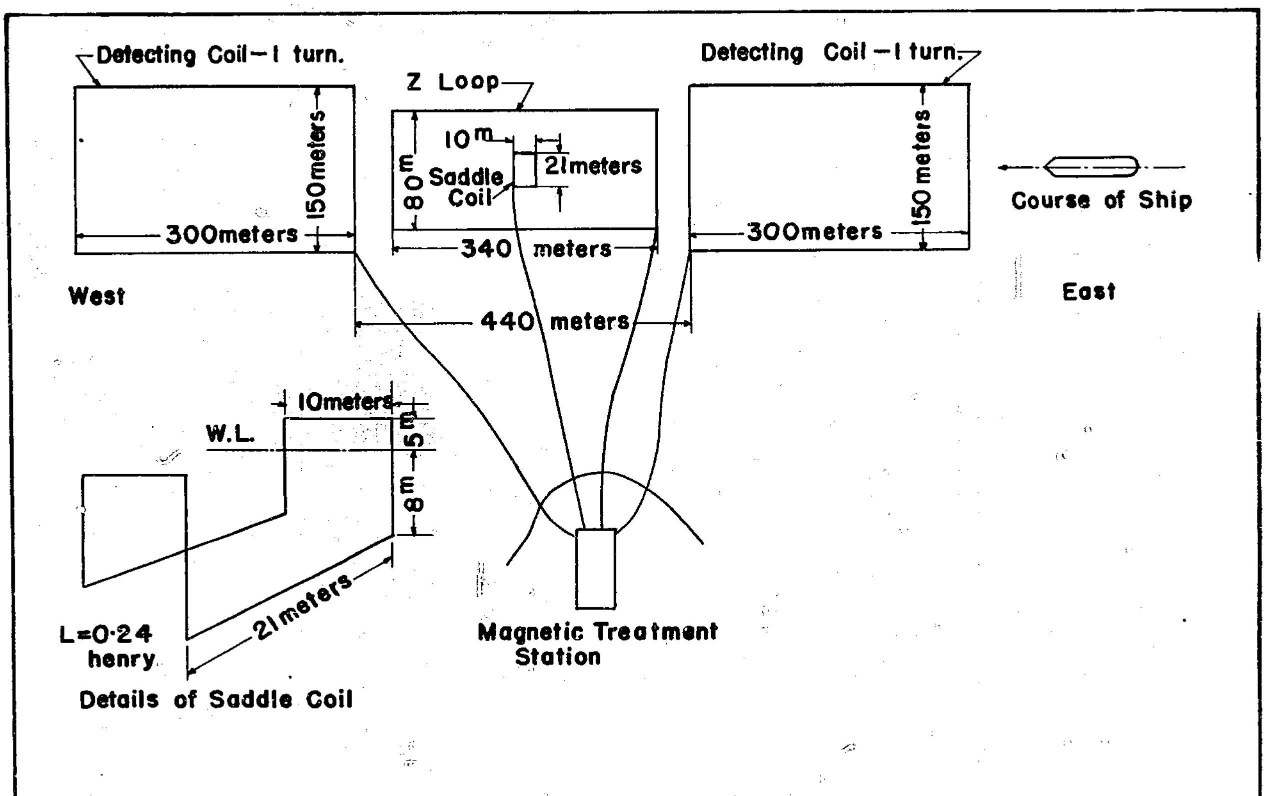


Figure 1(C)

ENCLOSURE (D)



Layout of Coils at Treatment Station.

Figure 1(D)

ENCLOSURE (E)

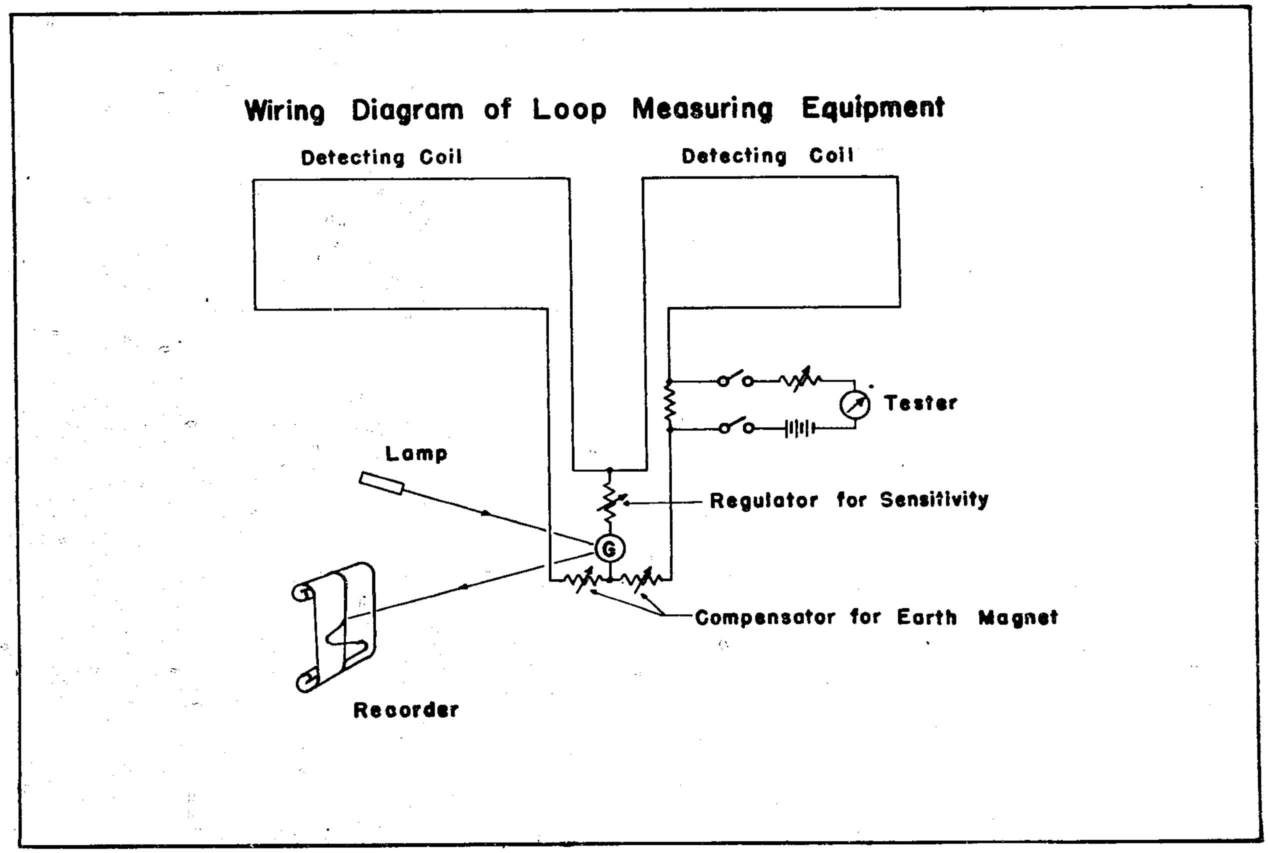


Figure 1(E)

ENCLOSURE (F)

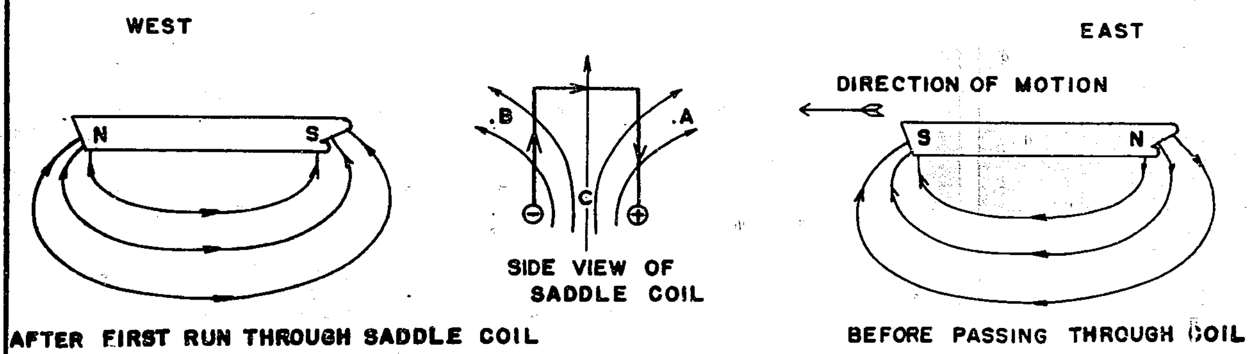


DIAGRAM SHOWING EFFECT ON A SHIP OF PASSING THROUGH SADDLE COIL AT TREATMENT STATION.

Figure 1 (F)

ENCLOSURE (G)

OPERATING INSTRUCTIONS FOR THE YZ TYPE MAGNETOMETER
(Translation)

A. Abstract

1. This is an instrument for measuring the intensity of magnetic fields weaker than about 0.75 gauss. (See C below.) The sensitivity is 5 milligauss.

2. The instrument consists of a detecting coil placed in a water-tight brass case, a cable of six conductors covered by thick rubber, a measuring set, and its electric source (i.e., one 200-volt battery and two 6-volt batteries).

3. The measuring set must be placed horizontal during the measuring. Normally a magnetometer is adjusted for one cable. If the cable is changed, certain adjustments must be made (see C below).

B. Method of Measuring

1. Locate the detecting coil at the point and in the direction to be measured, and connect the end of the cable to the plug on the measuring set. (All the dials of the adjustors and relators except the sensitivity adjustor must be adjusted previously to zero.)

2. Connect the electric source, and after about one minute, turn the dial of the output regulator to the right. This will cause the indicator of the micro-ammeter to move to the right (it should read between 50 and 100).

3. After closing the switch of the tertiary coil (determining its polarity by supposition), turn the dial of the rough adjustor to the right, then the deflection of the needle of the micro-ammeter will at first increase (or decrease) and afterward decrease (or increase) pointing out an extreme value. Regulate by the output regulator so that the maximum (or minimum) deflection of the micro-ammeter will be 120 to 150 (20 to 50).

NOTE

a. Whether the expressions are used inside or outside the parentheses depends on the internal resistors of the apparatus with respect to the cable and detector resistances.

b. If the micro-ammeter does not point out the extreme, reverse the polarity of the tertiary coil current; if it still does not point out the extreme, then the field intensity will be over 0.75 gauss or the instrument will be wrong somewhere.

4. By the fine adjustor make the extreme indication of the micro-ammeter as exact as possible. Let the value of the tertiary coil current be I milliamperes at that time; then the field intensity is kI milligauss, where k is the constant of the detecting coil.

5. If the polarity of the tertiary coil current is positive, the magnetic field is in the direction toward the cable from the end of the coil.

ENCLOSURE (G), continued

C. <u>Supplements</u>

1. Magnetic fields stronger than 0.75 gauss can be measured by changing the ammeter of the tertiary coil current to one of larger capacity. Under such conditions the sensitivity will be diminished.

2. If it is desired to use another cable, after working (2) in (B), let the indication of the micro-ammeter be minimum by turning the dial of the sensitivity adjustor and continue working (3) mentioned in (B) etc. If this cannot be done with the sensitivity adjustor, some of the fixed resistances in the measuring set must be changed.

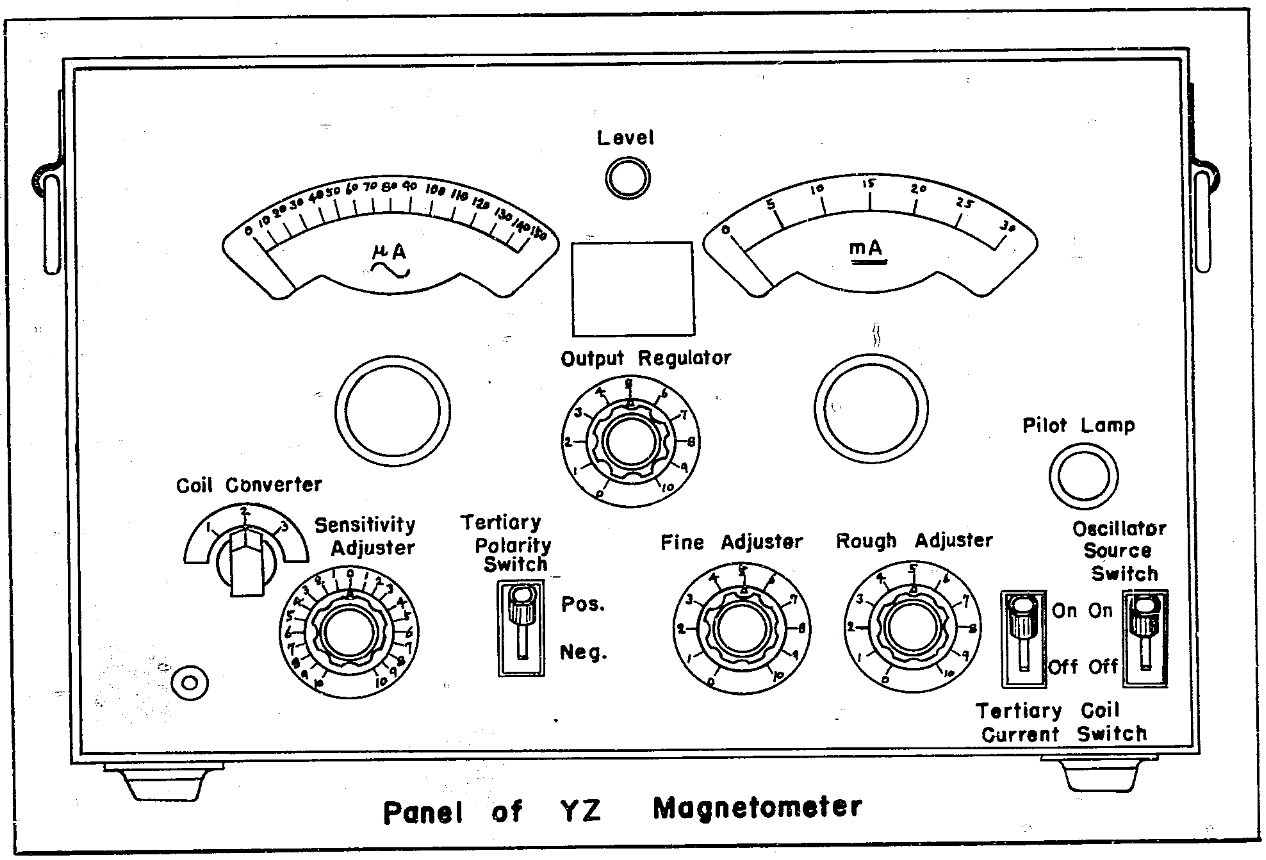


Figure 1(G)

ENCLOSURE (H)

DESCRIPTION, WIRING DIAGRAM, AND OPERATING INSTRUCTIONS FOR THE MITSUBISHI TYPE MAGNETOMETER (Translation)

A. General Description

This instrument is designed to measure electro-magnetically the strength of the outside magnetic field by the balance of the outside magnetic field and the standard calibrated magnetic field applied in opposite directions through a magnetic path made of special high permeability steel. The balance between the above magnetic fields is detected by the current through a set of coils wound around the above mentioned magnetic path making use of the sensitive magnetic saturation caused by a weak magnetic field.

B. Principle of the Measurement

The magnetic detector (C), the main part of this instrument, is constituted of a flux collecting plate A, core B, and three sets of windings (primary, secondary and tertiary) wound around the core B as shown in Figure 1. Core B has two legs, B1 & B2, to make a closed magnetic path with respect to the primary coil which excites this path nearly to the saturation point by the alternating current. The secondary coil detects the resultant change of magnetic flux in B1 & B2. The tertiary coil, excited by direct current, supplies the necessary magneto-motive force to cancel the outside magnetic field.

If there exists no outside field, that is, there is no continuous magnetic flux through the magnetic path A-B-A, the change of resultant magnetic flux in B1 and B2, which induced an alternating voltage in the secondary coil, is shown by curve 2 - 1 in Figure 2 (H). The secondary voltages induced in B1 and B2 cancel each other, resulting in no secondary output in the ideal condition.

If there exists an outside continuous field, magnetic saturation is caused in each half cycle in the paths B1 & B2 alternatively as shown in curve 2 - 2 in Figure 2 (H). The resultant induced voltage C2 in the secondary winding takes the form of curve 2 - 3 in Figure 2 (H) which is extremely unsymmetrical with respect to zero line.

Voltage C2 is amplified by the amplifier (shown in Figure 1 (H)) and rectified, positive and negative components separately, by the detector-rectifier, and then the difference of these two rectified components is indicated by a galvanometer which has its zero point at the center of its scale. The indication of this meter thus clearly shows the magnetic unbalance of the core as well as the direction of the outside continuous magnetic field.

As can be seen from the above explanation, if the magnetic path A-B-A is placed in an unknown outside field to be measured and the field in this path is cancelled by the continuous standard e.m.f. caused by the direct current flowing through the tertiary coil, and the balance of these two opposing e.m.f. is checked by means of the current induced in the secondary winding, the strength of the unknown outside field can be measured by the tertiary coil current which is calibrated to the standard magnetic field beforehand.

C. Constitution of the Apparatus. (Refer to the circuit diagram and the layout.)

1. Magnetic detector (C): Flux collector plates, magnetic core, primary, secondary, and tertiary coils and connecting cables.

2. Amplifier: Made up of oscillator, amplifier, detector-rectifier and

ENCLOSURE (H), continued

balancing meter (galvanometer) with four vacuum tubes, (Ut-6F7x2, UZ-6D6x2) one receiver and one supply source cable, three change-over switches for electric source, polarity selection and selective sensitivity. Three sets of resistance regulators for compensating magnetic field, fine control, and correction, are provided.

3. Magnetic field strength meter: As the tertiary coil current is designed to be about 0.05 gauss/mA, three ammeters of 20 mA, 10 mA, and 1 mA scale, each calibrated to the corresponding standard magnetic field, are recommended.

4. Electric supply source: D.C. 6 V, 1.3 A and D.C. 200 V, 30 mA.

D. Instructions for Using

1. Plug in connecting plugs and connect the supply source leads to the electric sources (6V and 200 V).

2. Connect the magnetic field strength meter (D.C. ammeter) to its place. (A meter having suitable scale according to the strength of field should be selected.) Connect the ear-phones and turn on the sensitivity change-over switch to the coarse position. The current value for the field strength meter is as follows:

Up to 1 gauss .... 20 mA
Up to 0.5 gauss .... 10 mA
Up to 0.05 gauss .... 1 mA

3. Correction: This correction is necessary to let the zero point of the induced e.m.f. of the secondary coil in the magnetic detector coincide with the zero point of the output voltage, which is obtained by amplification and rectification of the above secondary induced voltage by correcting the unbalance and error of the circuit by means of correcting potentiometer.

When correction for zero point is made, it is best to keep the compensating field current through the tertiary coil at zero and adjust the direction of the magnetic detector (C) relative to that of the terrestrial magnetic field so as to obtain the balanced position. When the above method is impractical, negative field exciting current can be applied to obtain the zero point. The correction is made as follows:

Bring the e.m.f. induced in the secondary coil to zero or to a minimum by the method described above. This point is found by the earphones connected to the terminal of the output transformer. When the above e.m.f. is a minimum or it is in the balanced position, a weak, low frequency (about 100 c.p.s.) continuous sound can be heard. But if it is in the unbalanced position, a stronger, higher pitched continuous sound rich in higher harmonics is audible. (about 200 c.p.s.) The larger the unbalance, the stronger will be the sound. After the balanced position for the field is obtained, bring the balancing meter indication to zero by means of the adjustment of the corrector potentiometer. Approaching to the balanced and corrected position, the sensitivity switch is turned over to the sensitive position to make the meter indication more accurate.

4. Measurement:

a. Turn on the coarse switch and let the direction of the arrow

ENCLOSURE (H), continued

marked on the magnetic detector (C) point to that of the outside field to be measured. Connect electric source.

b. Increase the compensating field current gradually by the compensating field coarse control to let the balancing or meter indication approach the zero point. If the indication increases, the polarity switch should be changed over.

c. When the indicator approaches zero, the sensitivity switch is turned over to sensitive position, and repeat the compensation.

d. Read the magnetic field strength meter indication and obtain the magnetic field strength by means of the calibration curve.

e. The direction of outside magnetic field is the same as that of the arrow on the magnetic-detector (C) if the polarity switch position is positive and opposite to the arrow if the polarity is negative.

E. Cautions

1. As the outside magnetic field path is somewhat changed by the magnetic detector core, it is recommended that this apparatus be used very carefully if the magnetic field gradient is large.

2. It sometimes happens that the unexpected leakage current, flowing into the tertiary coil from other circuits, causes a large error. In this case, reverse the direction of magnetic detector, changing over the polarity switch at the same time, and measure again. The mean value of both readings gives the correct value.

3. The balance of the amplifier circuit is slightly changed due to the fluctuation of the supply source voltage. But the error is not appreciable unless the fluctuation is very large. It is important to allow more than one minute after turning on the circuit before any measurements are taken.

ENCLOSURE (H), continued

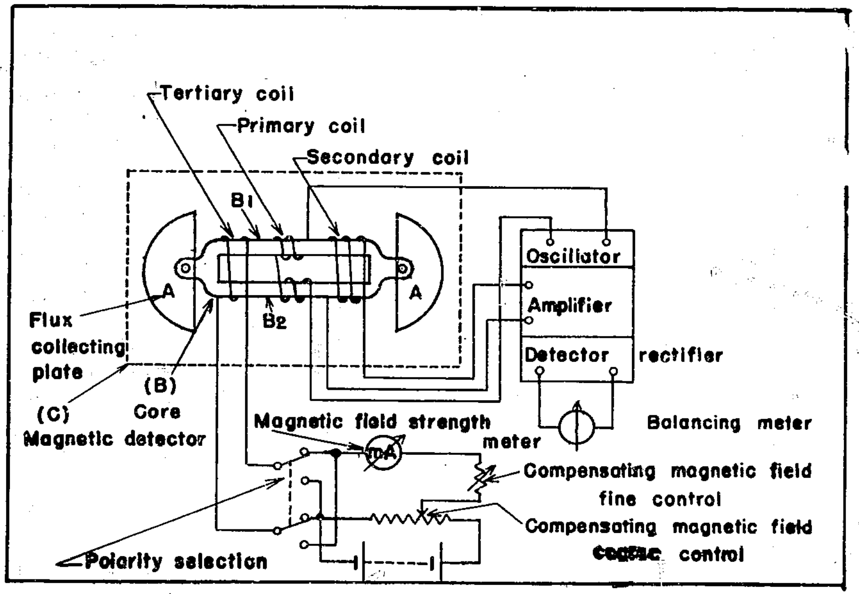


Figure 1(H)

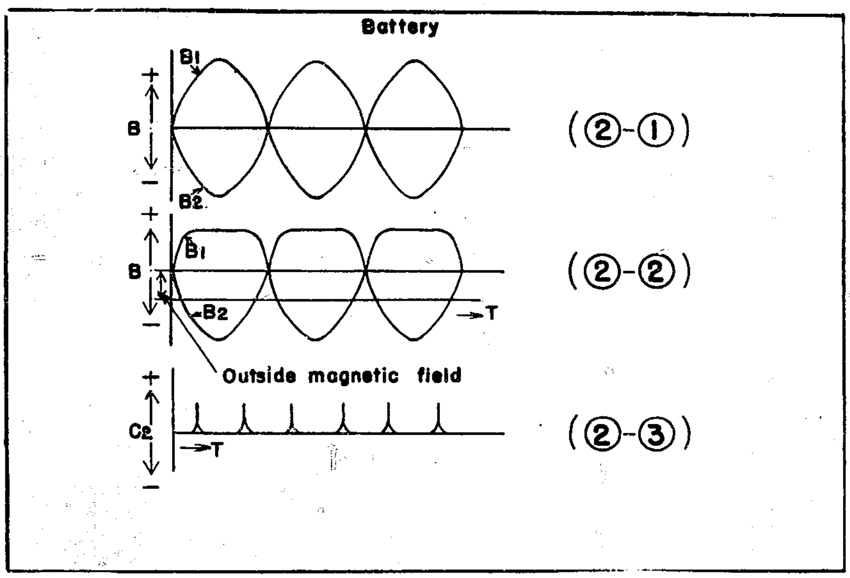


Figure 2(H)

ENCLOSURE (H), continued

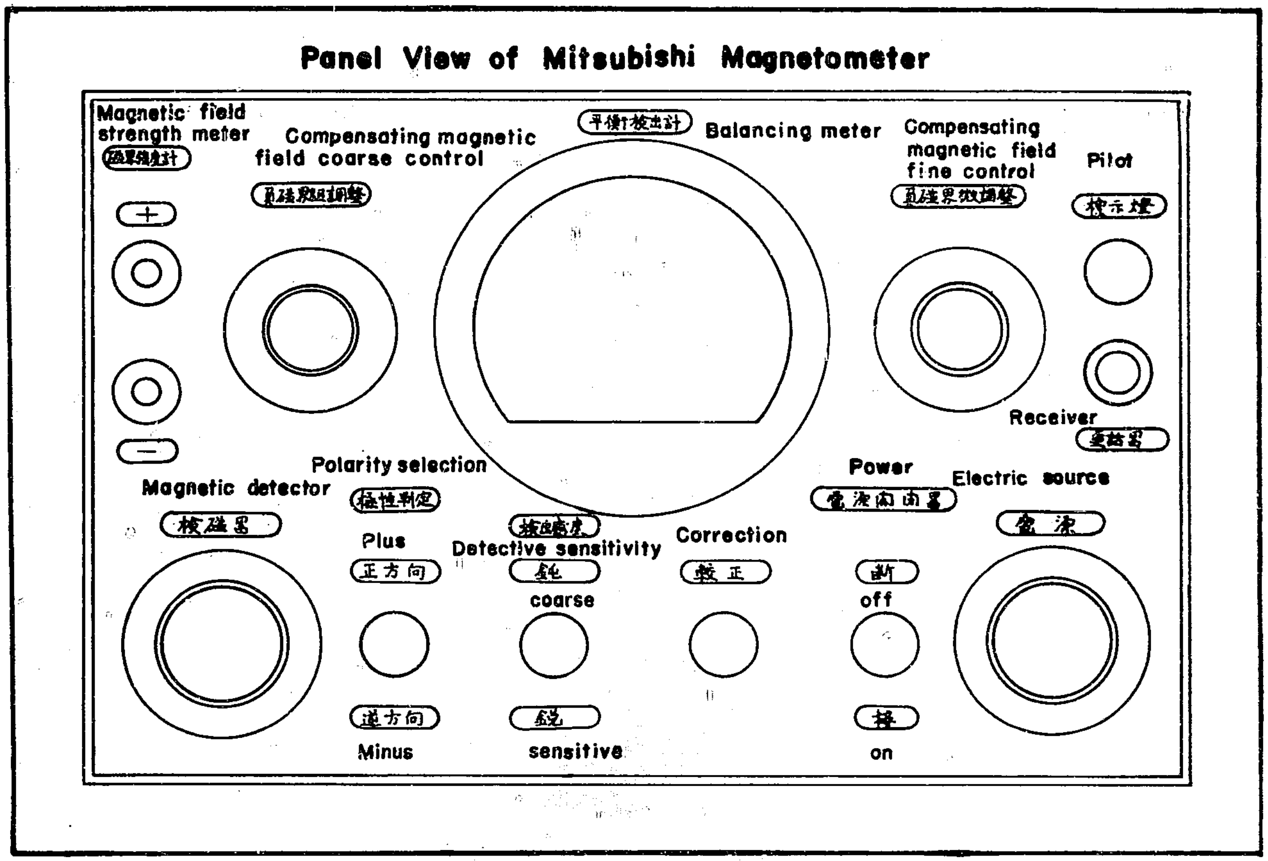
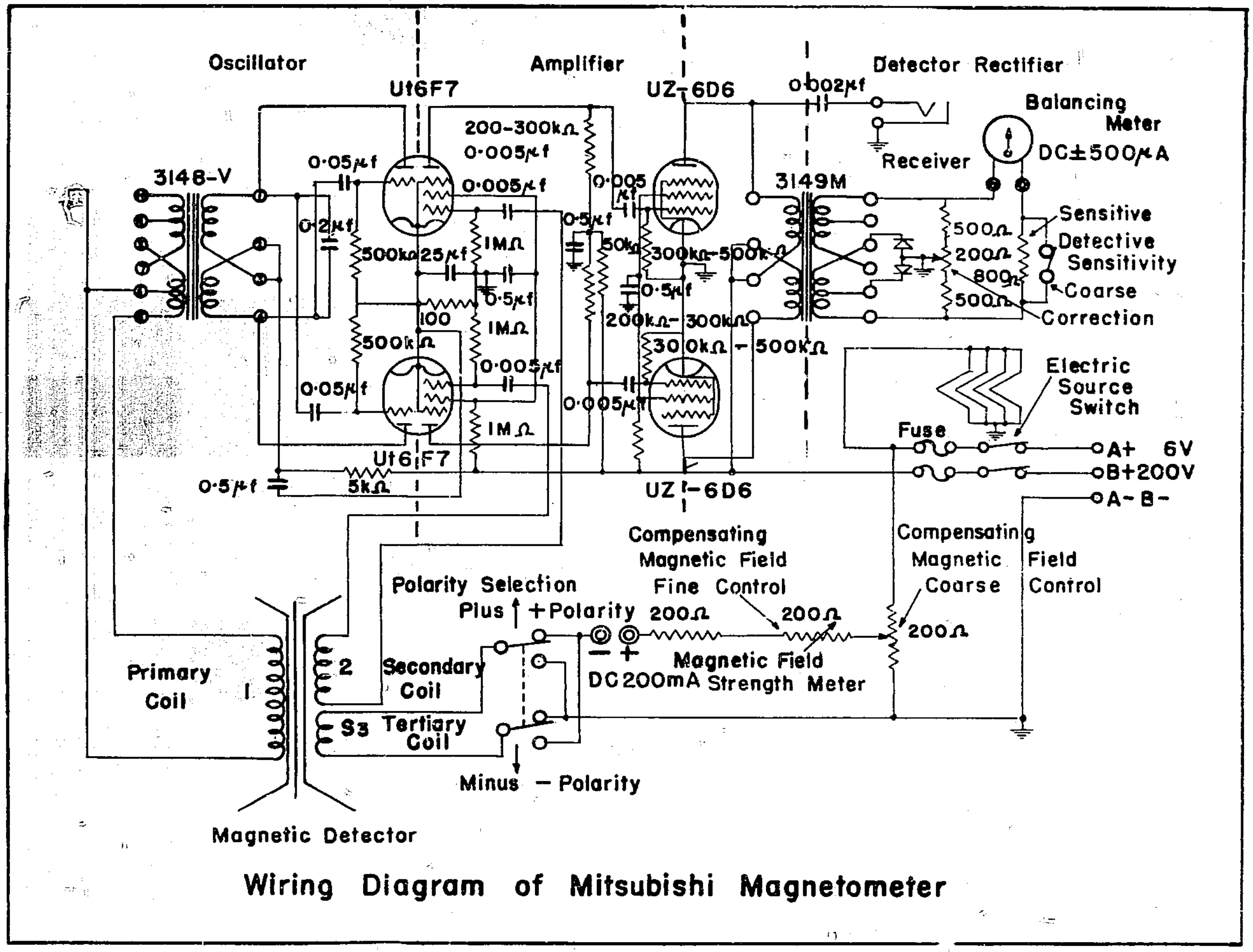


Figure 3(H)

ENCLOSURE (H), continued



Wiring Diagram of Mitsubishi Magnetometer

Figure 4(H)

ENCLOSURE (I)

DESCRIPTION, WIRING DIAGRAM, AND OPERATING INSTRUCTIONS FOR THE EXPERIMENTAL RECORDING MAGNETOMETER

A. Introduction

1. This instrument is designed to record automatically the variation of intensity of weak magnetic fields, its basic principle being the same as that of the YZ magnetometer. This instrument has, in addition, an amplifier, rectifier, and recording current meter, which, besides making recording possible, also increases the sensitivity of the instrument. The instrument is not linear with magnetic field intensity but must be calibrated by the use of the tertiary coil.

2. The measuring range can be readily changed from 20 milligauss to 200 milligauss for full scale of the recording current meter.

3. As a rule, the detecting coil and 6-conductor cable which is attached are not interchangeable with other detecting coils and cables. In order to interchange them, it may be necessary to change the values of the fixed resistances, etc., in the measuring set.

4. The construction of the instrument can be seen from the simplified diagram, the complete wiring diagram, and the specification.

B. Method of Measuring

1. Arrangement of Measuring

a. Set up the detecting coil in its proper position and orientation and then connect the cable to the measuring set.

b. Connect the power supply cord to the measuring set and then connect the batteries, first making sure that the three electric source switches are off.

c. Next, connect the recording current meter to the output terminal.

2. Adjusting

a. First, make sure that the output regulator is turned to zero, that the output switch is turned to the internal current meter side (upper), and that the sensitivity switch is turned to the low side (left).

b. Turn on the filament source switch, and then turn on the plate source switch.

c. Turn the output regulator to the right, and make the deflection of the output current meter about 9 milliamperes or its maximum value.

d. Make the indication of the output current meter minimum by turning the amplitude balancing adjustor to right or left. Then make the remaining deflection of the output current meter minimum by turning the phase balancing adjustor (rough and fine adjustor) to the right or left.

e. Increase and continue to increase the output by turning the output regulator to the right, repeating the operation (which was explained in (d)) each time the output regulator is adjusted. Put the sensitivity on "high", and repeat the above described operation until a minimum indication is obtained with the maximum output.

f. Confirm that the tertiary coil current adjustor is set at zero, put the tertiary coil current switch on, and then put the tertiary coil polarity switch to positive or negative.

g. The current of the tertiary coil is 7.5 milliamperes for measuring range of 200 milligauss. (0.75 milliamperes for 20 milligauss.) Adjust the output regulator to keep the output current at 5 milliamperes for 7.5 milliamperes tertiary coil current.

3. Measuring

a. Switch the output switch to the recording current meter side.

b. Record calibration lines with several values of tertiary coil current (for example, 1.5, 3.0, 4.5, 6.0, 7.5 milliamperes) which correspond to the required magnetic field intensity (for example, 40, 80, 120, 160, 200 milligauss) by turning the tertiary coil adjustor. The instrument is then ready for use.

c. It is desirable to record the calibration lines again after the measurements are finished.

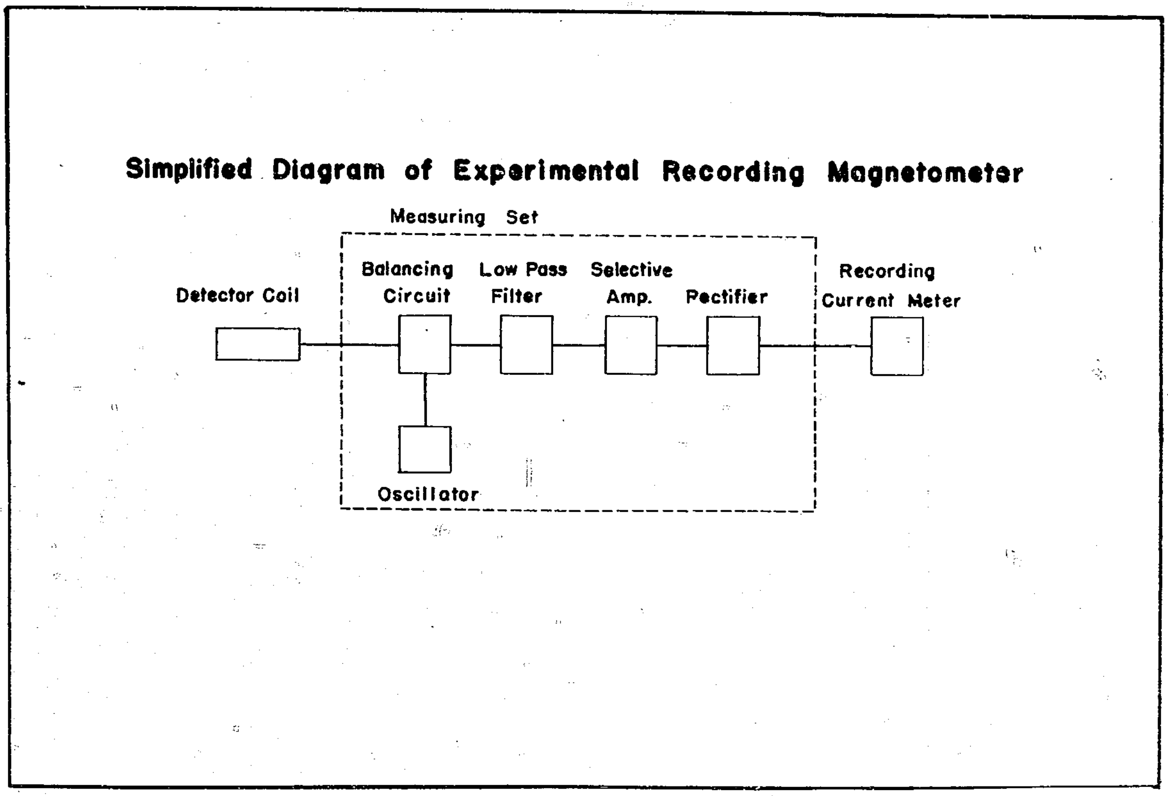


Figure 1(I)

ENCLOSURE (I), continued

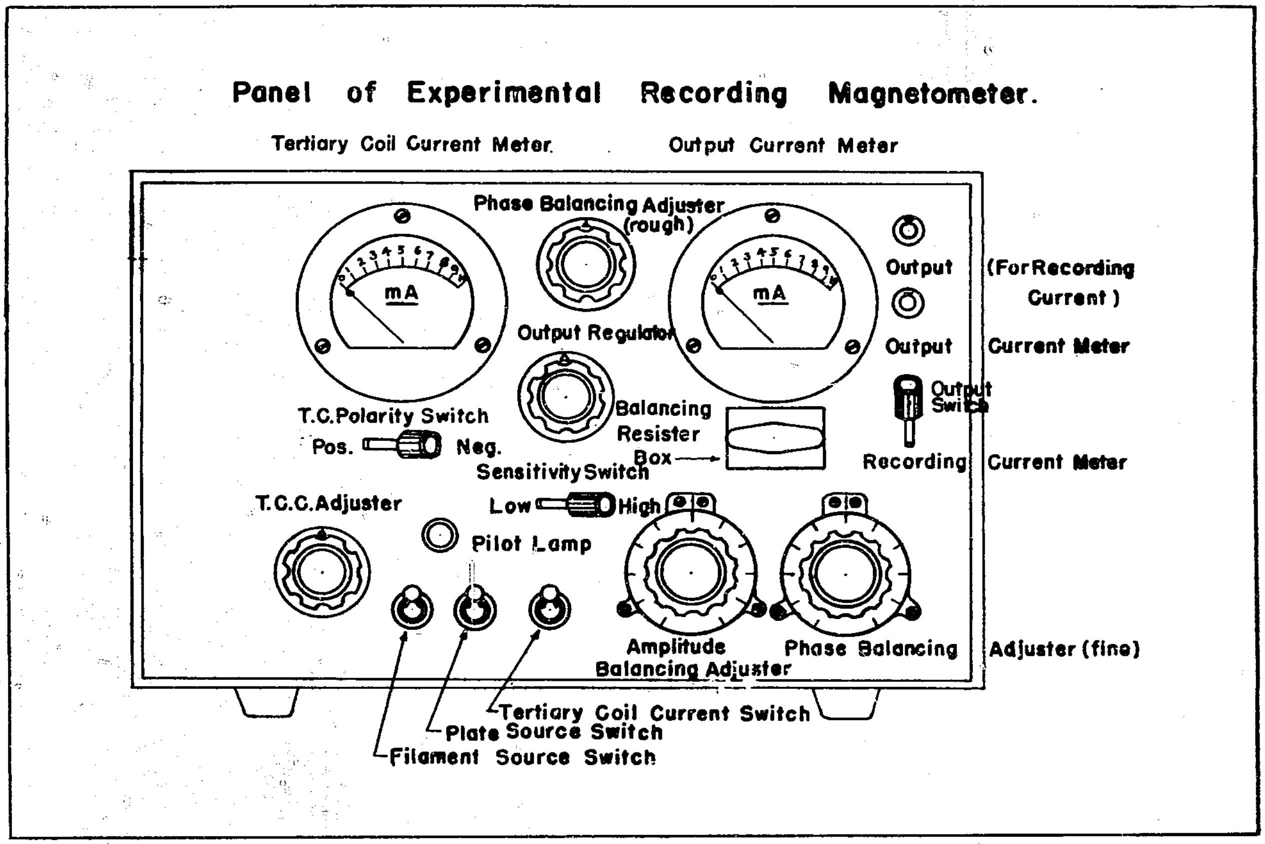


Figure 2(I)

ENCLOSURE (I), continued

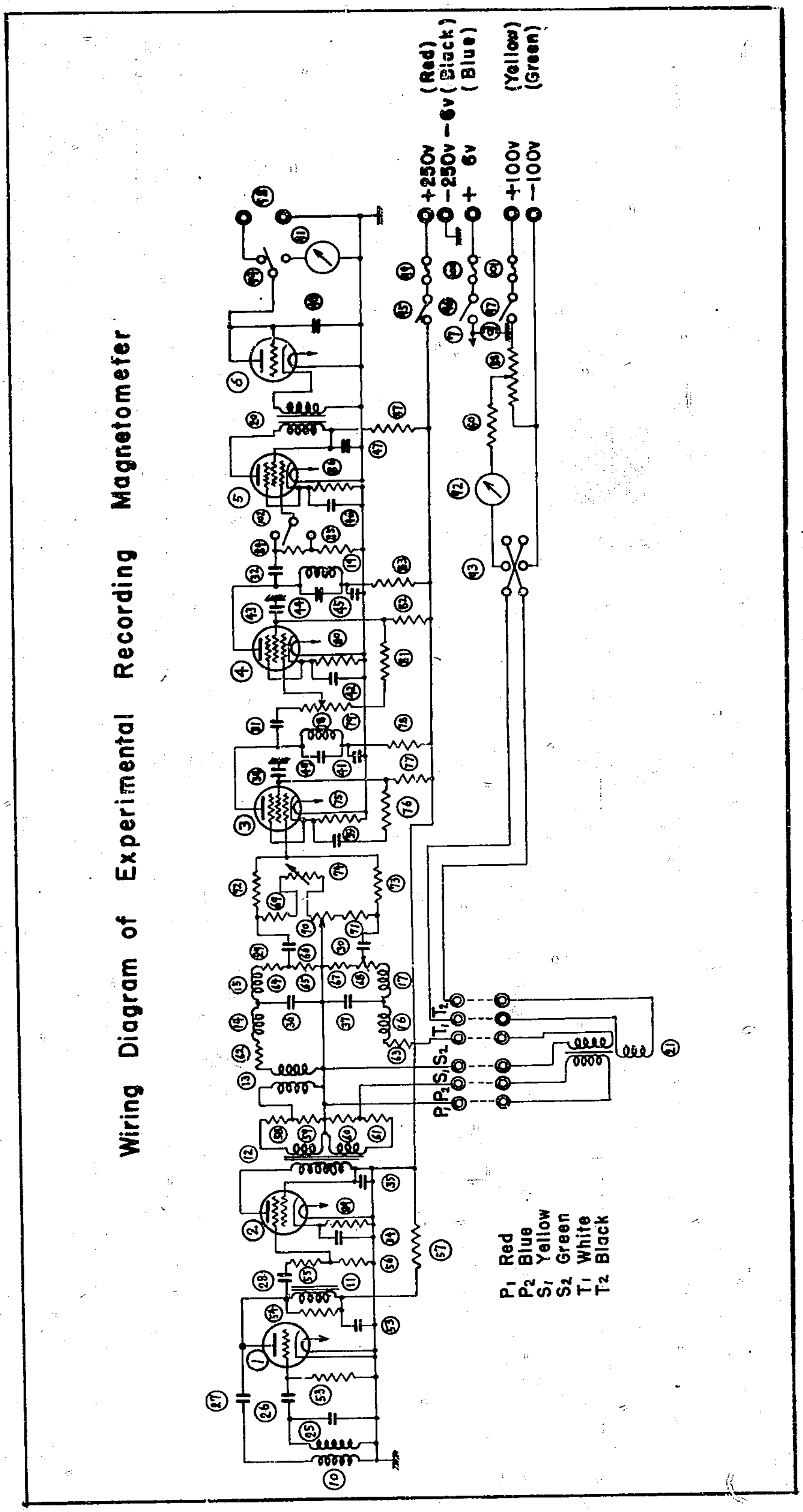
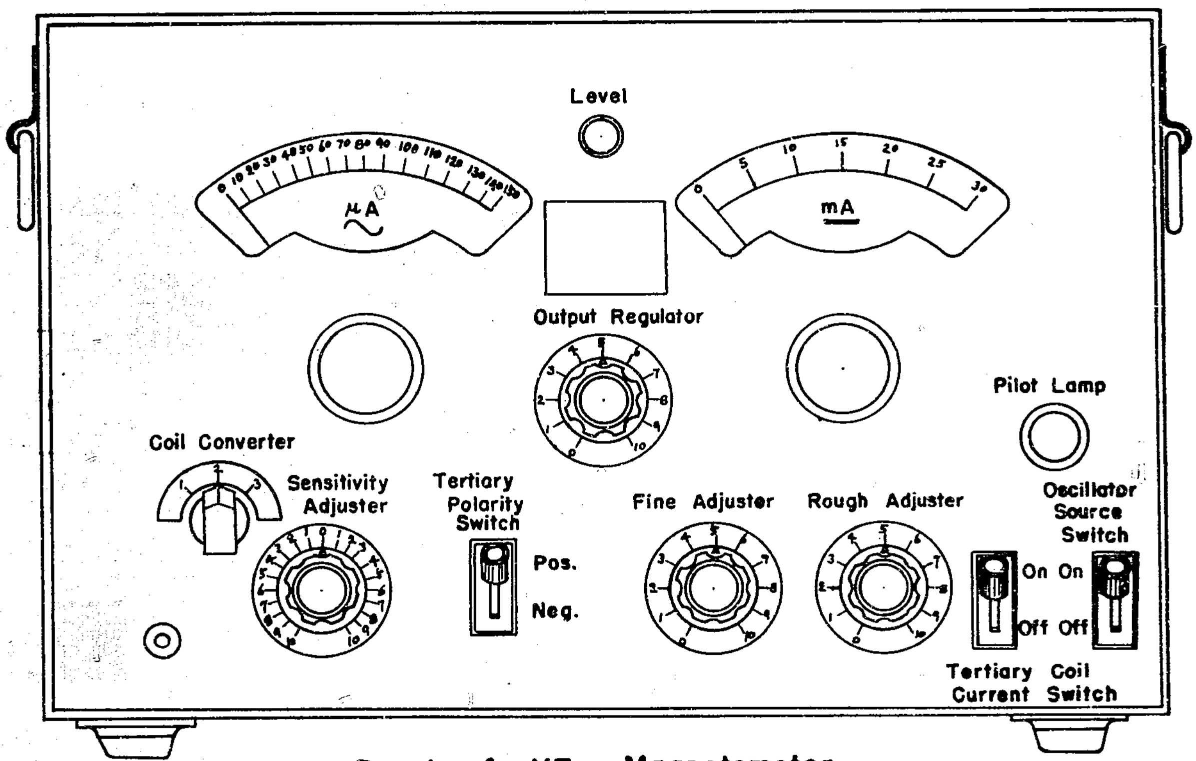


Figure 3(I)

ENCLOSURE (I), continued



Panel of YZ Magnetometer

Figure 4(I)

ENCLOSURE (I), continued

KEY TO ITEMS SHOWN IN FIGURE 3 (I)

No.	Specification		No.	Specification	
1	Oscillator Tube	UY 76	52		
2	Power Amplifier Tube	UZ 42	53	Grid Resistance	50kΩ
3	Voltage Amplifier Tube	UZ 606	54	Plate Load Resistance	100kΩ
4	Voltage Amplifier Tube	UZ 606	55	Screen Grid Voltage Divider Resistance	150kΩ
5	Power Amplifier Tube	UZ 41	56	Screen Grid Voltage Divider Resistance	50kΩ
6	Diode Rectifier Tube	UY 76	57	Power Supply Series Resistance	100kΩ
7	Pilot Lamp		58	Input Voltage Divider Resistance	180Ω
8			59	Input Voltage Divider Resistance	20Ω
9			60	T.C.C. Series Resistance	
10	Oscillator Transformer	NP = 1000T NS = 1000T	61		
11	Low Frequency	30 H 20mA	62	Low Pass Filter Series Resistance	10kΩ
12	Output Transformer	NP = 5000T NS = 175T	63	Low Pass Filter Series Resistance	10kΩ
13	Air Core Transformer		64	Amplitude Adjusting Resistance	5kΩ
14	Low Pass Filter Coil	7000T	65	Amplitude Adjusting Resistance	5kΩ
15	Low Pass Filter Coil	7000T	66	Amplitude Adjusting Resistance	3kΩ
16	Low Pass Filter Coil	7000T	67		5kΩ
17	Low Pass Filter Coil	7000T	68		10kΩ
18	Tuning Coil	350mH	69	Phase Adjusting Resistance	100kΩ
19	Tuning Coil	350mH	70	Phase Adjusting Resistance (Fine)	20kΩ
20	Output Transformer	1 : 5	71	Phase Adjusting Resistance (Fine)	20kΩ
21	Magnetic Research Coil		72	Bridge Arm Resistance	100kΩ
22			73	Bridge Arm Resistance	100kΩ
23			74	Phase Adjuster Resistance (Rough)	500kΩ
24			75	Grid Bias Resistance	1kΩ
25	Oscillator Condenser	0.11μF	76	Screen Grid Voltage Dividing Resistance	250kΩ
26	Coupling Condenser	0.1μF	77	Screen Grid Voltage Dividing Resistance	150kΩ
27	Coupling Condenser	0.1μF	78	Plate Series Resistance	10kΩ
28	Coupling Condenser		79	Sensitivity Adjusting Resistance	150kΩ
29	Coupling Condenser	0.1μF	80	Grid Bias Resistance	1kΩ
30	Coupling Condenser		81	Screen Grid Voltage Dividing Resistance	250kΩ
31	Coupling Condenser	0.1μF	82	Screen Grid Voltage Dividing Resistance	150kΩ
32	Coupling Condenser	0.1μF	83	Plate Series Resistance	10kΩ
33	Plate Bypass Condenser	4μF	84	Screen Grid Voltage Dividing Resistance	200kΩ
34	Cathode Bypass Condenser	2μF	85	Screen Grid Voltage Dividing Resistance	20kΩ
35	Plate Bypass Condenser	6μF	86	Grid Bias Resistance	500Ω
36	Low Pass Filter Condenser	0.005μF	87	Plate Series Resistance	10kΩ
37	Low Pass Filter Condenser	0.005μF	88	Tertiary Coil Current Adjusting Resistance	10kΩ
38	Cathode Bypass Condenser	2μF	89	Grid Bias Resistance	
39	Screen Grid Bypass Condenser	2μF	90		
40	Tuning Condenser	0.005μF	91	Output Current Meter	10mA DF 65
41	Plate Bypass Condenser	4μF	92	Tertiary Coil Current Meter	10mA DF 65
42	Cathode Bypass Condenser	2μF	93	Tertiary Coil Polarity Switch	
43	Screen Grid Bypass Condenser	2μF	94	Output Meter Exchange Switch	
44	Tuning Condenser	0.005μF	95	Plate Source Switch	
45	Plate Bypass Condenser	4μF	96	Filament Source Switch	
46	Cathode Bypass Condenser	2μF	97	Tertiary Coil Current Switch	
47	Plate Bypass Condenser	2μF	98	Output Terminal	
48	Plate Bypass Condenser	2μF	99	Fuse	100mA
49			100	Fuse	32A
50			101	Fuse	100mA
51			102	Sensitivity Switch	

ENCLOSURE (J)

RESEARCH ON DISTURBANCES OF TERRESTRIAL MAGNETIC FIELDS CAUSED BY MAGNETIC BODIES

September 1943

NAVAL TECHNICAL ARSENAL
PHYSICAL RESEATCH SECTION

Author: Keizo SHIBATA - Naval Technician
Translated By Lt.(jg) P. F. Myers, USNR

ENCLOSURE (J), continued

PRINCIPAL SYMBOLS USED

a	Half the length of the circular cylinder
b	Radius of the circular cylinder
B	Magnetic induction
e	Electro-motive force
H	Strength of magnetic field
H_o	Strength of terrestrial magnetic field
I	Represents maximum value of oscillating current, but in paragraph 3 it represents an integral expression
J	Represents amount of secondary current, but in paragraph 3 it represents an integral expression
k	A constant
M	Magnetization strength
N	Demagnetization factor
r	Distance between two points
s	Surface area
V	Magnetic potential
α	Dip of terrestrial magnetism
δ	Angle between terrestrial magnetic meridian and the axis (x) of the circular cylinder
μ	Magnetic permeability
κ	Magnetic susceptibility
ξ, ν, ζ	Co-ordinates of any point on the surface of the circular cylinder
mΓ	Strength of "milligauss" in magnetic field

Note: Bold letters indicate respective "vectors"
(TN: Bold face letters herein indicated by arrow placed above letter. Thus $\vec{H}$.)

ENCLOSURE (J), continued

GENERAL REMARKS

In this treatise, there is first an explanation of special equipment which is capable of easily measuring under water the strength of weak magnetic fields of 10^{-2} Gauss* or below.

Next, there is a theoretical computation of the magnetic field disturbance caused by a finite circular cylinder of uniform magnetic susceptibility in the terrestrial magnetic field.

Further, it has been possible to confirm the fact that the results of computation and the results of measurement of underwater disturbances of the magnetic field, using the above mentioned equipment for measuring weak magnetic fields where several types of vessels were at anchor, agree qualitatively.

Finally, the results of research and experiments in connection with methods of reducing magnetism by means of a solenoid wound around ship's hulls have been appended, and from these results every inference possible has been drawn relative to the distribution of underwater magnetic fields adjacent to vessels and the method of reducing their magnetism.

---

*"Oersted" is the actual unit of strength of magnetic fields, but "Gauss" is generally used as a unit of terrestrial magnetism, and so, in this treatise, "Gauss" is used as the unit of measurement of a disturbed magnetic field.

ENCLOSURE (J), continued

I INTRODUCTION

Because ships are generally constructed of steel, they are magnetized by the terrestrial magnetic field, and it is recognized in advance that a secondary magnetic field will be set up in the neighborhood of the ship, but as yet the research relative to details surrounding the distribution of the disturbed magnetic field has not been published.

In all the research of this sort which has been heretofore revealed, a magnetometer which depends on the deviations of a magnetic needle was used, and inasmuch as it is used when a ship is entering a dock, its measurements are extremely rough. Moreover, because there are, in the neighborhood of the dock, many cranes, buildings and other structures made of steel, as well as electric wires, etc., which radiate fairly strong magnetic fields, the degree of reliability of the results of measurement is extremely slight. Consequently, because of the fact that the ship's hull is actually present, it has not been determined whether or not the magnetic field produced circumjacent to it is dependent upon the permanent magnetism of the hull, and nothing has been known in regard to the problem as to what changes are brought about in the magnetic field when the same ship is in an area where the nature of the terrestrial magnetic field is different or when, in the same area, the heading of the bow is changed.

In spite of the fact that these problems were in the past considered rather important, satisfactory solutions were not obtained, and it is felt that this was principally because the proper measuring equipment had not been found.

That is, in order to make a thorough study, it is first necessary to obtain equipment for measuring weak magnetic fields, such that it will be capable of measuring the nature of the distribution of the underwater magnetic field when a ship is anchored by itself, and as soon as such equipment has been obtained, these problems can be easily solved, but as yet such a magnetometer has not been made known. Because these problems are probably considered important in foreign countries too, it may be that some intensive research has been conducted and good measuring equipment devised, but there are many divisions concerned with military secrets and since they have not been revealed, we are not able to get any information on them.

In the Department of Geophysics and Methods of Detecting Magnetism, research is being conducted on the problem of disturbances of the terrestrial magnetic field caused by large structures with a magnetic frame, but it seems that equipment for measuring weak magnetic fields underwater has not yet been devised. All sorts of theoretical computations of the disturbance of magnetic fields have been made but these have usually been thought up in connection with material objects which stretch out ad infinitum in one direction, and it is considered a little premature to apply then directly to ships*.

Consequently, the author, who received an order to conduct thorough-going research on these problems, devised equipment** for measuring weak magnetic fields underwater and then made theoretical computations for the nature of disturbances of terrestrial magnetism caused by a finite circular cylinder with a uniform magnetic ratio. The results of these theoretical computations and the results of measurement in connection with an actual ship, using the

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*H. Haalck. "Lehrbuch der Angewandte Geophysik." Physics Tests - Volume 11. Reports of the KAKIOKA Terrestrial Magnetism Observatory - Volume 2. Special Volume No. 1, etc.
**April 1939. Announced in Naval Report.

ENCLOSURE (J), continued

measuring equipment devised for experimental manufacture were studied comparatively, and it was possible to ascertain that they both agreed qualitatively.* And so it is felt that these problems are virtually and basically solved, and it is surmised that the limits to the application of this knowledge are rather broad. Further, there is a close relationship between these problems and the method of reducing the magnetism of a ship's hull by means of a solenoid wound about the circumference of a ship (Degaussing), a method announced by England, and so, at the end of this treatise, there is an explanation of one part of the basic research** it involved.

II EQUIPMENT FOR MEASURING WEAK MAGNETIC FIELDS UNDER WATER

The equipment used in the past to measure magnetic fields consisted of one type which depended on the deviations of a magnetic needle, another which depended on an induced electric current produced by rotating a wire coil at a fixed speed, and one which made use of the changes in the electrical resistance of bismuth, but the two former ones were not suitable for measuring the underwater magnetic field in the neighborhood of a ship's hull. The latter one could easily measure the underwater magnetic field at one point, but it is used principally to measure strong magnetic fields. Bismuth of the sort which could measure such weak magnetic fields as are produced by disturbances of the terrestrial magnetic field has not been found. In short, in order to measure the nature of the distribution of the magnetism of a ship's hull, it is necessary that the measuring be carried out in connection with a ship which is in the water and with equipment which makes its measurements by means of a completely waterproof and easily handled object, but among the things which have been heretofore made known, none have been found which were suited to the purpose.

Generally speaking, the magnetic permeability of permalloy changes quickly in a weak magnetic field and, if its composition and heat treatment are proper, this characteristic is most outstanding. Therefore, it has been possible to manufacture experimentally a device suitable for the purpose of measuring weak underwater magnetic fields.

Assuming that μ represents the magnetic permeability of permalloy, μ will generally be a function of the strength of the magnetic field, $\vec{H}$, and between magnetic induction $\vec{B}$ and $\vec{H}$, there will exist the following relationship:

$$\vec{B} = \mu\vec{H}$$

Fig. 1 (J) gives the example of the so-called B - H curve. Since the hysteresis loss is very slight, the hysteresis loop can be considered to follow a single line, as is done in the diagram. If an oscillating current of $I \sin \omega t$ is sent through the primary winding of a wire coil with a core of such a suitable permalloy, $\vec{e}$, the induced electromotive force produced in the secondary winding, is given in the following formula:

$$\vec{e} = k\frac{d\vec{B}}{dt} = k\left(\mu + \frac{\partial\mu}{\partial H}\right)\frac{\partial\vec{H}}{\partial t}$$

Here $\vec{H}$ expresses the strength of the magnetic field of the inner permalloy, and in this instance the exterior magnetic field which acts upon the permalloy is a compound of $h \sin \omega t$ which depends upon the alternating current $I \sin \omega t$ and magnetic field H_0 which formerly existed at that point. Assuming

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*January 1941. Announced in Naval Report.
**August 1941. Made public in Naval Report.

ENCLOSURE (J), continued

that this is $\vec{H}_{ex}$ (that is, $\vec{H}_{ex} = \vec{h} \sin \omega t + \vec{H}_1$), $\vec{H}$, the strength of the inner magnetic field, is given by the following formula:

$$\vec{H} = \vec{H}_{ex} - N\vec{M}$$

Here N is the demagnetizing factor (Entmagnetisierungs Faktor) of the permalloy and M is the value of the magnetization within the permalloy.

So, if κ stands for magnetic susceptibility (magnetische Suszeptibilitat),

$$\vec{M} = \kappa\vec{H}$$

Therefore, the following formula relationship is established:

$$\vec{H} = \frac{1}{1+\kappa N}\vec{H}_{ex} = \vec{h}' \sin\omega t + \vec{H}_1'$$

where $\vec{h}' = \frac{\vec{h}}{1+\kappa N}$ and $\vec{H}_1' = \frac{\vec{H}_1}{1+\kappa N}$

Using the above results, it is difficult to express this in a numerical formula with μ as a function of $\vec{H}$, but in any case $\vec{e}$ becomes a function of $\vec{H}_{ex}$ ($\vec{H}$ if $I \sin \omega t$ is fixed), and J, the current created in the secondary winding, becomes a function of H_1. This is expressed by $f(H_1)$.

That is, $J = f(H_1)$

When in Fig. 1 (J) $\vec{H}_1' = 0$, the magnetic induction is alternated with $\pm B_0$ as amplitude, but when magnetic fields H_1 or H_2 already exist, the alternate magnetic field becomes $\vec{H}_1' + \vec{h}' \sin \omega t$ or $\vec{H}_2' + \vec{h}' \sin \omega t$, and when the magnetic induction vibrates so that $\pm B_1$, or $\pm B_2$ is the amplitude, e, and consequently J, in both cases change not only their amplitude, but also their wave form.

This function, $f(H_1)$, is determined by the nature of the permalloy and, if one is selected whose $f(H_1)$ value is a weak magnetic field, such as the terrestrial magnetic field, changes to a marked degree in the face of a minute change in H_1, the strength of the magnetic field H_1, at that point can be readily known from J, the amount of current in the secondary side. Use can be made of the above mentioned principles in designing a magnetometer, the basic element of which is a coil with a permalloy core which can be immersed. It is easy to make such an element water-proof with a non-magnetic material, and its handling is extremely simple.

In Fig. 2 (J) the construction of the experimental equipment for measuring weak underwater magnetic fields is illustrated diagrammatically, and in the core of the portable magnetic receiver coil (1) the above mentioned specially heat treated permalloy was used. The change in the value of $f(H_1)$ corresponding to a slight (10^{-2} Gauss) change in H_1 is small by comparison with the value of J (J_0) when $H_1 = 0$. It is difficult to find the value of H_1 directly from the value of J, and so, for this special purpose, a coreless coil, that is a compensator coil (3) which is not affected by the strength of the external magnetic field of the secondary current, is provided. The same oscillating current as in the magnetic receiver coil is sent through the primary winding, and if the induction current J_c produced in the secondary winding is in the opposite direction from J, the combined current A_1 is also a function of H_1.

ENCLOSURE (J), continued

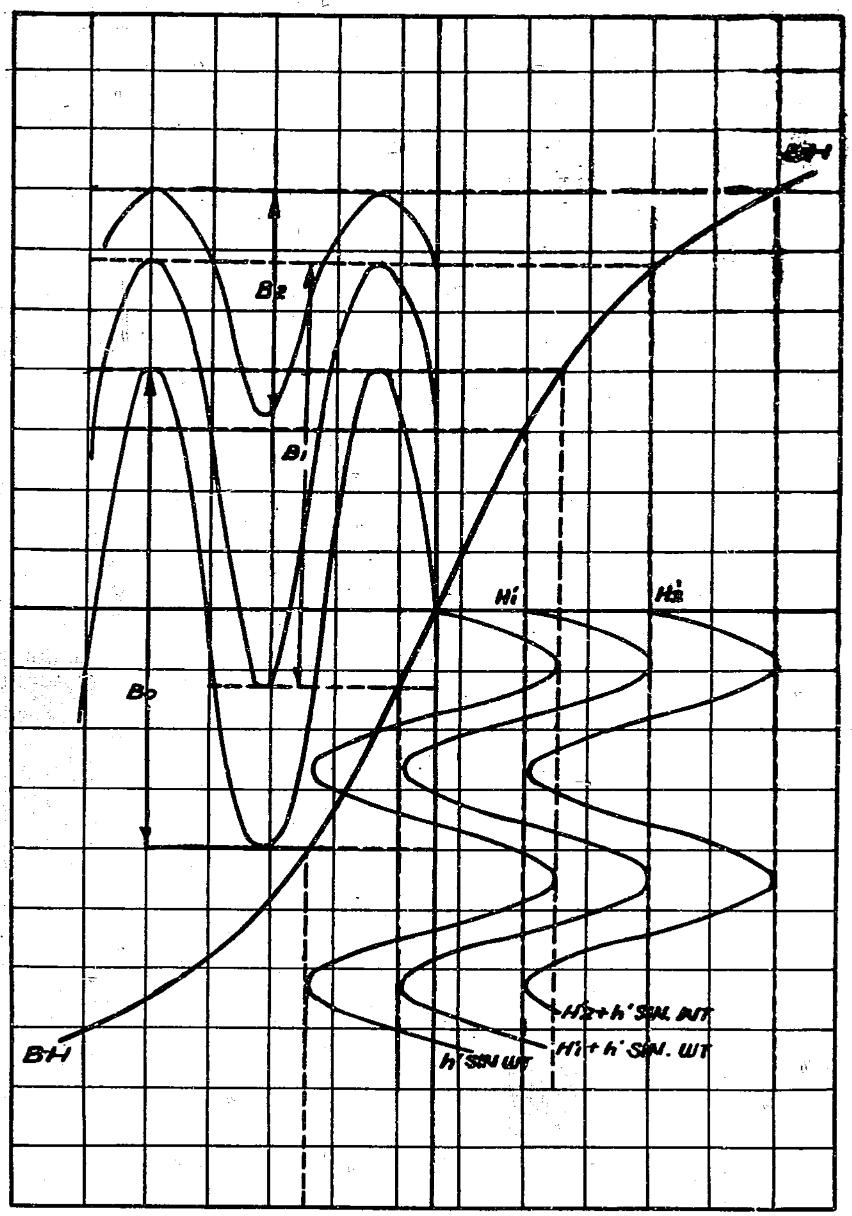

Figure 1(J)

ENCLOSURE (J), continued

$\frac{dA_1}{dH_1} / A_1(0)$, where $A_1(0) = J_o - J_c$, can be made larger than $\frac{dJ}{dH_1} / J_o$, and so it is possible to detect it with the proper ammeter.

Consequently, it should be possible to determine the value of H_1 from the value of A_1 but, because of fluctuations in the output of the oscillator and in the changes in the capacitance of the electric cable which extends out to the measuring point, it is difficult to calibrate directly the value of H_1 from the value of A_1. Therefore, in the magnetic receiver coil still a third winding is made and direct current A_2 is passed through it and, when a current of such magnitude and direction is produced so as to neutralize the magnetic field at that point, the external field which the permalloy receives becomes zero, and the current which is produced in the secondary winding becomes J_o.

However, $|J_o| > |J|$ in the case of such a curved line as $B-H$ in Fig. 1 (J) and so, if the compensating coil is adjusted so that $|J_o| > |J_c|$, it is possible for A_1 to assume a very high value within the necessary limits of H_1 (less than 1 Gauss) only when $H_1 = 0$. Therefore, if the variable resistance R_4 is adjusted so that A_1 shows up as very large, then the value obtained when the constant of the third winding (magnetomotive coil) is multiplied by the value of A_2, is H_1 which is the strength of the magnetic field at that point. And so, it is simple to look for the value of H_1 for there are no difficulties from the standpoint of measurement.

By this method, if adjustment were made so that when $H_1 = 0$, $J_o = J_c$ (that is, $A_1 = 0$), it was thought that the maximum reduction would have been reached, but J_o and J_c differ in wave form and phase, and so, quite to the contrary, in order to improve the reduction, the proper permalloy, as well as a suitable oscillating frequency and circuit constants needed to be decided upon. After various tests had been repeated, the hoped-for-objective was achieved by means of the following things:

(1) Portable magnetic receiver coil.
(Enclosed in completely waterproof brass case - See Fig. 4 (J)

(a) Core: Permalloy*
0.07cm thick
1.0cm wide
32cm long
(b) Primary winding - 5000 turns
Electric resistance - 290 ohms
(c) Secondary winding - 3000 turns
Electric resistance - 113 ohms
Insertion resistance - 610 ohms (R_3)
(d) Tertiary winding - 300 turns
Constant 17.3

(2) 6-Core waterproof cable
(About 150 meters in length)

(3) Measuring instrument

(a) A_1 - AC ammeter
150ma sensitivity
Oxidized copper rectifier attached

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ENCLOSURE (J), continued

(b) A_2 -DC ammeter
30 M.A. sensitivity
One graduation = 0.2 M.A.

(c) C - Oscillator
Vacuum tube type
Frequency 4000

(4) <u>Compensating coil.</u>
(Insert properly in the measuring instrument)

(a) Primary winding - 10,000 turns
Electric resistance - 145 ohms
Insertion resistance - 690 ohms (R_1)

(b) Secondary winding - 6000 turns
Electric resistance - 226 ohms
Insertion resistance - 822 ohms (R_2)

(Symbols are the same as those used in Fig. 2 (J))

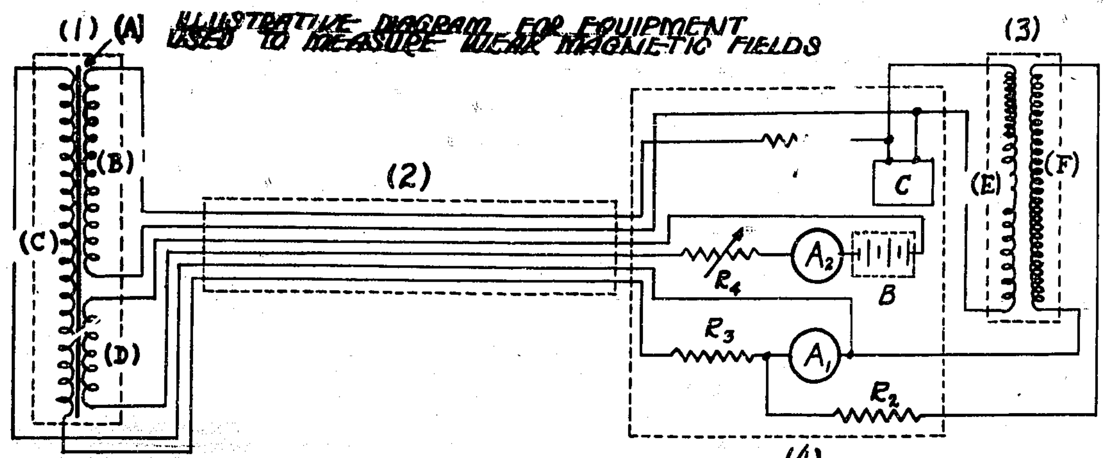
By rotating the magnetic receiver coil from an East-West direction to a North-South direction in a horizontal plane, A_1, the composite value of the secondary winding is measured and the values derived from measuring the strength of the horizontal magnetic field every 10° in that direction are shown in the following table.

Because 0.307 Gauss was obtained when the horizontal component value, H_h, of the terrestrial magnetic field at this point was measured with an ordinary magnetometer, the strength of the magnetic field when the coil was rotated θ degrees from East-West is clearly $H_h \sin\theta$, and since the error between this and the measured value, as shown in the following table is less than 6×10^{-3} Gauss, the ratio of error is less than 2.1%.

Angle (From E-W) $\theta°$	Deviation of Ammeter A_1 (Micro-amperes)	Value of Required Induced Magnetic Current A_2 (Milli-amperes)	Strength of Measured Magnetic Field (Milli-gauss)	Strength of Magnetic Field in That Direction $H_h \sin\theta$	Error (Milli-gauss)	Percentage of Error
00	140					
10	128	3.1	54	53	+1	1.9
20	104	6.2	107	105	+2	1.9
30	85	8.9	154	154	0	0.0
40	72	11.4	197	197	0	0.0
50	63	13.5	234	235	-1	0.4
60	56	15.4	267	266	+1	0.4
70	51	16.3	283	288	-5	1.7
80	49	17.1	296	302	-6	2.0
90	48	17.6	305	307	-2	0.7
				Average	2	1.0

Because the error in rotation angle of the magnetic receiving coil is included among these errors, it may be said that this equipment is accurate for measuring magnetic fields up to 10^{-2} Gauss. The results of measurement of the deflection of ammeter A_1, as current is passed through the tertiary (magnetomotive) winding and the magnetic receiver coil is placed in an east-west direction on a horizontal plane, as well as when the coil is turned in an arbitrary direction, are given in Fig. 3 (J). In reference to (b) in Fig. 3 (J),

ENCLOSURE (J), continued



1 - PORTABLE MAGNETIC RECEIVER COIL
  A-Core (Permalloy)
  B-Primary winding
  C-Secondary winding
  D-Magnetomotive winding

2 - 6 core cabtyre cable

3 - Compensating coil (no core)
  E-Primary winding
  F-Secondary winding

4 - Measuring Equipment
  A1-Alternating current ammeter
  A2-Direct current ammeter
  B-Battery used to induce magnetic current
  C-Oscillator
  R_1,R_2,R_3- Fixed Resistances
  R_4-Variable resistance

Figure 2(J)

ENCLOSURE (J), continued

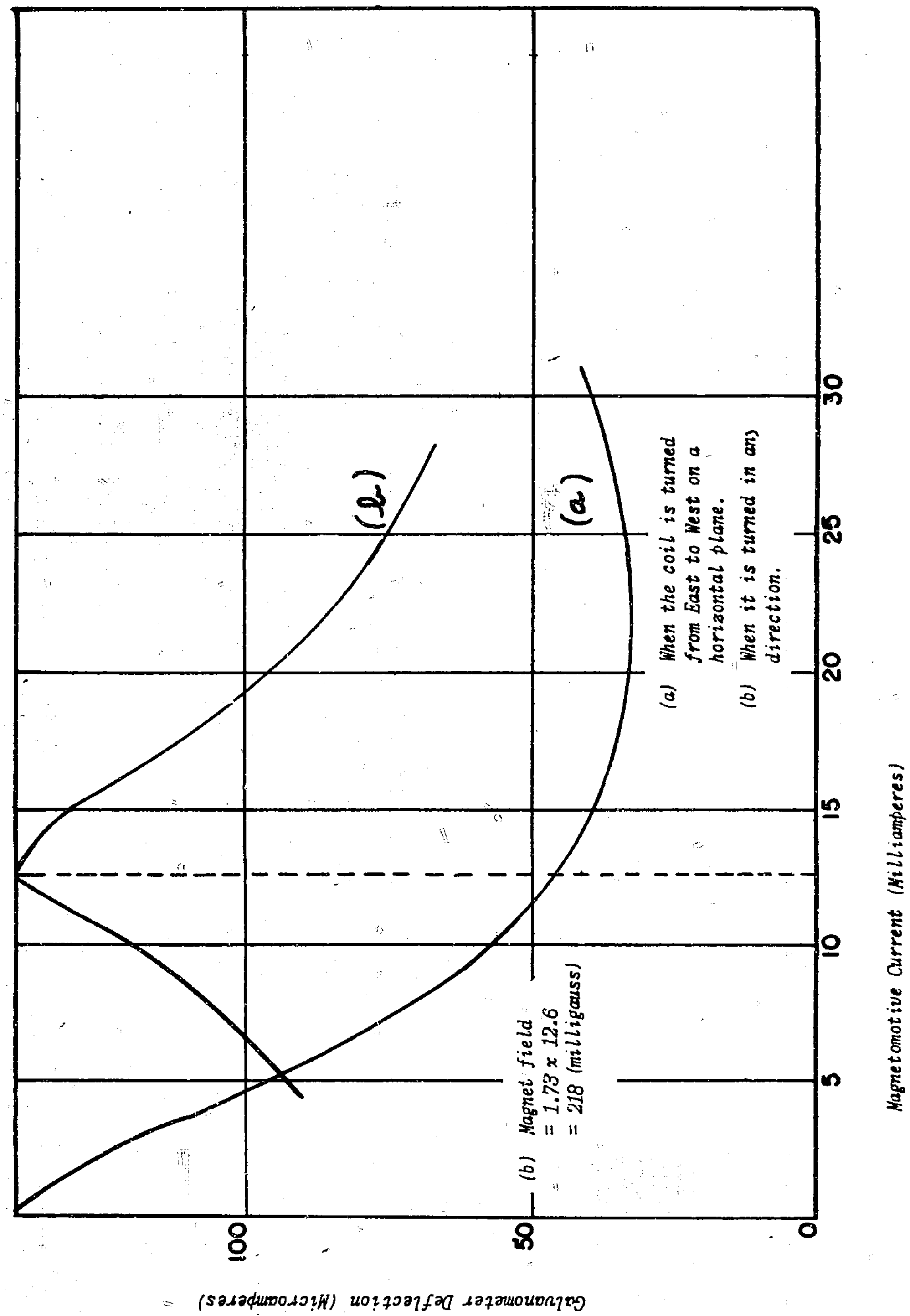


Figure 3(J)

ENCLOSURE (J), continued

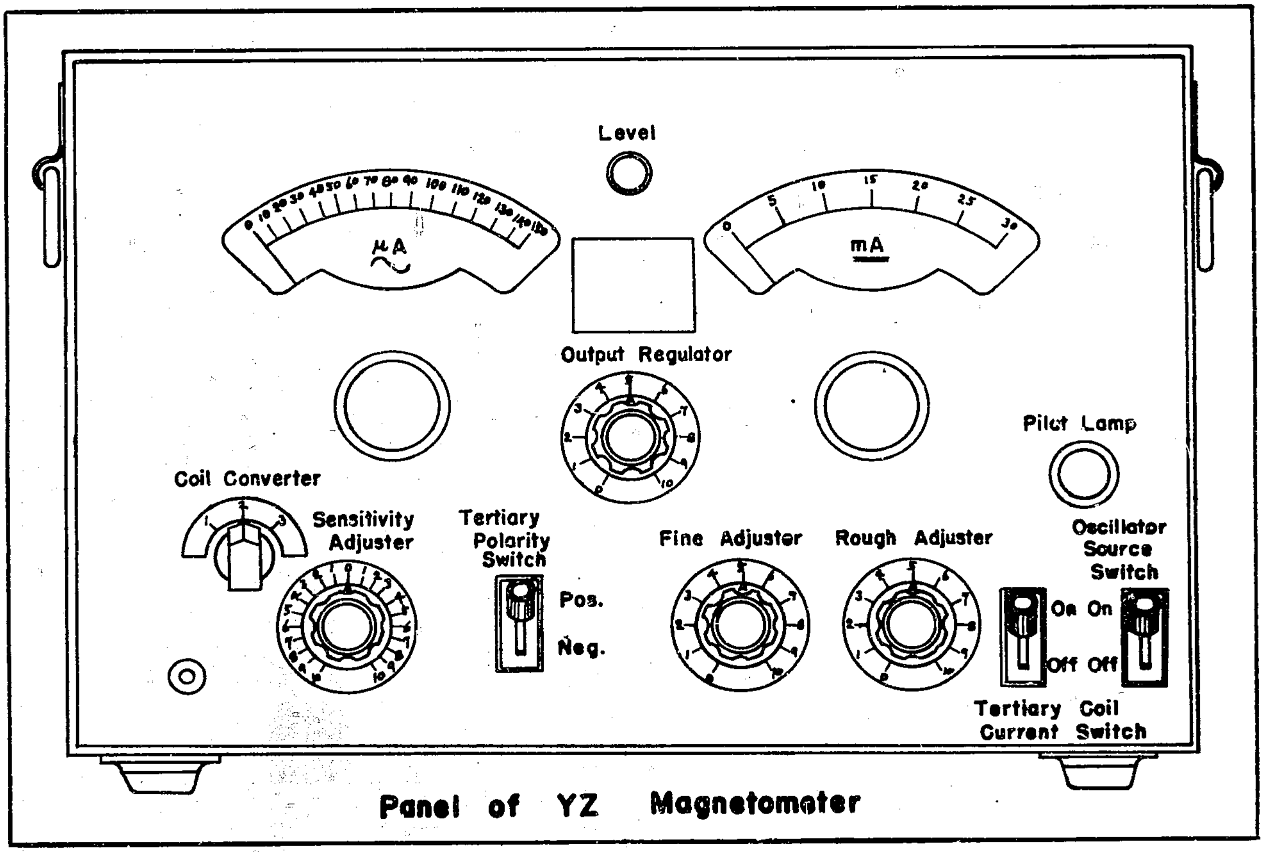


Figure 4(J)

A_1 becomes maximum when the magnetomotive current is 126 milliamperes; so the strength of the magnetic field in the direction of the magnetic receiver coil at that time is 17.3 x 12.6 or 218 milligauss (17.3 is a constant in the tertiary winding).

As is clear from the above explanation, this equipment makes dependable measurements of the average magnetic strength within the vicinity of about 30 centimeters, but it cannot measure the strength of the magnetic field at one geometric point.

By making use of these basic principles, it is possible to manufacture equipment which will measure narrower magnetic fields (close to a single point) as well as weaker magnetic fields (up to 10^{-4} Gauss), but it is extremely difficult to locate the magnetic receiver coil in the exact direction of the point to be measured, when measuring the distribution of the underwater magnetic field adjacent to the ship, and so, inasmuch as the errors which occur in trying to measure the magnetic field at a single point are in general far larger than those which occur in the measuring equipment, this equipment is believed to be satisfactory for present purposes.

The equipment which has been manufactured for actual use* requires two 6 volt batteries and one 200 volt battery for power, as shown in Fig. 4 (J). Data in regard to the wiring of the various parts is given in Fig. 5 (J).

III THEORETICAL COMPUTATION OF DISTURBANCES OF MAGNETIC FIELD CAUSED BY A FINITE CIRCULAR CYLINDER WITH A UNIFORM MAGNETIC SUSCEPTIBILITY

The shape of a ship is extremely complex; so it is almost impossible to express it accurately in mathematical terms. It may be that the external form alone can be so expressed, but when the problem of disturbances of the adjacent magnetic field are considered, there are, of course, differences in the external form, because of differences in hulls, and these together with the differences in the magnetic substances, that is, the varieties of steel, included within the hull make a complex problem. Consequently, it may well be said that it is impossible to produce a formula equal to computing such disturbances accurately. And so a finite circular cylinder was selected as representing sufficiently accurately the form of a ship, and which could be easily used, moreover, to make mathematical computation. Computations were then made of the disturbances of the adjacent magnetic field when it was placed within the terrestrial magnetic field.

Certain types of vessels closely approximate an oblate spheroid or a square column in shape, but it is only possible to arrive at a qualitative tendency by theoretical computation anyway; so, it is all right to use a cylinder for the purposes of study.

Generally, when a homogeneous magnetic substance with magnetic susceptibility κ lies in the terrestrial magnetic field H_0, there is a disturbance of the magnetic field about the magnetic substance. Now, if we let ds stand for a small area at any point $Q(\xi, \nu, \zeta)$ on the surface of the magnetic substance and $\vec{n}$ stand for the unit vector of the outer normal at that point, then at any point $P(x, y, z)$ outside of the magnetic substance, the magnetic potential V caused by this magnetic body is given in the following formula:

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*Assistance was received from Mr. Isao TAKAHASHI of the Japan Tel. & Tel. Co. in connection with the manufactured article.

ENCLOSURE (J), continued

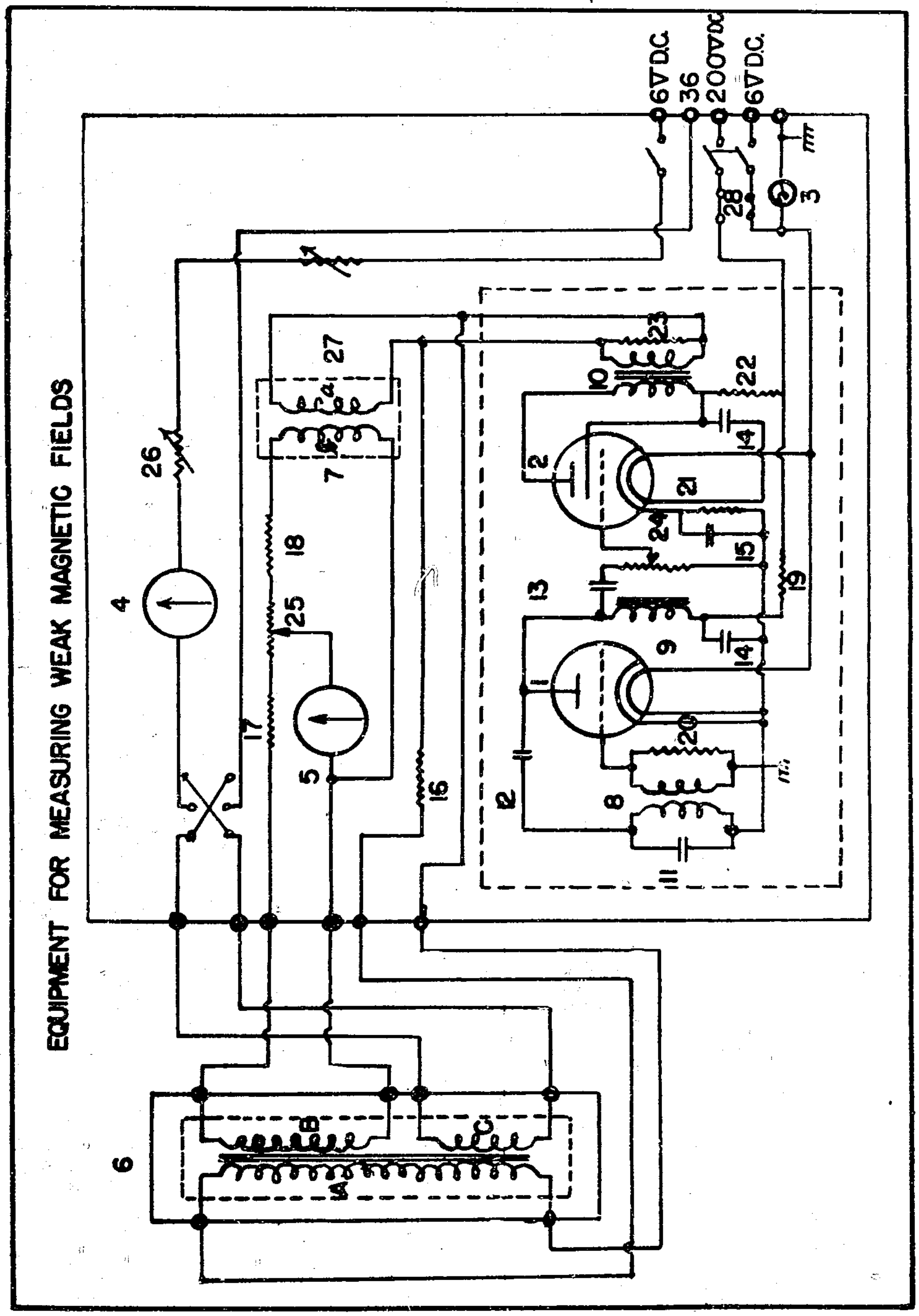

Figure 5(J)

ENCLOSURE (J) continued

DATA ON EQUIPMENT FOR MEASURING WEAK MAGNETIC FIELDS

(Items correspond to those shown in Fig. 5(J))

No.	Name	Data	Remarks
1 2	Vacuum tube (oscillator)	UY-37 UY-38	To amplify oscillator To amplify
3	Power supply pilot light	6v-8v small lamp	
4 5	D.C. Ammeter	30ma 1 Calibration - 0.2ma 150ma Internal resistance 330 Ω	Precision type
6	Magnetic receiver coil	A_1 Primary winding 6000T 184 Ω B_1 Secondary winding 3000T 88 Ω C_1 Tertiary winding 552T 7.8 Ω	Permalloy core-0.7cm thick, 1.0cm wide, 32cm long, Enclosed in brass box
7	Compensating coil	a_1 Primary winding 5000T 68 Ω b_1 Secondary winding 6000T 205 Ω	2 - parallel 2 - series
8	Oscillator coil	N_P = 1000T N_S = 1000TΩ	
9	Choke coil	30H T-30 Type	
10	Output transformer	17.1ma Type	
11	Oscillator condenser	0.11mf Mica condenser	
12 13	Coupling condenser	0.1mf Paper condenser 0.1mf Tubular condenser	
14	Anode by-pass condenser	2mf Paper condenser	
15	Cathode by-pass	2mf Paper condenser	
16 17 18 19 20 21 22 23	Fixed resistance	1300Ω 3000Ω 6780Ω 50KΩ 150KΩ 1KΩ 1KΩ 100Ω	Winding Winding Winding Rikenomu 1C Type Rikenomu 1C Type Rikenomu 1C Type Rikenomu 1C Type ½C Type
24 25 26 27	Variable resistance	300KΩ 600Ω 600Ω 5000Ω	LUX LUX 713 Type LUX 713 Type LUX 713 Type
28	Fuse		

ENCLOSURE (J), continued

$$V = \kappa \int \frac{1}{r} (\vec{H}_0 \cdot \vec{\eta})\, ds \quad \text{.......... (1)}$$

where r denotes the distance between P and Q. That is,

$$r = \sqrt{(x-\xi)^2 + (y-\nu)^2 + (z-\zeta)^2}$$

Consequently, if we let H′ equal the intensity of the disturbance of the magnetic field caused by the magnetic substance, we get the following formula:

$$H = -\operatorname{grad} V \quad \text{.......... (2)}$$

When the surface of the magnetic substance is expressed by the equation:

$$F(\xi,\nu,\zeta) = 0$$

the direction cosines of the outer normal of the surface are given as follows:

$$\frac{1}{G}\frac{\partial F}{\partial \xi}, \quad \frac{1}{G}\frac{\partial F}{\partial \nu}, \quad \frac{1}{G}\frac{\partial F}{\partial \zeta}, \qquad G^2 = \left(\frac{\partial F}{\partial \xi}\right)^2 + \left(\frac{\partial F}{\partial \nu}\right)^2 + \left(\frac{\partial F}{\partial \zeta}\right)^2$$

If we let H_{ox}, H_{oy}, and H_{oz} equal the three scalar values of $\vec{H}_0$, we get:

$$(\vec{H}_0 \cdot \vec{\eta}) = \frac{1}{G}\left(H_{ox}\frac{\partial F}{\partial \xi} + H_{oy}\frac{\partial F}{\partial \nu} + H_{oz}\frac{\partial F}{\partial \zeta}\right) \quad \text{.......... (3)}$$

Now, taking as our reference points the x axis (axis of the finite circular cylinder with diameter 2b and length 2a) and center point O, we draw the axis vertically downward. (See Figure 6(J).) Assuming that the axis of the cylinder lies in a horizontal plane, that is, making the direction of the x axis the bow to stern center line of a ship, we assume that plane xy is a horizontal plane. If we consider the surface of the cylinder divided into side and end surfaces and assume that V_1 is the portion of the magnetic potential contributed by the side surface, V_2 as the portion contributed by end surface x = a , and V_3 as the portion contributed by end surface x = -a , we get the equation:

$$V = V_1 + V_2 + V_3 \qquad \vec{H}' = \vec{H}_1 + \vec{H}_2 + \vec{H}_3$$

$$H_i = -\operatorname{grad} V_i \quad \text{where} \quad i = 1, 2, 3, \quad \text{.......... (4)}$$

If we let α equal the dip of the field of terrestrial magnetism $\vec{H}_0$ and δ equal the angle between the ship's longitudinal axis and the magnetic meridian, then V_1, the magnetic potential contributed by the side surface, becomes, from formulas (1) and (3):

$$V_1 = \kappa H_0 \int \frac{1}{r}\frac{1}{b}(\nu \cos\alpha \sin\delta + \zeta \sin\alpha)\, ds$$

If we use cylindrical coordinates,

$$\eta = b\cos\theta, \qquad S = b\sin\theta, \qquad dS = b\, d\theta\, d\xi$$

and so,

$$V_1 = \kappa b H_0 \int_{-a}^{a} d\xi \int_0^{2\pi} \frac{1}{r_1}(\cos\alpha\sin\delta\cos\theta + \sin\alpha\sin\theta)\, d\theta \quad \text{.......... (5)}$$

Where $r_1^2 = (x-\xi)^2 + y^2 + z^2 + b^2 - 2b(y\cos\theta + z\sin\theta)$

ENCLOSURE (J), continued

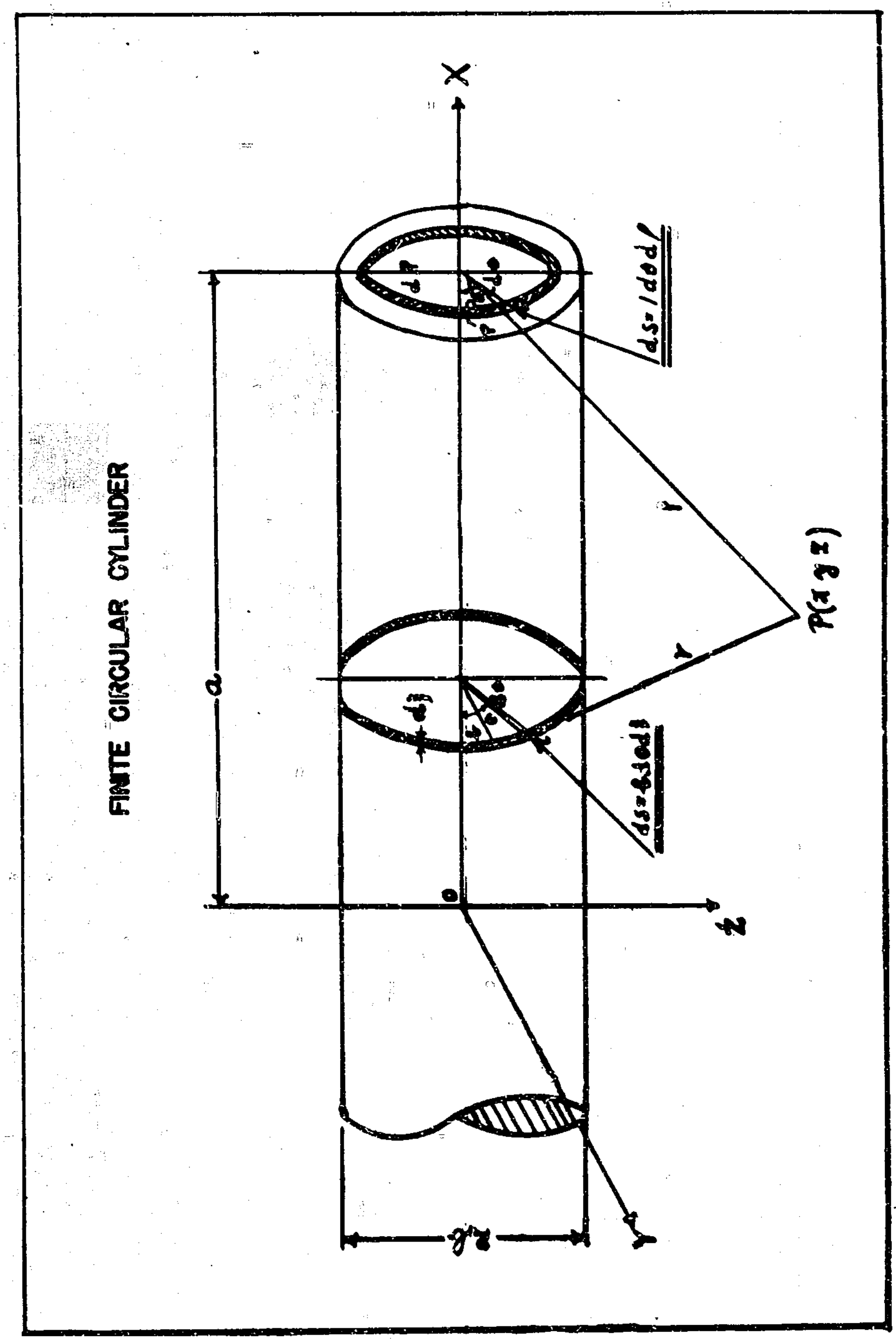

Figure 8(J)

ENCLOSURE (J), continued

If we use the variable ρ in the same way in connection with the end surfaces and let $\nu = \rho\cos\theta$ and $\zeta = \rho\sin\theta$, we get $dS = \rho\, d\theta \cdot d\rho$, and so,

$$V_2 = \kappa H_0 \cos\alpha \cos\delta \int_0^b \rho\, d\rho \int_0^{2\pi} \frac{1}{r_2}\, d\theta \quad \ldots\ldots(6)$$

$$r_2^2 = (x-a)^2 + y^2 + z^2 + \rho^2 - 2\rho\,(y\cos\theta + Z\sin\theta)$$

At $\xi = -a$ end surface, the direction of the normal is the exact opposite to that of the end surface at $\xi = a$ and it differs only in the sign ξ. Therefore, the value of V_3 is obtained by replacing $(x-a)$ in the expression of V_2 with $(x+a)$ and changing the sign of the whole expression. That is, it is all right to change the sign of x in the expression of V_2, and so, writing this as $V_2(-x)$, we obtain the following relationship:

$$V_3 = -V_2(-x) \quad \ldots\ldots(7)$$

Next, if $(x-\xi)^2+y^2+z^2+b^2 = A$ and $2b(y\cos\theta + z\sin\theta) = x$, so long as point $P(x,y,z)$ remains outside the magnetic cylinder

$$r_1^2 = A^2 - X > 0 \qquad \text{that is,} \qquad 1 > \frac{X}{A^2} > -1$$

Therefore, when

$$\frac{1}{r_1} = \frac{1}{A}\,\frac{1}{\left(1-\frac{x}{A^2}\right)^{\frac{1}{2}}} = \frac{1}{A}\left\{1 + \sum_{n=1}^{\infty} \frac{1\cdot 3\cdot 5\cdot\ldots\ldots(2n-1)}{2\cdot 4\cdot 6\cdot\ldots\ldots 2n}\left(\frac{x}{A^2}\right)^n\right\}$$

is developed, it converges. So, by replacing $y = h\cos\beta$ and $z = h\sin\beta$ we get $x = 2bh\cos t$, and $d\theta = dt$, where $\theta - \beta = t$ and $h^2 = y^2 + z^2$. Therefore, we get

$$\int_0^{2\pi} x^n \cos\theta\, d\theta = (2b\cdot h)^n \int_{-\beta}^{2\pi-\beta} (\cos\beta\cos^{n+1}t - \sin\beta\sin t\cos^n t)\, dt$$

and

$$\int_0^{2\pi} x^n \sin\theta\, d\theta = (2b\cdot h)^n \int_{-\beta}^{2\pi-\beta} (\cos\beta\sin t\cos^n t + \sin\beta\cos^{n+1} t)\, dt$$

and since

$$\begin{cases} \int_0^{2\pi} \cos^{2p} t\, dt = \int_0^{2\pi} \sin^{2p} t\, dt = \dfrac{1\cdot 3\cdot 5\cdot\ldots\ldots(2p-1)}{2\cdot 4\cdot 6\cdot\ldots\ldots 2p}\, 2\pi \\ \int_0^{2\pi} \cos^{2p-1} t\, dt = \int_0^{2\pi} \sin^{2p-1} t\, dt = \int_0^{2\pi} \cos^n t\sin t\, dt = \int_0^{2\pi} \sin^n t\cos t\, dt = 0 \end{cases}$$

(where p and n are positive integers),

we get the following formulae:

$$\left.\begin{aligned} \int_0^{2\pi} \frac{1}{r_1}\cos\theta\, d\theta &= 2\pi b y I \\ \int_0^{2\pi} \frac{1}{r_1}\sin\theta\, d\theta &= 2\pi b z I \end{aligned}\right\} \quad \ldots\ldots(8)$$

Where

$$I = \frac{2}{A^p}\sum_{p=1}^{\infty} \frac{1\cdot 5\cdot 9\cdot\ldots\ldots(4p-3)}{2\cdot 6\cdot 10\cdot\ldots\ldots(4p-2)}\cdot\frac{1\cdot 3\cdot 5\cdot\ldots\ldots(2p-1)}{2\cdot 4\cdot 6\cdot\ldots\ldots 2p}\left\{\frac{4b^2(y^2+z^2)}{A^4}\right\}^{p-1} \quad \ldots(8)_1$$

ENCLOSURE (J), continued

Similarly, we obtain the following formula:

$$\int_0^{2\pi} \frac{1}{r_2} d\theta = 2\pi I' \qquad \text{.......(9)}$$

$$I' = \frac{1}{A_1'} \left[1 + \sum_{p=1}^{\infty} \frac{3 \cdot 7 \cdot 11 \cdot \ldots (4p-1)}{4 \cdot 8 \cdot 12 \cdot \ldots 4p} \cdot \frac{1 \cdot 3 \cdot 5 \cdot \ldots (2p-1)}{2 \cdot 4 \cdot 6 \cdot \ldots 2p} \left\{ \frac{4p^2(y^2+z^2)}{A_1'^4} \right\}^p \right] \qquad \text{...(9)}_1$$

$$A_1'^2 = (x-a)^2 + y^2 + z^2 + \rho^2$$

Consequently, if

$$\left.\begin{aligned} J_1 &= \int_{-a}^{a} I \, d\xi \\ J_2 &= \int_0^{b} \rho . I' d\rho \end{aligned}\right\} \qquad \text{.......(10)}$$

the three components of magnetic potential V are derived from (5)~(10) and are given in the following formulae:

$$\left.\begin{aligned} V_1 &= 2\pi\kappa\, b^2 H_0 (y \cos\alpha \sin\delta + z \sin\alpha) J_1 \\ V_2 &= 2\pi\kappa\, H_0 \cos\alpha \cos\delta \cdot J_2 \\ V_3 &= - V_2 (-x) \end{aligned}\right\} \qquad \text{.......(11)}$$

Therefore, according to formula (4) the intensity of the disturbance of the magnetic field is as follows:

$$\left.\begin{aligned} H_x &= H_{1x} + H_{2x} + H_{3x} \\ H_y &= H_{1y} + H_{2y} + H_{3y} \\ H_z &= H_{1z} + H_{2z} + H_{3z} \end{aligned}\right\} \qquad \text{.......(12)}$$

$$\left.\begin{aligned} H_{1x} &= -2\pi\kappa\, b^2 H_0 (y \cos\alpha \sin\delta + z \sin\alpha) \\ H_{2x} &= -2\pi\kappa\, H_0 \cos\alpha \cos\delta \frac{\partial J_2}{\partial x} \\ H_{3x} &= H_{2x} (-x) \end{aligned}\right\} \qquad \text{.......(13)}_1$$

$$\left.\begin{aligned} H_{1y} &= -2\pi\kappa b^2 H_0 \left\{J_1 \cos\alpha \sin\delta + (y \cos\alpha \sin\delta + z \sin\alpha) \frac{\partial J_1}{\partial y}\right\} \\ H_{2y} &= -2\pi\kappa\, H_0 \cos\alpha \cos\delta \frac{\partial J_2}{\partial y} \\ H_{3y} &= - H_{2y} (-x) \end{aligned}\right\} \qquad \text{.....(13)}_2$$

$$\left.\begin{aligned} H_{1z} &= -2\pi\kappa\, b^2 H_0 \left\{J_1 \sin\alpha + (y \cos\alpha \sin\delta + z \sin\alpha) \frac{\partial J_1}{\partial z}\right\} \\ H_{2z} &= -2\pi\kappa\, H_0 \cos\alpha \cos\delta \frac{\partial J_2}{\partial z} \\ H_{3z} &= - H_{2z} (-x) \end{aligned}\right\} \qquad \text{.......(13)}_3$$

ENCLOSURE (J), continued

Now,
$$\int A^{-(4P-1)}\,d\xi = \int \frac{-d(x-\xi)}{\{(x-\xi)^2+B^2\}^{\frac{4P-1}{2}}}$$

$$= -\left\{\frac{1}{4P-3}\cdot\frac{P_{4P-1}}{B^2} + \frac{4P-4}{(4P-3)(4P-5)}\cdot\frac{P_{4P-3}}{B^4} + \ldots\ldots\right.$$

$$\left.\ldots + \frac{(4P-4)(4P-6)\ldots 0\cdot 8\cdot 48}{(4P-3)(4P-5)\ldots -1\cdot 15\cdot 63}\;\frac{P_3}{B^{4P-2}}\right\}$$

Where
$$P_m = \frac{x-\xi}{\{(x-\xi)^2+B^2\}^{\frac{m-2}{2}}} \qquad B^2 = y^2+z^2+b^2$$

Therefore, from formulae (8) and (10) the following relationship is obtained:

$$J_1 = 2\sum_{P=1}^{\infty} \frac{1\cdot 3\cdot 5\cdot\ldots(2P-1)}{2\cdot 4\cdot 6\cdot\ldots\ldots 2P}\cdot\frac{1}{4P-2}\,\{4b^2(y^2+z^2)\}^{P-1}$$

$$\left\{\frac{1}{B^{4P-2}}\left(\frac{x+a}{A_2}-\frac{x+a}{A_1}\right)+\frac{1}{2B^{4P-4}}\left(\frac{x+a}{A_2^3}-\frac{x-a}{A_1^3}\right)+\ldots\ldots\right.$$

$$\left.\ldots\ldots+\frac{1\cdot 5\cdot 9\cdot\ldots\ldots(4P-3)}{0\cdot 4\cdot 8\cdot\ldots\ldots(4P-4)}\cdot\frac{1}{B^2}\left(\frac{x+a}{A_2^{4P-3}}-\frac{x-a}{A_1^{4P-3}}\right)\right\}\ldots\ldots\ldots(14)_1$$

and

$$\frac{\partial J_1}{\partial y} = 2y\sum_{P=1}^{\infty}\frac{1\cdot 3\cdot 5\cdot\ldots\ldots(2P-1)}{2\cdot 4\cdot 6\cdot\ldots\ldots 2P}\cdot\frac{1}{4P-2}\,(4b^2)^{P-1}(y^2+z^2)^{P-2}$$

$$\left\{\{2(P-1)b^2-2P(y^2+z^2)\}\left\{\frac{1}{B^{4P}}\left(\frac{x+a}{A_2}-\frac{x-a}{A_1}\right)+\frac{1}{2B^{4P-2}}\right.\right.$$

$$\left(\frac{x+a}{A_2^3}-\frac{x-a}{A_1^3}\right)+\frac{-1\cdot 3\cdot 7\cdot\ldots\ldots(4P-5)}{0\quad 4\quad 8\quad\ldots\ldots(4P-4)}\;\frac{1}{B^4}\left\{\frac{x+a}{A_2^{4P-3}}-\frac{x-a}{A_1^{4P-3}}\right.$$

$$\left.+\frac{-1\cdot 15\cdot 63\cdot\ldots(4P-5)(4P-3)}{0\cdot 4\cdot 8\cdot\ldots\ldots\ldots(4P-4)}\;\frac{(y^2+z^2)}{B^2}\left(\frac{x+a}{A_2^{4P-2}}-\frac{x-a}{A_1^{4P-1}}\right)\right\}\ldots(14)_2$$

Where
$$A_1^2 = (x-a)^2+y^2+z^2+b^2 \qquad A_2^2 = (x+a)^2+y^2+z^2+b^2$$

includes only y and z as (y^2+z^2) and so, the relationship

$$\frac{1}{y}\frac{\partial J_1}{\partial y} = \frac{1}{z}\frac{\partial J_1}{\partial z}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)_3$$

is established

Next, (x,y,z) are points outside of the circular cylinder, and so, from formula (10) we get

$$\frac{\partial J_1}{\partial x} = \int_{-a}^{a}\frac{\partial I}{\partial x}\,d\xi$$

ENCLOSURE (J), continued

and because x and ξ in the expression I are included only as $(x - \xi)$

$$\frac{\partial I}{\partial x} = -\frac{\partial I}{\partial \xi}$$

Therefore $\frac{\partial J_1}{\partial x} = -\int_{-a}^{a} \frac{\partial I}{\partial \xi} d\xi = -(I_{(\xi=a)} - I_{(\xi=-a)})$

$$= 2 \sum_{P=0}^{\infty} \frac{1 \cdot 5 \cdot 9 \cdot \ldots (4P-3)}{2 \cdot 6 \cdot 8 \cdot \ldots (4P-2)} \cdot \frac{1 \cdot 3 \cdot 5 \cdot \ldots (2P-1)}{2 \cdot 4 \cdot 6 \cdot \ldots 2P}$$

$$\{4b^2(y^2 + z^2)\}^{P-1} \left\{ \frac{1}{A_2^{4P-1}} - \frac{1}{A_1^{4P-1}} \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)_4$$

and moreover, $\frac{\partial J_2}{\partial y} = \int_0^b \rho \frac{\partial I'}{\partial y} d\rho = \frac{1}{2\pi} \int_0^b \rho \, d\rho \int_0^{2\pi} \frac{y - \rho\cos\theta}{r_2^3} d\theta$

Therefore, if it is handled in the same way as when we computed I' we get t following formulae:

$$\frac{\partial J_2}{\partial y} = -y \sum_{P=0}^{\infty} \frac{5 \cdot 9 \cdot 13 \ldots (4P+1)}{4 \cdot 8 \cdot 12 \ldots 4P} \cdot \frac{3 \cdot 5 \cdot 7 \cdot \ldots (2P+1)}{2 \cdot 4 \cdot 6 \cdot \ldots 2P} \{4(y^2+z^2)\}^P$$

$$\times \int_0^b \left\{ \frac{\rho^{2P+1}}{A_1'^{4P+3}} - \frac{4P+3}{2(P+1)} \cdot \frac{\rho^{2P+3}}{A_1'^{4P+5}} \right\} d\rho$$

$$= -\frac{yb^2}{A_1^3} \sum_{P=0}^{\infty} \frac{3 \cdot 7 \cdot 11 \cdot \ldots (4P-1)}{4 \cdot 8 \cdot 12 \cdot \ldots 4P} \cdot \frac{1 \cdot 3 \cdot 5 \cdot \ldots (2P-1)}{2 \cdot 4 \cdot 6 \cdot \ldots 2P} \cdot \frac{4P+1}{2P+2}$$

$$\times \left\{ \frac{4b^2(y^2+z^2)}{A_1^4} \right\}^P \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)_5$$

and $\frac{1}{z} \cdot \frac{\partial J_2}{\partial z} = \frac{1}{y} \cdot \frac{\partial J^2}{\partial y}$ ……………………………… $(14)_6$

Next,

$$\int A_1'^{-(4P+1)} \rho^{2P+1} d\rho = \int A_1'^{-4P} (A_1'^2 - D^2)^P dA'$$

$$= -\sum_{q=0}^{P} (-1)^q {}_PC_q D^{2q} \frac{A_1'^{2(P+q)+1}}{2(p+q)+1}$$

Where $A_1'^2 = (x-a)^2 + y^2 + z^2 + \rho^2 = D^2 + \rho^2$ that is, $D^2 = (x-a)^2 + y^2 + z^2$

ENCLOSURE (J), continued

Therefore, from both formulae (9) and (10) we get the following formula:

$$\frac{\partial J_2}{\partial x} = (x-a) \sum_{P=0}^{\infty} \frac{3 \cdot 7 \cdot 11 \cdot \ldots (4P-1)}{4 \cdot 8 \cdot 12 \cdot \ldots\ldots 4P} \cdot \frac{1 \cdot 3 \cdot 5 \cdot \ldots (2P-1)}{2 \cdot 4 \cdot 6 \cdot \ldots\ldots 2P}$$

$$x\,(4P+1)\,\{4\,(y^2+z^2)\}^P \Big[\sum_{q=0}^{P} \frac{P(P-1)(P-2)\ldots(P-q+1)}{1 \cdot 2 \cdot 3 \cdot \ldots q}$$

$$\times \frac{(-1)^q}{2(P+q)+1} \left\{ \frac{1}{A^{2P+1}} \left(\frac{D}{A_1}\right)^{2q} - \frac{1}{D^{2P+1}} \right\} \Big] \ldots\ldots\ldots\ldots\ldots\ldots (14).$$

Thus, given the constants a, b, H_0, κ etc., if we use formulae (12), (13, 1 thru 3) and (14, 1 thru 7), we can compute the intensity of the disturbance of the magnetic field at various points outside of the circular cylinder. The convergency of the infinite series in the above various formulae is rapid when the points (x, y, z), whose intensity in the magnetic field are sought, are distant from the surface of the circular cylinder, and for our purposes satisfactory results can generally be obtained, if three or four terms are taken. (If allowance is made, in general, for an error of less than three percent, no difficulty will be experienced from a practical standpoint.)

IV NUMERICAL EXAMPLES AND COMPARISON WITH TEST RESULTS

By means of the various formulae given in previous paragraphs, the intensity of the disturbance of the magnetic field caused by the circular cylinder at any point outside of it can be computed no matter what the orientation or location of the cylinder may be. Now, in order to make a rough qualitative comparison between various types of ships and the cylinder, we let $a = 50$ meters, $b = 60$ meters, and $2\pi\kappa = 1$. Now we shall try to compute the intensity of the disturbance of the magnetic field in the following four places with three different orientations, that is where $\delta = 0$ (the bow facing north), $\delta = 30^\circ$ (the bow facing N30°W) and $\delta = 90^\circ$ (the bow facing west).

(1) $\alpha = 0$, $H_0 = 370$mΓ (PALAU I. area)

(2) $\alpha = 30^\circ$, $H_0 = 416$mΓ (TAIWAN area)

(3) $\alpha = 49^\circ 51'$, $H_0 = 502$mΓ (YOKOSUKA area)

(4) $\alpha = 60^\circ 20'$, $H_0 = 517$mΓ (MURORAN area)

The values of α and H_0 given above for (1) and (2) are those given on the charts of terrestrial magnetism prepared by the Naval Hydrographic Office, and for (3) and (4), we used the measured values. These measured values differ a little from those given on the charts, but it makes little difference for practical purposes which are used; so we decided to use the measured values.

Figure 7(J) shows the variation of the three components of H along three axes in the case of a ship pointing North in the YOKOSUKA area, and Figures 11(J) and 12(J) at the end of this report show the computed values. From figure 11(J) we know how the distribution of the adjacent magnetic field in that area was affected by changes in orientation, and from Figure 12(J) we know the nature of the variation in the various areas.

On the right hand side of Figure 8(J) are shown the measured results obtained at Yokosuka harbor with the ship's bow pointing north and east, as an example of the results of actual measurement of an underwater magnetic field, using the equipment described in paragraph 2, for measuring weak magnetic

ENCLOSURE (J), continued

WHEN α=49°51' HO=502 δ=0
(YOKOSUKA POINTING NORTH)

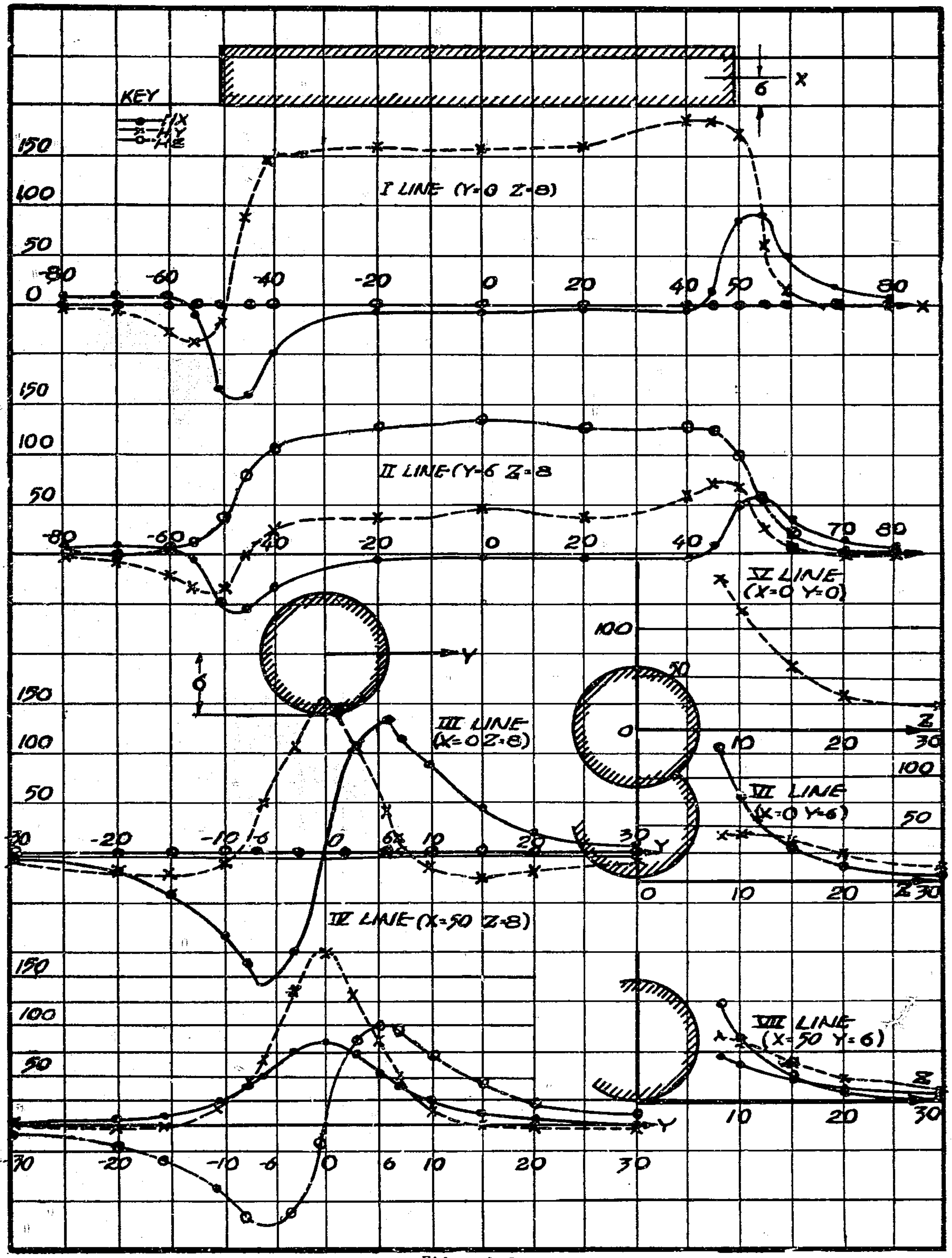

Figure 7(J)

ENCLOSURE (J), continued

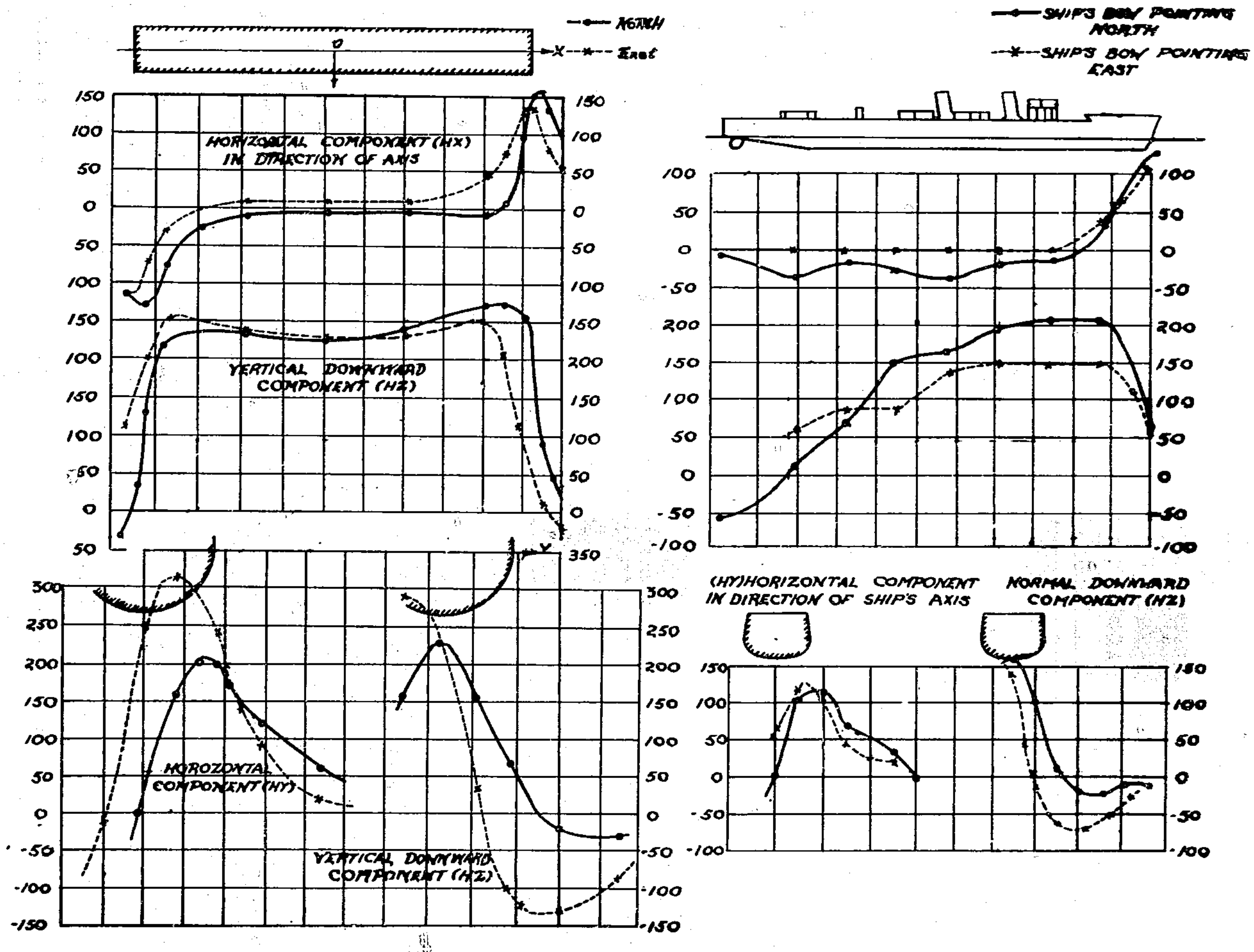

Figure 8(J)

ENCLOSURE (J), continued

fields. The results computed from the circular cylinder with $\mathfrak{z}\pi\kappa$ = 1.45 are shown on the left for the purpose of comparison. From this diagram it can be seen that both sets of results coincide very closely in respect to the following:

(I) Variation in the longitudinal cross section along the ship's axis.

(1) The horizontal component (H_x) along the ship's axis.

(a) Near the bow, large positive values were taken on both when pointing north and when pointing east. The positive value was larger when pointing north than when pointing east.

(b) In both cases, it rapidly decreased toward the middle part of the hull and was smaller when the ship pointed north than when it pointed east. Finally it became negative (at the stern).

(2) Vertical downward component (H_z)

(a) Near the bow, large positive values were taken on, both when pointing north and when pointing east, but the positive value was greater when pointing north. The difference between the two however diminished toward the middle part of the hull, and finally became larger when the ship was pointing east.

(b) At the stern, when the ship was pointing north, rather large negative values (upward) were taken.

As is clear in Figure 8(J) a ship differs greatly from the circular cylinder in shape, both at the bow and stern; so it is natural that the two should differ to a great extent quantitatively in the distribution of the disturbance of the magnetic field.

(II) Variation in the cross sectional plane normal to the ship's axis.

(1) Horizontal component (H_y) normal to the ship's axis.

(a) At the center (directly beneath the line of the keel), it is zero when pointing north, but rather large positive values were taken on when pointing east.

(b) When pointing north the maximum values occurred directly below the side of the ship, and when pointing east, the maximum values were taken close to the center of the ship. Gradually the positive value decreased and became smaller than that when pointing north.

(2) Vertical downward component (H_z)

(a) Maximum positive value when pointing north was taken at the center of the ship, and when pointing east, on the left side as you face Figure 8(J), but it decreased rapidly in the latter case and become smaller than when pointing north.

(b) The sign changed at a point directly below the side of the ship and pointed upward. The magnitude of the upward intensity was larger when pointing east than when pointing north.

The steel which forms the structure of a ship, in addition to being temporarily magnetized by terrestrial magnetism, contains a considerable amount of magnetism caused by permanently magnetized material. Therefore, we cannot apply the results computed with the previously mentioned circular cylinder directly to actual cases. It is, however, believed that that part of the variation which is caused by the values of the terrestrial magnetism (dip and magnitude) and the different positions of the ship's bow can be determined qualitatively from the above mentioned computed results.

There were, as shown in Figure 8(J), rather considerable differences quantitatively, but it can be observed that the results seem to agree qualitatively. Moreover, the same results were obtained when other types of ships were used and different locations were chosen to conduct the measurement.

V. METHOD OF REDUCING MAGNETISM BY MEANS OF A SOLENOID

Now let us give a thought to the matter of "degaussing" by means of which an attempt is made to reduce the disturbance of the magnetic field due to the presence of a ship's hull. This method involves passing an electric current through a coil which has been wound about a ship's hull.

If we use a finite circular cylinder in place of a ship's hull, as mentioned previously, and wind a solenoid closely about it, it becomes a rectangle in the horizontal plane, $z = 0$. Letting STUV represent the rectangle, the coordinates of the four points are fixed as follows:

$$S(a, b, o) \quad T(a, -b, o) \quad U(-a, -b, o) \quad V(-a, b, o)$$

If we pass an electric current through the rectangular solenoid STUV and let $\vec{H}_s$ equal the intensity of the magnetic field set up outside of it, the exterior magnetic field, $\vec{H}'$ which affects the magnetic circular cylinder is given as follows:

$$\vec{H}' = \vec{H}_o + \vec{H}_s \qquad (15)$$

If we let N be the coefficient of the magnetic resistance of the magnetic body which comprises the circular cylinder, the strength of magnetic resistance is expressed by $N\vec{M}$ and the intensity $\vec{H}_e$ of the magnetic field within the circular cylinder is expressed as follows:

$$\vec{H}_e = \vec{H}' - N\vec{M} \qquad (16)$$

$\vec{M}$ is the magnetization strength of the circular cylinder, and so, we get

$$\vec{M} = \kappa \vec{H}_e = \kappa (\vec{H}' - N\vec{M})$$

$$\vec{M} = \frac{\kappa}{1+\kappa N} \vec{H}' \qquad (17)$$

Therefore, if we let V_e equal the magnetic potential outside the circular cylinder, V_e is expressed by the following formula:

$$V_e = \int \frac{1}{r} (\vec{M}\eta)\, ds$$

And from formula (17) we get

$$V_e = \int \frac{1}{r} \left(\frac{\kappa}{1+\kappa N} \vec{H}'\eta \right) ds \qquad (18)$$

Therefore, $\vec{H}'$, the intensity of the disturbance of the magnetic field, adjacent to the circular cylinder when it has been wound about with a solenoid,

ENCLOSURE (J), continued

is sought from the formula:

$$\vec{H}_1 = -\operatorname{grad} V_e \quad \text{.......} (19)$$

but κ and N are, in general, functions of M and the form of those functions cannot be accurately determined. In the present instance, $\vec{H}_s$, hence N differ in value at various points within the circular cylinder. Therefore, when it comes to the integration of equation (18), the value of V_e, hence $\vec{H}_1$, cannot be calculated accurately, because κ and N differ in value at various points.

If we let $\vec{H}$ represent the intensity of the disturbance of the magnetic field caused by the circular cylinder without sending an electric current through the solenoid, the shape of the solenoid and the amount of current must be set so that they fulfill this relation:

$$|\vec{H}| > |\vec{H}_s + \vec{H}_1|$$

if we wish to reduce the magnetism by sending an electric current through the solenoid. We cannot, however, determine the value of H_1 theoretically, and so, we cannot hastily conclude whether or not we will always be able to maintain such a relation. In this section we assume that $\vec{H}_1 - \vec{H} = 0$ in the expression $\vec{H}_s + \vec{H}_1 - \vec{H}$ which is the intensity of the magnetic field decreased or increased by means of a solenoid, that is we ignore the disturbances of the outer magnetic field caused by magnetization of the circular cylinder by the magnetic field set up by the electric current in the solenoid and we consider only $\vec{H}_s$, the magnetic field produced directly by the current, as the reduced magnetic field*

In general, when we have electric current i along circuit $\vec{l}$ the vector potential, $\vec{A}$ at a point outside of and caused by the electric circuit, is expressed by the following formula:

$$A = \int \frac{1}{r}\, d\vec{l}$$

where $d\vec{l}$ expresses the elementary vector at an arbitrary point Q on $\vec{l}$ and where r is the distance PQ. Therefore, when we send electric current i through the rectangular solenoid STUV in the direction $S \to T \to U \to V$, the direction VS and TU are different from ST and UV; so it is convenient to make our calculations by dividing the vector potential into $\vec{A}_1$, caused by the former, and $\vec{A}_2$, caused by the latter. That is,

$$\vec{A} = \vec{A}_1 + \vec{A}_2 \quad \text{.......} (20)$$

Each component of $\vec{A}_1$ and $\vec{A}_2$ along three axes is expressed as follows:

$$A_{1x} = i\int_{-a}^{a} \frac{1}{r_1}\, d\xi - i\int_{a}^{-a} \frac{1}{r_1'}\, d\xi \quad \text{.......} (20)_1$$

---

* The results of measurement using an actual ship indicate that it is all right to assume that the reduced magnetic field is the product of $\vec{H}_s$, the magnetic field caused by the current, and $\alpha\,(\alpha \geqq 1)$. No difficulty is encountered in actual practice in assuming the relationship, $\vec{H}_s + \vec{H}_1 - \vec{H} = \alpha \vec{H}_s$ thus we get $\vec{H}_1 - \vec{H} = (\alpha - 1)\vec{H}_s$, that is, $\vec{H}_1 = \vec{H} + (\alpha + 1)\,\vec{H}_s$. That means that the disturbance of the magnetic field caused by the magnetization of the circular cylinder is the summation of $\vec{H}$, the value when there is no electric current in the solenoid, and a certain percentage of the magnetic field caused by the electric current.

ENCLOSURE (J), continued

$$\left.\begin{aligned} A_{1y} &= A_{1z} = 0 \\ A_{2x} &= A_{2z} = 0 \\ A_{2y} &= i\int_{b}^{-b} \frac{1}{r_2}d\eta - i\int_{-b}^{b} \frac{1}{r_2'}d\eta \end{aligned}\right\} \ldots\ldots\ldots\ldots (20)_2$$

$$r_1^2 = (x-\xi)^2 + (y-b)^2 + z^2, \qquad r_1'^2 = (x-\xi)^2 + (y-b)^2 + z^2$$

$$r_2^2 = (x-a)^2 + (y-\nu)^2 + z^2, \qquad r_2'^2 = (x+a)^2 + (y-\nu)^2 + z^2$$

$(\xi\ \nu,\ \theta)$ are coordinates of arbitrary points on the solenoid.

The intensity of the magnetic field caused by the electric current is generally expressed by rot $\vec{A}$; and so the various components of H_s, the intensity of the magnetic field caused by the solenoid are expressed in the following formulae:

$$H_{sx} = -i\left\{ \frac{z}{(a-x)^2+z^2}\left(\frac{b-y}{PS} + \frac{b+y}{PT}\right) - \frac{z}{(a+x)^2+z^2}\left(\frac{b-y}{PV} + \frac{b+y}{PU}\right)\right\} \ldots (21)_1$$

$$H_{sy} = -i\left\{ \frac{z}{(b-y)^2+z^2}\left(\frac{a-x}{PS} + \frac{a+x}{PV}\right) - \frac{z}{(b+y)^2+z^2}\left(\frac{a-x}{PT} + \frac{a+x}{PU}\right)\right\} \ldots (21)_2$$

$$H_{sz} = -i\left\{ \frac{b-y}{(b-y)^2+z^2}\left(\frac{a-x}{PS} + \frac{a+x}{PV}\right) + \frac{b+y}{(b+y)^2+z^2}\left(\frac{a-x}{PT} + \frac{a+x}{PU}\right)\right.$$

$$\left. + \frac{a-x}{(a-x)^2+z^2}\left(\frac{b-y}{PS} + \frac{b+y}{PT}\right) + \frac{a+x}{(a+x)^2+z^2}\left(\frac{b-y}{PV} + \frac{b+y}{PU}\right)\right\} \ldots\ldots (21)_3$$

Where

$$PS = \sqrt{(a-x)^2 + (b-y)^2 + z^2} \qquad PT = \sqrt{(a-x)^2 + (b+y)^2 + z^2}$$

$$PU = \sqrt{(a+x)^2 + (b+y)^2 + z^2} \qquad PV = \sqrt{(a+x)^2 + (b-y)^2 + z^2}$$

By means of the above formulae, the intensity of the magnetic field caused by any rectangular solenoid may be found. Figure 9(J) illustrates the computation of the various values of H_{sx} and H_{sz} along line $y = 0$, and of H_{sy} along line $x = 0$ on horizontal plane $z = 8$ when current $i = 1000$ amperes is sent through the solenoid surrounding the circular cylinder ($a = 50$ meters, $b = 6$ meters) mentioned in Section 4.

In the same diagram are the computation of the respective components of $\vec{H}$ and $\vec{H} - \vec{H}_s$ and disturbances of the magnetic field when $2\pi\kappa = 16$ and when the axis of the circular cylinder was pointed north in the YOKOSUKA area (Magnitude of terrestrial magnetism $H_0 = 502m\Gamma$ and dip equals 49°51'). According to this, the maximum values of the various components of magnetic field $\vec{H} - \vec{H}_s$, after reduction of magnetism, are equal in all cases. (That is, the value of κ is so chosen as to obtain this result.) Figure 10(J) shows on lines $x = 0$ and $y = 0$ the comparative attenuation, in the direction of z (depth), of the vertical components of $\vec{H}_1$ the magnetic field when current is not seen through the solenoid and of $\vec{H}_s$ the magnetic field due to the solenoid. In the same figure, a small 12 meter square solenoid has been placed on the left end (north end) of the surrounding solenoid.

ENCLOSURE (J), continued

DISTORTION OF THE MAGNETIC FIELD CAUSED BY THE STEEL CIRCULAR CYLINDER AND REDUCTION OF MAGNETISM BY THE SURROUNDING SOLENOID

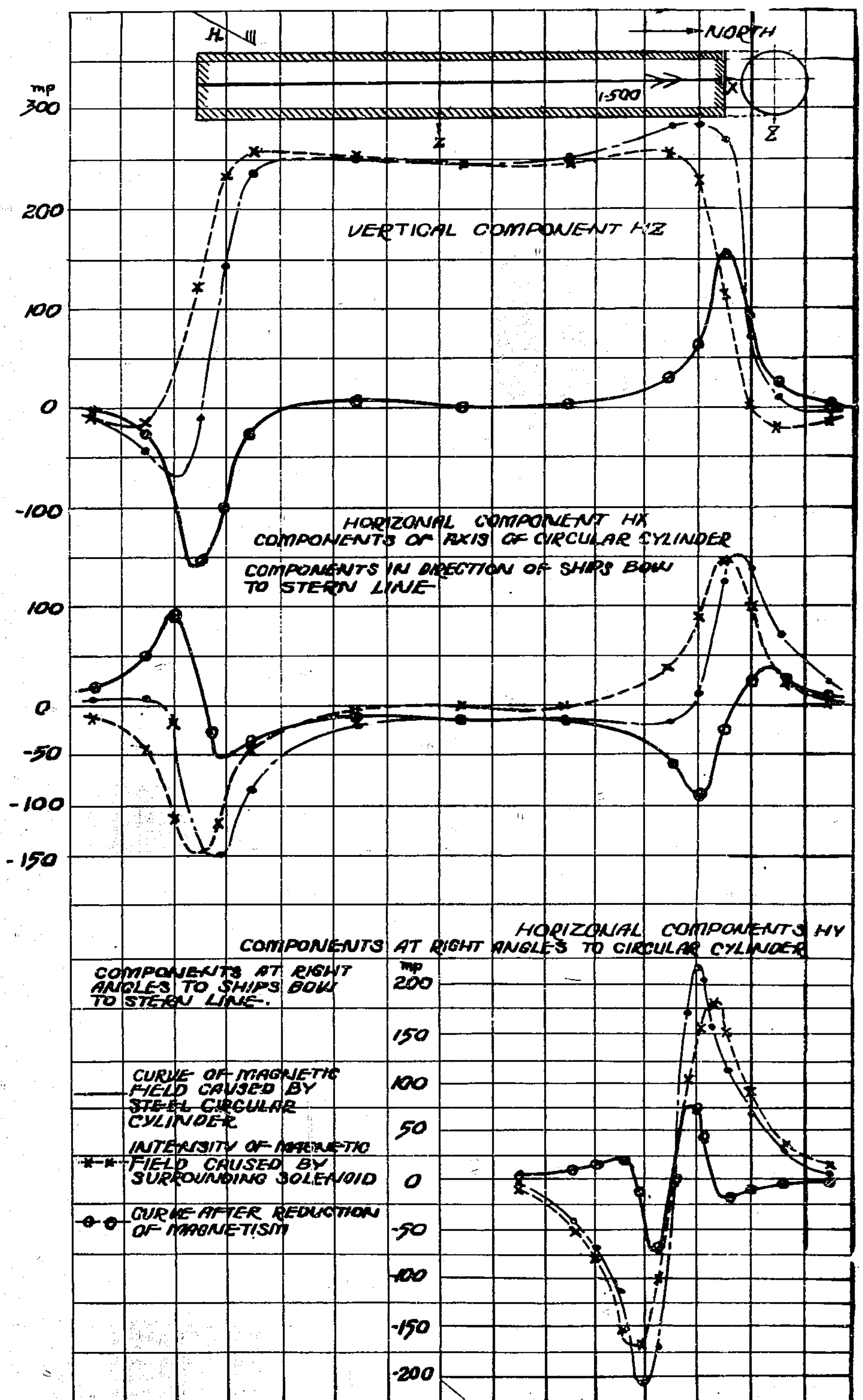

Figure 9(J)

ENCLOSURE (J), continued

COMPARISON OF REDUCTION OF INTENSITY OF MAGNETIC FIELD IN DIRECTION OF DEPTH

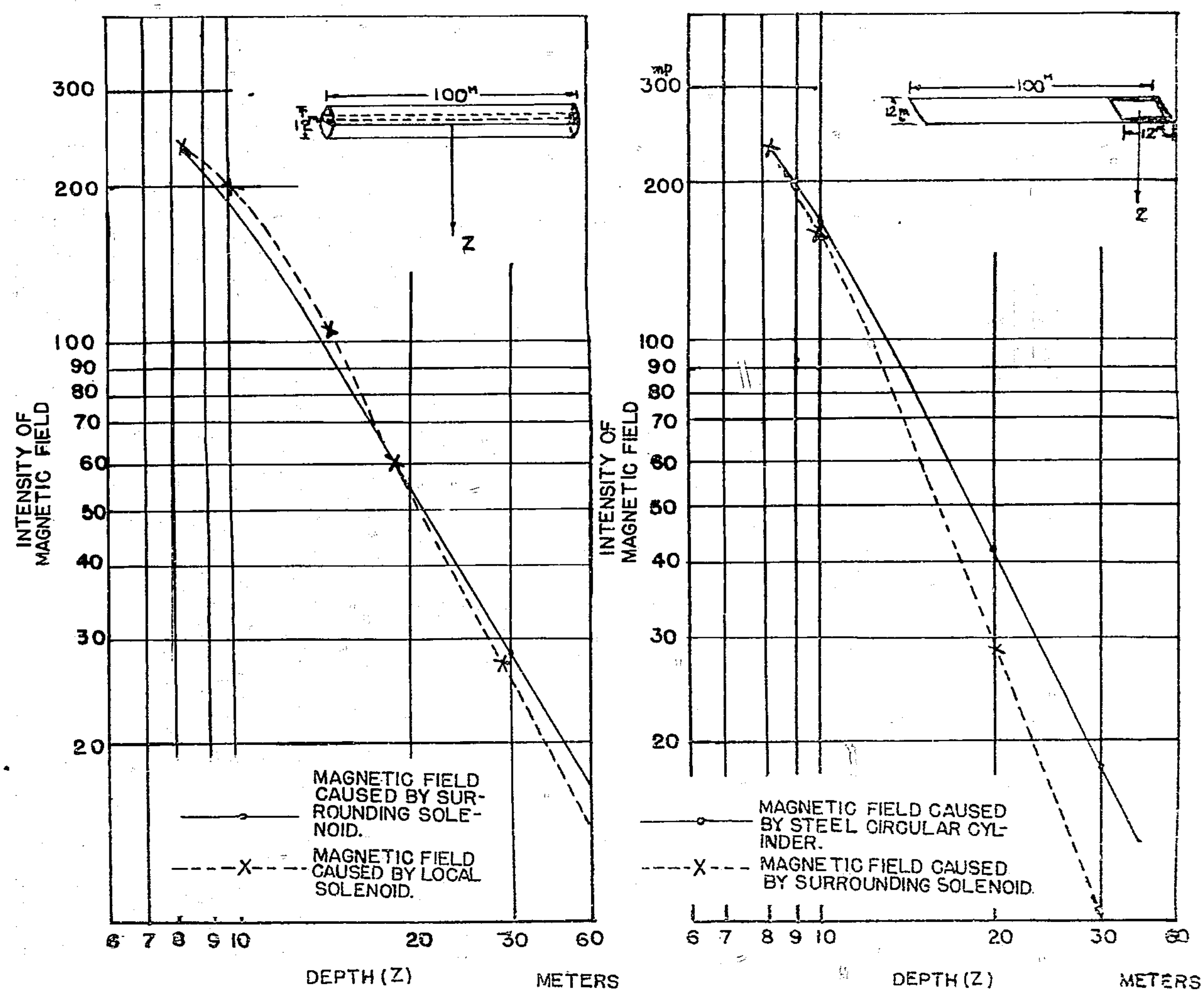

Figure 10(J)

ENCLOSURE (J), continued

The figure shows the comparative attenuation of the z component in direction z of both solenoids, when the current in the small solenoid has been so adjusted that the z component of the magnetic field caused by this small solenoid at a point where $x = 44$ meters, $y = 0$, and $z = 8$ meters, is equal to that of the surrounding solenoid.

In this report only one or two numerical examples are presented, but by means of such calculations as are given we know that we can anticipate qualitatively the various problems related to degaussing. Therefore, if we make a few measurements with actual ships, we can reach relatively accurate conclusions about those problems.

CONCLUSION

As already mentioned in earlier sections, the results of theoretical computations of the disturbances of the magnetic field adjacent to ships using a finite circular cylinder and the actual tendency of those disturbances agree. Therefore, rather than consider the distribution of the adjacent magnetic field as though the ship had been changed into a huge permanent magnet, it would be closer to the truth to assume that it is a magnetic mass, and that it disturbs the terrestrial magnetic field. This is because the nature of the surrounding magnetic field varies with the heading of the ship's bow and the area in which the ship is located. And so, if we measure the actual distribution of the magnetic field at one point and with the ship headed in one direction, we can accurately determine the distribution of the adjacent magnetic field of that same ship in other locations or headed in different directions, by means of the results of theoretical computations based on the circular cylinder. Of course, in order to know the distribution in detail, we must make actual measurements, but to carry out measurements for each and every circumstance would necessitate expenditure of time and money, and at times it is not even possible to make such measurements. Therefore, it is extremely valuable to be able to know the nature of general tendencies, even though we cannot make actual measurements.

The following is a summary of points previously made:

(1) In order to measure the distribution of the magnetic field adjacent to a ship, a necessarily light and portable instrument for measuring weak underwater magnetic fields has been devised and produced experimentally.

(2) We have made theoretical computations of the disturbance of the terrestrial magnetic field using a finite circular cylinder.

(3) We have ascertained the fact that the results obtained from measurements with instruments devised for use with certain types of ships and the results of computations using a circular cylinder agree qualitatively.

(4) We have stated that we can make qualitative tests by means of theoretical computations even in connection with "degaussing", and that by making actual measurements with the measuring instrument, we can determine its effectiveness.

ENCLOSURE (J), continued

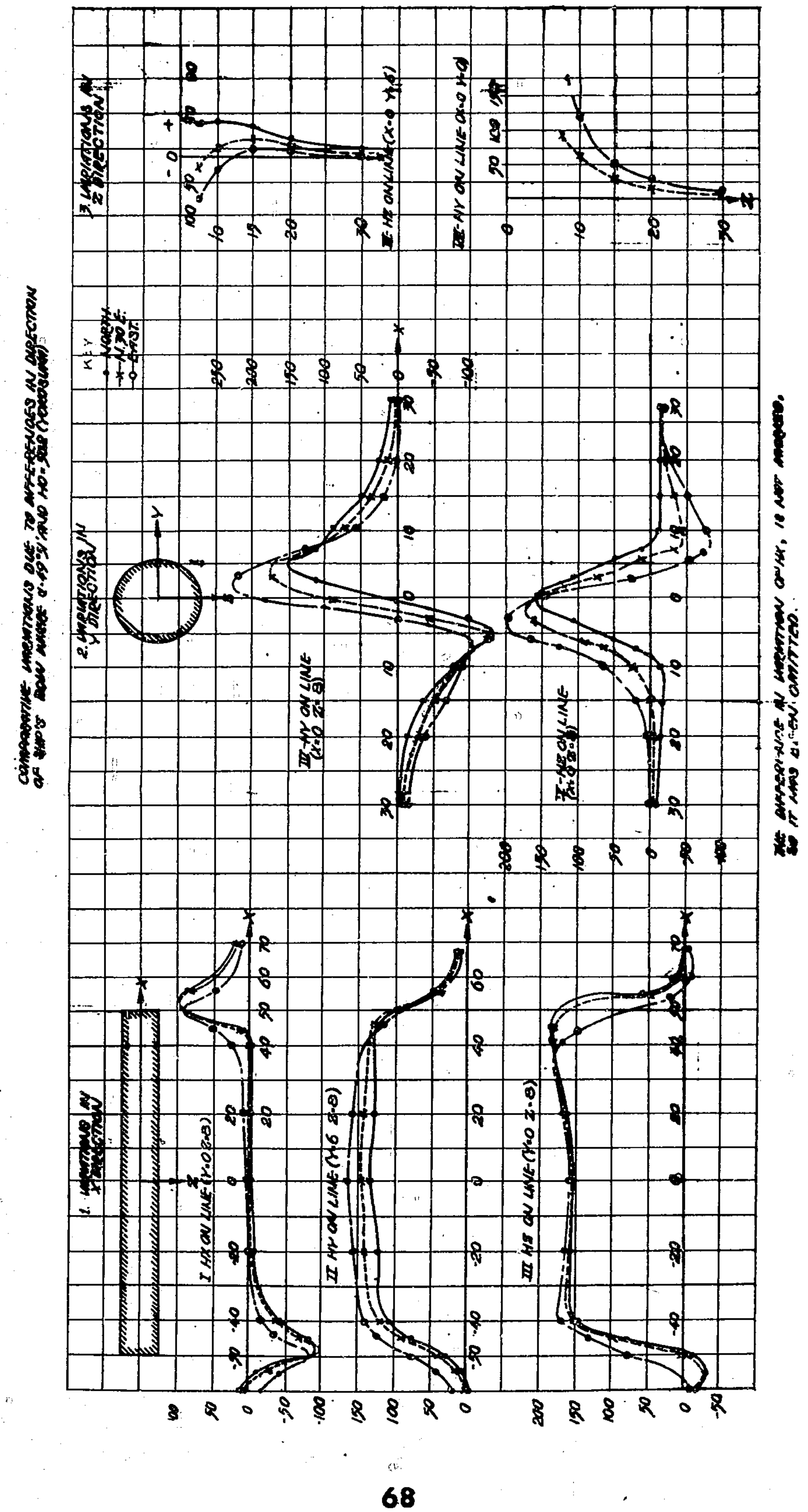

Figure 11(J)

ENCLOSURE (J), continued

COMPARISON OF SEPARATE AREAS

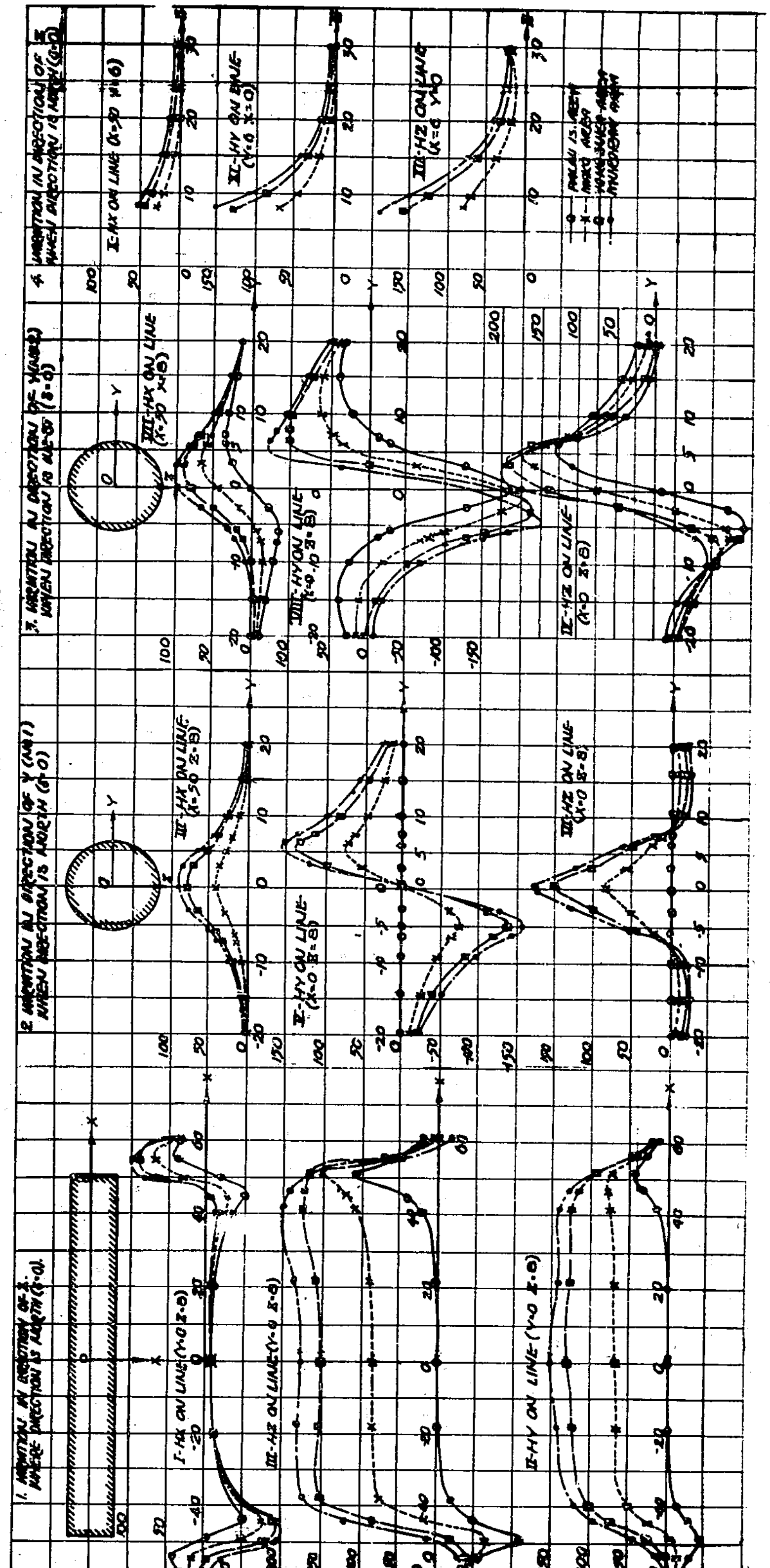

Figure 12(J)

ENCLOSURE (K)

LIST OF EQUIPMENT FORWARDED TO SCIENTIFIC DEPARTMENT, NAVAL ORDNANCE LABORATORY, WASHINGTON, D. C.

It is recommended that further study be made of Japanese measuring instruments for field and laboratory use. To this end, a sample of each of the following has been forwarded to the Scientific Department, Naval Ordnance Laboratory, Navy Yard, Washington, D. C:

NavTechJap Equipment No.	Item
JE50-1173	YZ Magnetometer
JE50-1174	Mitsubishi Type Magnetometer
JE50-1175	Experimental Type Recording Magnetometer