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

Subject: Target Report - Magnetic Development in Japan During World War II.

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

1. Subject report, covering Targets X-15 and X-34(N) of Fascicle X-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by the following U.S. Naval Technicians: Dr. R. M. Bozorth, Mr. F. T. Chesnut, Dr. G. W. Elmen, Mr. R. L. Sanford, and Mr. W. D. Williams; assisted by Ens. I. I. Morris, USNR, as interpreter and translator.

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MAGNETIC DEVELOPMENT IN JAPAN DURING WORLD WAR II

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE X-1, TARGET X-34(N)

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

MISCELLANEOUS TARGETS

MAGNETIC DEVELOPMENT IN JAPAN DURING WORLD WAR II

The subject of magnetism in Japan may be discussed under three headings: research, manufacture, and applications.

Research on new magnetic materials and magnetic phenomena was carried on in universities, and was not affected seriously by the war until many of the laboratories were destroyed by bombing. There was little co-operation with the Army and Navy. The research was influenced substantially by Japan's lack of nickel and cobalt, and led to the development of a new iron-aluminum alloy, Alfer, which was used in magnetostriction oscillators as a substitute for nickel. The Japanese also investigated the iron-nickel-silicon alloys and found one having low nickel content and high permeability. Studies of these alloys and of iron-silicon alloys of high purity have raised some interesting scientific problems regarding magnetostriction and superstructure.

The Japanese manufacture about twenty different magnetic materials, of which four are not made in America. These are Alfer, already referred to; Sendust, a high-permeability alloy of iron, silicon and aluminum; and two permanent magnet materials, NKS and OP, both of which were developed before the war. On the other hand, Japan manufactures only a small quantity of the high-nickel, high-permeability alloys used in quantity in the United States and does not make any of our best permanent magnet material, Alnico V. Their manufacturing processes are on a par with those used ten years ago in the United States and elsewhere. For example, silicon-iron transformer sheet is never processed by cold rolling.

One important new application of magnetic materials has been the use of Alfer in magnetostriction supersonic projectors and microphones. The NKS permanent magnet alloy and the high-permeability Sendust have been used in various kinds of apparatus in conventional ways. In the theory of the magnetic amplifier, they are far behind the United States and Germany. No evidence was found that the Japanese Navy ever received magnetic amplifiers from Germany or that they ever used them.

NavTechJap personnel interviewed about 60 individuals and visited 20 plants and institutions located between SENDAI, Honshu and FUKUOKA, Kyushu. In common with other investigators, the group found evidence of an amazing lack of co-ordination or even sympathy between military authorities and civilian scientists or manufacturers. Even when requested by military officials to undertake certain investigations, scientists were not sufficiently informed as to the ultimate objects to enable them to attack the problems in an intelligent manner, and consequently could not make important contributions to the war effort.

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LIST OF ENCLOSURES

LIST OF ILLUSTRATIONS

REFERENCES

Location of Targets:

Japanese Navy Ministry, TOKYO.
Tohoku Imperial University and Research Institute for Iron, Steel and Other Metals, SENDAI.
Tohoku Kinzoku, SENDAI.
Nippon Electric Co., Tokyo Office and Tamagawa Plant, TOKYO.
Tokyo Imperial University, TOKYO.
Tokyo University of Engineering, TOKYO.
Second Naval Technical Institute, TOKYO.
Nippon Electrolytic Iron Works, TOKYO.
Electrotechnical Laboratory, Board of Communications, TOKYO.
Nagoya Imperial University, NAGOYA.
Sumitomo Steel Works, OSAKA.
Suita Plant of Sumitomo Steel Works, SUITA.
Kawasaki Sheet Steel Works, KOBE.
Japanese Naval Base, KURE.
Kyushu Imperial University, FUKUOKA.
Nippon Iron and Steel Co., Yawata Works, YAWATA.
Aeronautical Research Institute, Tokyo Imperial University, Tokyo.
Mitsubishi Steel Works, TOKYO.
Institute of Physical and Chemical Research, TOKYO.
Furukawa Physico-Chemical Research Institute, TOKYO.

Japanese Personnel Interviewed:

As listed in Enclosure (I).

INTRODUCTION

In view of the fact that the Japanese had been particularly active in research and development in the field of magnetics before the war, and on the assumption that this activity had been continued during the war, an investigation was made with respect to research and manufacture, as well as the application of magnetic materials during the war for both industrial and military use.

In particular, information was desired regarding the used of magnetic amplifiers (transductors) which the Naval Technical Mission in Europe found had been used with great success by the Germans as power amplifiers for servo controls in fire control equipment. According to its report, the Germans sold some of these magnetic amplifiers to the Japanese Navy together with complete instructions and design information.

Leading Japanese scientists, various engineers engaged in the production and application of ferromagnetic materials, and officers and technical men in the military services were interrogated.

THE REPORT

Part I - MAGNETIC RESEARCH

A. GENERAL

The research discussed in this part of the report may be divided into three classes as follows:

1. Fundamental physical studies.
2. Investigation of new alloy systems.
3. Experimental engineering applications.

By far the most important location for fundamental studies is in SENDAI at the Research Institute for Iron, Steel and Other Metals, directed by K. HONDA. In the section devoted to magnetism there are three full professors, eight assistant professors and ten technical assistants, also about twenty non-technical men. The whole institute has a staff of about 200 and is part of the Tohoku Imperial University. During the war, professors and assistant professors were exempt from military duty, but did not effectively co-operate in the war effort. Consequently, their fundamental work on magnetic materials continued with little diminution until rather late in the war when most of the Institute was demolished by bombing.

Also at SENDAI are the Tohoku Metal Industries, Ltd., manufacturers of magnetic materials and tungsten products, and the Electrical Engineering Department of the University wherein some applications of magnetic materials have been studied.

Other important locations for magnetic research are Tokyo Imperial University at TOKYO, and Kyushu Imperial University at FUKUOKA. Work is carried on in several institutes in TOKYO.

The most important result in magnetism obtained in Japan during the war is probably the investigation and development of iron-aluminum alloys, and their use in magnetostriction projectors and microphones. Perhaps second in importance is the study of the iron-rich, iron-nickel-silicon system of alloys, some of which have high permeability and are susceptible to heat-treatment in a magnetic field.

Throughout Japan, it was found that universities and civilian institutes were rarely requested to do work for the Army or Navy, and that when they did so, the people performing the work were given only the necessary minimum number of facts, not enough to enable them to work intelligently. They were not told the purpose of the work or the use to which their results were put.

B. FUNDAMENTAL PHYSICAL STUDIES

A list of researches carried out during the war is given as Enclosure (A). It is believed that the most important results of physical research were obtained by the Sendai group under HONDA and MASUMOTO, and by KAYA and MIHARA in TOKYO.

Many of the researches are concerned with the accumulation of data on a variety of magnetic materials. Special emphasis seems to have been placed on magnetostriction and Young's Modulus, but measurements are also reported on thermal expansion, resistivity, and change of magnetization with stress, especially in relation to composition and heat treatment.

In the field of magnetostriction, it has been found that when aluminum is added to iron, the magnetostriction is increased until, at 13% aluminum, the change of length for saturation is 40×10^{-6}. It is interesting that the addition of a non-magnetic element to iron can have such an effect. The magnetostriction of magnetite, Fe_3O_4 has also been found to be large, 30 to 40×10^{-6}. In the Fe-Ni-Si and the Fe-Ni-Cu-Cr systems, on the other hand, the compositions of greatest interest are those having a magnetostriction approaching zero. They have the highest initial permeabilities, in accordance with accepted theory. YAMAMOTO has shown that this is also true for Sendust (Fe-Si-Al).

Another interesting matter uncovered by the Japanese is the occurrence of superstructure in the Fe-Ni-Si and Fe-Si-Al alloys (see NavTechJap Document No. ND50-5042, Enclosure G). This is associated with the low magnetostriction mentioned above, and one or both of these phenomena are believed to be responsible for the peculiar properties observed in alloys having a limited range of compositions. When annealed in a magnetic field, these alloys show the large changes in properties previously associated only with nickel-rich iron-nickel alloys. Both series of alloys show constancy of permeability with field strength after annealing for a long time at relatively low temperature (500°C).

Finally, special mention may be made of the investigation of iron-silicon alloys of high purity. For the first time, MIHARA has been able to make them respond markedly to heat treatment in a magnetic field. Peculiarly enough, he has found that the response is greatest for a field strength of 0.1 to 1.0 oersted, and is markedly less when the field is higher or lower. If this result is substantiated, it will require some revision of the theory of heat treatment.

C. INVESTIGATION OF ALLOY SYSTEMS

Systematic studies have been made of the magnetic properties of the following alloys:

Fe-Al .... (HONDA, NISHINA and others)
Fe-Ni-Si .... (YAMAMOTO, TAKEDA)
Fe-Ni-Cu-Cr .... (MIHARA)
Fe-Me-W .... (SHIRAKAWA)

The iron-aluminum alloys are important for their magnetostriction. One of them, Alfer (13% Al), was chosen for commercial production and was found useful in magnetostriction oscillators in Navy ordnance (see NavTechJap Document No. ND50-5041, Enclosure G). Its development was stimulated by the lack of nickel, for which it is a substitute. The maximum magnetostriction change in length is about equal to that of nickel but has the opposite sign (positive). Alloys containing a smaller amount of aluminum, about 3%, have been tried as a substitute for silicon-iron in transformer sheet but have not been used on a commercial scale.

The iron-nickel-silicon alloys (0 to 25 Ni, 0 to 20 Si), especially those in the neighborhood of 15 Ni, 12 Si(Senperm) have high permeability, respond to heat treatment in a magnetic field by showing hysteresis loops with steep sides, and upon prolonged heating at a relatively low temperature (about 500°C), show the perminvar characteristics of constant permeability and constricted hysteresis loop (See NavTechJap Document No. ND50-5040, Enclosure G). These properties are believed to be associated with the formation of superstructure, and X-ray examination indicates that there are two phases present after annealing and slow cooling.

In a separate study of silicon-iron alloys, MIHARA has found that pure specimens, prepared from specially purified iron and silicon, respond to heat treatment in a magnetic field (See NavTechJap Document No. ND50-5047). Such an alloy containing 5.1% silicon, heat treated in a field of 1.0 oersted, has a maximum permeability of over 200,000 and a coercive of force 0.06.

The effect of cold rolling on the magnetic properties of silicon-iron alloys of commercial purity was studied in detail in a joint project of the Nippon Iron and Steel Manufacturing Company and Prof. KAYA of Tokyo Imperial University (See NavTechJap Document No. ND50-5045). The ultimate objective was to improve the quality of transformer sheet. In all, about 3,000 specimens were rolled at the company's Yawata plant and tested in TOKYO. The material contained about 3.2% Si and was cold rolled with a reduction of 50, 60, 70, or 80%. The temperature of annealing was varied up to 1300°C, and the annealing was accomplished in an atmosphere of air or hydrogen, or in vacuo. Measurements were made of permeability, coercive force, hysteresis loss, and magnetostriction in different directions in the sheet, the crystal orientations were determined by X-rays. Best results were obtained with cold reductions of 80% and subsequent annealing for five minutes in air at 900°C, then for one hour in hydrogen at 1000°C, and finally for one-half hour in a vacuum at 1300°C. The material so treated had the following properties:

Initial permeability	1200
Maximum permeability	18000
Coercive force	0.23
Hysteresis loss: 10,000 B_m	0.50
(w/kg at 50 cyc) 15,000 B_m	1.10
Field strength for 15,000 B	7.0

The X-ray tests showed that the crystals were orientated with a 100 direction parallel to the rolling direction and a 110 plane parallel to the plane of the sheet. Permeability was highest when measured parallel to the direction of rolling. Magnetostriction (Joule effect) was greatest in the cross-direction. No commercial application has been made of the results of these experiments.

MIHARA studied an extensive series of alloys containing iron, nickel, equal proportions of copper and chromium, and 2% manganese (See NavTechJap Document No. ND50-5046). They cover the range of 40 to 100% Ni, 0 to 30% of Cu plus Cr. Specimens were subjected to various heat treatments and measurements were made of saturation magnetization, initial and maximum permeabilities, coercive force, hysteresis loss, change of resistivity and Young's Modulus with magnetization, and magnetostriction. High initial permeability (about 20,000) and zero magnetostriction are found near the composition 12 Fe, 78.5 Ni, 3.5 Cu, 3.5 Cr, 2 Mn. This alloy, known as Furukawa Magnetic Alloy, was chosen for commercial exploitation and its manufacture and commercial properties are described below.

The system iron-molybdenum-tungsten is age-hardenable and the alloys may be used as permanent magnets. SHIRAKAWA reported that in the alloy containing 10% Mo and 20% W, the highest energy product is 0.87 x 10^6, the coercive force, 290, and the residual induction, 8,500. As far as is known, this alloy is not made commercially.

Investigations have also been made of some of the properties of other ferromagnetic alloy series, these include:

Fe-Pt	Thermal expansion
Fe-Co	Young's Modulus, density
Fe-Ni	Young's Modulus
Fe-Si	Magnetostriction, permeability
Co-Ni	Density
Ni-Cu	Young's Modulus, thermal expansion
Fe-Ni-Cu	Magnetic recording of speech
Fe-Co-Ni	Barkhausen effect
Fe-Si-Al	Magnetostriction, superlattice
Fe-Co-Cr	Temperature coefficient of Young's Modulus

D. EXPERIMENTAL ENGINEERING APPLICATIONS

This heading refers mainly to the theory of the use of magnetic material in magnetostriction projectors and microphones. In a series of articles, the factor of merit of a material for these applications has been derived theoretically, and the appropriate constants of various materials determined experimentally. These considerations are basic for design.

Probably the most important constant for this application is the susceptibil' multiplied by the change in stress produced by the application of a field. Constants were determined for nickel, Alfer, and some other alloys. In the following table, the constants of several materials are given together with the steady polarizing field (in oersteds) used for attaining the maximum value of the constant.

Table I
MAGNETOSTRICTION CONSTANTS OF SOME MATERIALS

Material	Constant*	Field
Ni	0.57	10
NF (4 Al, 2 Si)	0.29	2
NC (50 Ni)	0.81	7

*Unit, 10^6 dynes/cm^2 oersted.

Part II - MATERIALS

A. PERMANENT MAGNET MATERIALS

Although no new permanent magnet materials were developed by the Japanese during the war, information regarding commercial practice in the production of the older permanent magnet materials was obtained, some of which is not given in publications. For the sake of completeness this information is given below.

1. KS and New KS

Production in tons per year by the Sumitomo Steel Works at their Suita Plant, near OSAKA, is given in the following table:

Table II
PRODUCTION IN METRIC TONS PER YEAR OF KS AND NEW KS

Year	1941	1942	1943	1944	1945
KS	70	46	44	20	2
New KS	47	62	134	237	74
Soft Iron (pole pieces)			21	52	12

Compositions were given as follows:

KS

Co 35
W 6
Cr 3
C 0.8
Fe .... Balance

New KS

Al 12
Ti 3
Ni 25
Fe .... Balance

a. Production of KS

(1) Melting: melted in a high-frequency induction furnace in the following steps:

(a) Co, Fe, and W are charged and melted.

(b) Ferromanganese and ferrosilicon are then added as deoxidizers (0.4 Mn, 0.2 Si).

(c) Ferrochromium is added (and melted).

(d) Melt held about 5 min. at 1450°C.

(e) Melt is poured, either into iron molds to make ingots or is cast in sand molds to the final form.

(2) Forging: Ingots are soaked two to three hours at 1100°C and then forged. Bars vary in thickness from 3 to 10mm. If the temperature drops to 900°C, ingots are reheated before continuing forging. The material can be drawn into wire 1mm in diameter.

(3) Forming: Magnets are formed from bars at a temperature somewhat above 900°C.

(4) Heat Treatment: Magnets, either forged or cast, are quenched in oil from 970°C and aged for 10 hours at 100°C.

(5) Magnetization: Magnetization is done either by an electromagnet or an ignitron magnetizer.

(6) Magnetic properties: Br = 1000, Hc = 250, and (BH)m = 1.0×10^6.

b. Production of New KS

(1) The melting practice is the same as for KS except that Ti is added last in the form of ferrotitanium. (Since the aluminum content is high, it is not so critical as the titanium.) The furnace lining is basic, as Ti is hard on acid linings.

(2) New KS cannot be forged, but is cast to final form in sand molds. The pouring temperature is 1250°C. Magnets are finished by grinding.

(3) The cast magnets are annealed (age hardened) two to three hours at 600°C. A more uniform product could be obtained by an initial quench, but this is "not economical" and is not done in practice. (Ferrotitanium is produced from "sand iron" which contains 8 to 12% Ti. The ferrotitanium has about 25% Ti.)

(4) Magnetic properties: Br = 5000, Hc = 500. In the laboratory, Br = 8000, and Hc = 650 have been obtained.

2. MK ALLOYS

a. Characteristics: These alloys, as produced commercially, have the compositions and magnetic properties shown in the following table:

Table III
COMPOSITION AND PROPERTIES OF MK ALLOYS

Type	Ni	Al	Co	Cu	Fe	Br	Hc
I	24	13	3	4	Bal.	(6000 (6500	450
II	22.5	11	1.5	2	Bal.	(7500 (6500	350
III	26	10	1.5 to 3.0		Bal.	7500	350
IV	26	13	6.5	3	Bal.	5500	550

Dr. MISHIMA said that he had experimented with various elements, in addition to Ni, Al, and Co, such as Mo, W, Mn, and Si, but had found that Cu is best. He also said that MK is made only by the Mitsubishi Steel Works in TOKYO.

b. Melting practice: Alloys are melted in high-frequency induction furnaces, 150 KVA, 150 kilograms in a heat. The furnace is lined with 90% magnesia (dead burned) mixed with silica or alumina. Flux is always used (CaO about 2 to 3% by weight). The procedure is as follows:

(1) Charge the nickel, usually electrolytic but sometimes mond.

(2) Add proper amount of Co (usually from Belgium).

(3) Add the iron in the form of very low carbon steel (about 0.1% C).

(4) Add scrap magnets of the same composition. The scrap constitutes from 40 to 60% of the total charge.

(5) Heat until all is melted. The melting time starting with a cold furnace is about two hours. Subsequent heatings take about 1½ hours.

(6) Add aluminum allowing about 5% of the aluminum content to account for the loss on heating. The charge is mixed by the inherent vortex action in the furnace.

(7) Take a test sample, and cast in a sand mold to make a specimen 10cm long and 1cm in diameter and test with magnetometer.

(8) If the properties of the test piece are not satisfactory, adjust the composition by adding small quantities of aluminum or nickel until the proper values are obtained. Dependance is placed primarily on aluminum content.

(9) When satisfactory properties are obtained, cast in a mold to the desired shape. Sand molds are used for Types I, II and IV. Type III is cast in a steel mold.

The cooling rate is controlled by the pouring temperature and temperature of the mold. The pouring temperature is not measured, but is judged by eye.

c. Heat treatment: In practice, magnets are annealed one hour at 650°C. In the laboratory, it has been found that from 5 to 10% better results are obtained by a preliminary quench in water from 1200 to 1300°C, but this is not done commercially. In the laboratory, the best properties obtained are Hc = 700, Br = 4500 to 5000. Photomicrographs show that after quenching the structure is homogeneous, but after annealing, there is evidence of a slight amount of precipitation of the alpha-prime phase from the alpha phase.

3. OP Magnets

As described by Prof. T. TAKEI, who with Prof. KATO developed the sintered oxide type of magnets called OP, the manufacturing procedure is as follows:

a. Material used: The materials used are natural Fe_2O_3 (the ore limonite), and cobalt oxide CoO (obtained before the war from the United States, later from mines near OSAKA). These are crushed to 100 mesh or finer and mixed in the ratio of 2.5 molecular weights of Fe_2O_3 (400 parts by weight) to one of CoO (75 parts by weight). This is pressed into a block at two tons per square inch and heated in air from one to two hours at 800°C. At this time, one molecular weight of Fe_2O_3 combines with one of CoO to form cobalt ferrite $CoFe_2O_4$.

The material is crushed again to powder (about 100 mesh) and pressed to the desired final form, then heated three minutes in vacuum (1mm) at 1000°C. It is taken from the furnace and placed immediately between the poles of an electromagnet excited by alternating current giving a field of 3000 oersteds. During the heating, the Fe_2O_3 not already converted to ferrite is said to be reduced to Fe_3O_4. The final composition is then 50% $CoFe_2O_4$, 50% Fe_3O_4. There is a shrinkage of about 10% during this process. OP was produced only by the Mitsubishi plant near YOKOHAMA, now bombed out.

b. Magnetic properties: As regularly produced, the material has a coercive force of about 1000 oersteds and a residual induction of 2500 gausses. A field strength of 5000 oersteds is used for magnetization. A residual induction of 3000 gausses has been obtained experimentally. The electrical resistivity is high but no value was given.

c. Applications: OP magnets are used in magnetic chucks, magnetic ore separators, telephone receivers, loud speakers for airplanes, bicycle lamp generators, etc., all made by Mitsubishi at OFUNA.

4. Molybdenum Magnet Alloy

This is a Koster-type alloy containing 20 to 24% Mo, 1.5% Cr, 1% Sn, and the balance, Fe (no cobalt). It is difficult to make, partly because carbon, which must be kept low, is present in the molybdenum. After casting, the magnets are heated to 1200 - 1300°C in salt bath (barium chloride and boric acid) and then quenched in oil at room temperature. They are then baked for three hours at 600°C. The coercive force is 240 and the residual induction is 8000.

5. Senalloy (copper-nickel-iron alloy)

The Tohoku Kinzoku Co., in SENDAI, makes an alloy especially for recording tape and wire. Its composition is briefly mentioned in the October 1940 issue of the "Japan Nickel Review (NavTechJap Document No. ND50-5043, p.260) as ranging from 20-50% Fe, 15-55% Ni and 15-55% Cu. A typical example was given as 40% Fe, 40% Cu, and 20% Ni. Other compositions reported were 30% Fe, 30% Cu, and 40% Ni; and 60% Cu, 20% Ni, and 20% Fe.

An alloy similar to the last composition listed is made in the United States and called "Cunife". In some instances, the wire is hard drawn from 6mm diameter to 0.3mm.

B. CORE MATERIALS

1. Alfer (Alfero) (AF)

Alfer, an alloy containing 13% aluminum, and the balance, iron, was developed by Drs. K. HONDA, and H. MASUMOTO, and associates, at Tohoku Imperial University, as a substitute for pure nickel for use in magnetostrictive devices. Research work tending toward improved production efficiency was done by the Second Naval Technical Institute in TOKYO which dictated the production method (not always followed) to the Tohoku Kinzoku, SHIBAURA (Tamagawa Works) and Oki Denki companies, which made the ingots.

The alloy was quite successful and it is reported that some 400-800 tons per year of finished sheet were made in 1943 and 1944.

The alloy is reported in a paper dated 1944, entitled "The Magnetostriction of Iron-Aluminum Alloys and a New Alloy 'Alfer'," (NavTechJap Document No. ND50-5041).

The aluminum content of Alfer was said to be 10-14%, but the only alloy apparently made under that name was of the following analysis:

Al	13%
Fe	Balance

Impurities less than:

C	0.08%
Si	0.3%
Mn	0.4%
P and S	0.05%

Alfer is not to be confused with Alperm, the high-permeability alloy containing 14-16% aluminum; or with B.S., the 3% aluminum alloy made from the Alfer scrap as a substitute for the "B"-class silicon steels (3% Si).

Alfer is melted in basic high-frequency furnaces of 100-300 kg capacity. The iron is melted quickly at full power and carried under a calcium slag to 1600°C at which temperature it is held for 10-15 minutes. For best results, the iron should contain a minimum of hydrogen and oxygen. The bath is slagged off and deoxidized with ferrosilicon or magnesium while being held at low power. Power is then increased to full and the aluminum, in rod form, is fed into the bath gradually. Bath temperature during this period is maintained at about 1530°C. The melt is then poured into a ladle and cast at 1500°C in 6" x 6" cast iron molds holding approximately 50 kg of metal. Bar samples, about four inches long and 5mm in diameter, are taken between two ingot pours for magnetic testing.

At the Second Naval Technical Institute, it was said that the best ingots were obtained if the metal was "coat cast" through a liquid slag comprising 40% CaO, 40% Al_2O_3 and SiO_2, and 20% CaF. At the Shibaura plant, however, it was said that the slag was cleared before pouring.

The ingots are hot rolled at 1000-900°C to about a 1-1½" thickness, after which they are reheated to 1100°C and rolled to 12mm. They are then sent to the Osaka Zosen Co., at TSURUMI, where they are hot rolled to 0.3mm thickness, first in packs of two sheets, then four and finally, eight sheets.

The net yield of finished sheets is said to be only 30-40% of the material charged into the furnaces, with losses as follows:

In ingot making .... 10% +
In hot rolling .... 20% +
In finishing process .... 30% +

After laminations are stamped from the finished Alfer sheets, they are annealed for three hours at 950°C in air. They are then coated with a bakelite or other varnish.

The specific resistance of Alfer is said to be three to four times as high as that of pure nickel. Its initial permeability is said to be from 70-80 and its magnetostrictive constants 0.3 to 0.4 x 10^6 dynes/cm^2 oersted and 35 to 40 x 10^{-6} cms/cm.

2. Alperm

Alperm, an alloy containing from 14 to 16% aluminum, and the balance, iron, was developed about 1942 by Dr. H. MASUMOTO of Tohoku Imperial University, in an attempt to find a substitute for the more critical permalloy used in the cores of transformers for communication apparatus. Being very brittle and hard to roll or punch, the alloy was not a commercial success and only a small quantity was made.

The analysis found to be best was:

Al 16%
Fe .... Balance
(electrolytic iron)

The ingot material was made by the Tohoku Kinzohu and Shibaura (Tamagawa) companies. The metal was rolled by Osaka Zosen, at TSURUMI, and finish annealing and stamping was done at the Tohoku or Tamagawa plants. The melting was done in basic high-frequency furnaces.

The sheets were annealed for one hour in air at 900°C and then air or water quenched at 650° to 400°C; 650°C was said to give the best results.

Initial permeability was said to be from 1000 to 3100 and maximum permeability from 20,000 to 50,000.

3. B.S. Alloy

B.S. Alloy is an alloy containing 3% aluminum, the balance, iron. It has about the same properties as 3% silicon ("B" class) steel and was developed to find a use for the punched scrap resulting from the making of Alfer laminations. It has not been used to any great extent, only 10 tons having been made for experimental applications.

The alloy is made in the high-frequency furnace by first melting pure iron to form 60% of the melt, and then adding the AF scrap to form the balance of the melt.

Magnetic properties were not given.

4. 30% Nickel Alloy

This alloy having a composition of 30% Ni, 0.5% each of Mn and Si, and the balance Fe, is used for temperature compensation of permanent magnets over the range from 60-80°C. At 0°C, its permeability is 15. Permeability is linear with temperature to about one at 80°C. Variation is plus or minus 10%. It was made by the Nippon Electrolytic Iron Works in TOKYO.

5. Superpermalloy

Superpermalloy is a high-nickel alloy having high initial and maximum permeabilities. It was made in Japan by the Nippon Electrolytic Iron Works in TOKYO and also by the Tohoku Kinzoku at SENDAI. Because of the critical shortage of nickel, very small amounts were made. The Iron Works, for instance, made but one or two tons per year. The material was used mostly for shielding meters or war instruments.

The composition is 80% Ni, 2.5% Cr, 0.5 to 0.2% Sn, 0.5% Mn, 1.0% Si and the balance, Fe. The alloy was melted in 300 and 500 kg basic high-frequency induction furnaces powered with 300 kw.

After fabrication, the material was annealed in a closed container in air at 1000°C and cooled slowly. Some experimental annealing was done in hydrogen at the same temperature.

Specific resistance was reported as 65-70 microhms/cm^3. Permiability was said to be 20,000 initial and 50,000 maximum.

6. NC Alloy

This alloy is similar to 45 permalloy made in the United States. It was made by the Nippon Electrolytic Iron Works in TOKYO to the extent of two to three tons annually, and was used largely for radio transformers.

The composition of NC alloy is 45% Ni, 0.5 to 0.2% Sn, 0.5% Mn, 1.0% Si and the balance, Fe. It was processed and annealed in the same manner as superpermalloy.

Resistivity is 60-65 microhms/cm^3. Permeability is 4000 initial and 50,000 maximum.

7. Japanese Nicalloy

This material, made by the Nippon Electrolytic Iron Works, has an analysis of 40% Ni and 60% Fe. It was used by Mr. S. OKADA of the Electrotechnical Laboratory, Board of Communications, as a core material for magnetic amplifier research. It was said to be superior to ordinary silicon steel transformer sheet, but inferior to permalloy (78% Ni) which was unavailable. Japanese nicalloy cores gave amplifications of 60 as compared with six to eight for the silicon steel cores.

This alloy does not have just the same composition as the nicalloy made in the United States.

8. Sendust

This material, developed as a substitute for high-permeability Ni-Fe alloys, was described by H. MASUMOTO in "Sci. Rep. Tohoku Imperial University (SENDAI) Anniversary Vol. (1936)", p.388. It has the composition 5 ± 0.3 Al, 10 ± 0.3 Si, the balance, Fe, and is melted in a high-frequency induction furnace.

a. Manufacturing process:

(1) Melted and cast.

(2) Crushed to coarse lumps and annealed three hours at 1000°C and cooled slowly.

(3) Crushed again and graded by screen. Finer than 300 mesh used for r.f. cores, 300 to 200 mesh used for other purposes.

(4) Dust heated two hours at 900°C in vacuum and then small amount of air admitted to form an insulating oxide on the particles.

(5) Cooled and mixed with water glass and boric acid and dried until plastic.

(6) Pressed in molds and baked an hour at 600°C. The pressure used in molding determines the magnetic permeability; eight tons/cm^2 gives a permeability of about 80. Cores of this value are used for voice frequencies. For carrier frequencies, permeability is 20 or 50. It is also pressed into hollow plugs for radio frequency cores. Permeability of these cores is from two to three. Sendust is also used for magnetic shielding in cast form.

9. Magnetic Oxide Loading-Coil Cores

Various combinations of oxides have been tried for the cores of loading coils, including copper ferrite and cobalt ferrite. For frequencies of 10^7 cycles a Q of 250 and permeability of three to five were obtained with cobalt ferrite. At lower frequencies, such as 10,000 cycles, copper ferrite mixed with 20 to 25% of zinc oxide gave permeabilities of 50 to 70. Fe_2O_3 was also used. The cores were formed under pressure and heated to 1000°C. The cores were produced only in one small plant of the Tokyo Electrochemical Co. in Northwest HONSHU.

10. N.F. Alloy

N.F. is an alloy developed by Prof. NUKIYAMA of the Tohoku Imperial University at SENDAI. Its composition is 4% Al, 2% Si, the balance, Fe. It is still in the experimental stage. N.F. is said to have sufficient residual magnetism to operate a receiver for underwater sound waves, without D.C. polarization, thus reducing "noise" due to unsteady D.C. The alloy is not good for transmitting underwater sound waves.

11. TM3 (TM1) (TM2)

These alloys were interesting because cores of the magnetic amplifiers tested by Prof. HARADA of Kyushu Imperial University were made of TM3 and plain silicon steel.

The analysis of TM3 is 76% Ni, 4% Cu, 3 to 4% Mo and the balance, Fe. Its initial permeability is 10,000 to 20,000. Analysis of TM1 is 50% Ni and 50% Fe, and of TM2 78% Ni and 22% Fe.

These alloys are now being made in experimental melts on a commercial scale, by the Tohoku Kinzoku K.K. at SENDAI.

12. Electrolytic Iron

The Nippon Electrolytic Iron Works in TOKYO produced some 20 tons per month of electrolytic iron which was used for making special alloys and for pole pieces for electromagnets, etc. Late in the war, the plant was moved to FUKUSHIMA on the road to SENDAI.

The process used was to rotate a tin cathode, with wipers, in a wooden tub containing scrap iron as the anode, and a solution of ammonium sulphate and sulphuric acid as the electrolyte. The ph of the electrolyte was between five and six, and the temperature 50-60°C. The curved sheet of deposited iron was stripped from the cathode and was said to be soft and flexible.

The analysis of the iron obtained was given as 99.98% Fe, 0.001% P, 0.001% S, 0.001% C with a trace of Mn and Si.

For an H of 10 oersteds, the induction was said to be 20,000 gausses.

13. Silicon Steel

All the 4% silicon steel used for electrical purposes in Japan is made by the Yawata plant of the Nippon Iron and Steel Co. (total production of all steels at Yawata in 1938 was said to be 2,000,000 tons), and by the Kobe plant of the Kawasaki Steel Mfg. Co. Of the total, Yawata makes about 60%, Kawasaki about 40%. Production by Yawata was 40,000 tons in 1938 and 20,000 tons in 1944. Kawasaki made 1150 tons in 1931, 23,000 tons in 1939 and 9,000 tons in 1942. Both companies made small amounts of 3%, 2% and 1% silicon steel. The Nippon Iron and Steel Co. covers an area of some 6,200 acres, 2,700 of which are at Yawata, and regularly employs 18,000 men (10,000 at Yawata). During the war, there were 80,000 employees, 47,000 of whom were at YAWATA.

The following discussion deals with the 4% silicon steel.

In both companies the metal is melted in arc furnaces of from 10 to 17 ton capacity, and only scrap iron is used as a base. Since the treatment of the melt and rolling varies somewhat, the procedures as reported at Yawata (see NavTechJap Document No. ND50-4044), and at Kawasaki will be treated separately.

For a typical melt at the Yawata plant, the furnace lining is repaired from the previous heat and 200 kg of lime and 17,000 kg of carbon steel, plate or cogging scrap, are fed in. The charge is melted and heated to 1600°C and a test is made. Carbon content at this point is about 0.08%. The bath is then slagged off and 100 kg of iron ore and 150 kg of lime are added. Temperature is raised to 1620°C and a second test shows the carbon content to be about 0.04 to 0.05%. The slag is again raked off and a new slag of 350 kg lime, 125 kg crushed ferrosilicon (75% silicon), 35 kg fluorspar, and 20 kg sand, is added. At a temperature of 1645°C, the slag is yellowish white and a third test shows the metal to contain about 0.06% C. The slag is again partically raked off and 950 kg of (75% Si) ferrosilicon is added. The bath is stirred, temperature raised to 1660°C, 17 kg of aluminum added, and the charge is tapped. Power consumption is 550 KWH per ton. Five ingots are made, each having a 60 sq. cm. cross section and weighing 3400 kg. Melts are poured at about five hour intervals.

The ingots are soaked at 1180°C and rolled first to 21cm square, then to 1.1 by 25cm, without reheating. The plates are annealed at 1150°C in a mixed gas atmosphere and are reduced to 3.1mm. These are again annealed at 950°C and pack rolled (8 sheets maximum) to 0.35mm or final thickness. Hot rolling is accomplished with 25 inch rolls. The sheets are cold rolled slightly to straighten and separate them, and are annealed for 2.5 hours at 830°C to develop their magnetic properties. They are finally straightened again by passing between a series of five rolls. Specimens are tested for magnetic quality, before the last straightening, by the differential Epstein method, using a watt meter and fluxmeter.

A typical ladle analysis of the metal is 0.06% C, 4.10% Si, 0.20% Mn, 0.02% P, 0.1% S and the balance, Fe.

The finished sheet (0.35mm) containing 4 to 4.5% silicon has a loss of 1.2 to 1.5 watts per kg measured at 10,000 gausses and for 50-cycle alternating current. It is separated into four grades, depending upon quality.

The thinnest material normally manufactured is 0.2mm thick but some 0.1mm sheet was made experimentally. Data on permeability were not available.

The Yawata plant experimented with cold rolling of silicon steel sheet, and in collaboration with Prof. KAYA in TOKYO, obtained best results with reductions of 80% and subsequent annealing in air for five minutes at 900°C, then for one hour in hydrogen at 1000°C, and finally in a vacuum for one-half hour at 1300°C. These tests and the resulting magnetic characteristics obtained have been discussed in the section of this report dealing with research.

At the Kawasaki plant, manganese ore is added to the scrap before melting and a good grade of iron ore is added after melting. The slag contains about 45% lime, 15% iron oxide, and 25% silica. The slag is removed during the reducing period, and then lime and coke are added. Half of the silicon is added in the furnace, as ferrosilicon, and half in the ladle. Aluminum is added in the same way. The charge is poured when the gas content, as judged by eye, is sufficiently low.

The ingots at the Kawasaki plant are 23 square cm in section and weigh 900 kg. They are heated to 1100°C and hot rolled to 6mm. They are then reheated to 980°C and are pack rolled (8 sheets maximum) to final thickness (0.35mm). Some special sheet was rolled to 0.05mm for Sumitomo Tsushin in TOKYO.

A representative analysis of the KAWASAKI product is as follows:

C	0.06%
Si	3.9 to 4.2%
Mn	0.10%
P and S	0.02%
Cu	0.10%
Ni	0.25%
Fe	Balance

Magnetic properties were reported as follows:

H	5	10	25	50	100	300
B	12,000	13,300	14,000	15,000	16,000	18,000

Electrical loss at 10,000 gausses with 50-cycle alternating current was said to be 1.375 watts per kg for the 0.35mm sheet.

14. Senperm

This alloy, having a composition of approximately 16% Ni, 10% Si, and the balance, Fe, was developed by Dr. YAMAMOTO at Tohoku Imperial University. It is peculiar in that it is in the Fe-Ni-Si class but has magnetic characteristics like those of the Fe-Co-Ni, or perminvar, alloys. It has a temperature coefficient which is small and which is said to be less than that of Sendust. Maximum permeabilities as high as 36,000 were obtained by heat treating in a magnetic field.

This alloy has been referred to in the section of this report dealing with research, and is described in a doctor's thesis by T. YAMAMOTO (See NavTechJap Document No. ND50-5040). It is neither produced nor used commercially.

15. Furukawa Magnetic Alloy

The Furukawa Electric Co. made from 30 to 50 tons of a high-nickel alloy for use in commercial transformers for audio-frequency applications. The alloy was developed at Furukawa Institute by Dr. MIHARA.

The analysis was 78.5% Ni, 3.5% Cr, 3.5% Cu, 2.0% Mn and the balance, Fe. It was melted in 12 kg lots in the high-frequency induction furnace. Mond nickel and electrolytic iron were used.

Ingots were forged to 20mm and hot rolled to 5mm. They were cold rolled to 1.5mm, annealed at 900-1000°C, and again cold rolled to 0.3mm without further annealing. To prevent oxidation, punchings of the 0.3mm stock were pack-annealed in pots at 1000°C, sometimes in a hydrogen atmosphere. They were reheated to 500°C and cooled by a fan.

When it was desired to use the material for 100,000 cycle transmission, it was rolled to a thickness of 0.05mm. This required many passes in a rolling mill having four-inch rolls.

Table IV
COMMERCIAL PRODUCTION OF MAGNETIC MATERIALS IN JAPAN
(Approximate Maximum Yearly Output in Long Tons)

Material	Output	Material	Output
Silicon Iron	60,000	KS	100
Alfer	500	New KS	250
Sendust	—	MK	—
High-Nickel Alloys	50	OP	10

Part III - APPLICATIONS

A. MAGNETIC AMPLIFIER

The magnetic amplifier, or transductor as it is also called, has been developed and used in the United States and in Germany. In Germany, it was used primarily in fire control circuits for large guns on naval ships. It was thought that it was used also by the Japanese Navy, either with its own or a German design. The investigation of this subject was of special interest and a considerable amount of time and effect was spent in following all possible leads.

It was apparent that no magnetic amplifier had been used by the Japanese Navy. There was some evidence that the Japanese Navy had negotiated with Germany regarding the magnetic amplifier. Comdr. S. ABE stated that he understood the Germans had been requested to supply a sample amplifier and design data and that the Germans had agreed to this, provided the Japanese Government paid ¥10,000,000. Later this statement was denied by ABE and no further information on the transaction could be obtained.

Regarding the experimental work on magnetic amplifiers, it was found that work had been carried on at three places, the Tamagawa Plant of the Nippon Electric Co., the Electrotechnical Laboratory of the Board of Communications, and the Kyushu Imperial University.

1. Work at the Tamagawa Plant:

The work done in the laboratory of this plant was started for the purpose of determining if a magnetic amplifier could be used in place of a three-stage vacuum tube amplifier. The cores were permalloy "C", built up from laminations 0.2mm thick. It was stated that one and two stages of vacuum tube amplification could be replaced by the magnetic amplifier. More amplification was obtained by tuning the output circuit to resonate at a certain frequency. No data were available. The difficult with this amplifier was claimed to be due to the fact that no source of 50-cycle power was found to be stable enough to make the amplifier a success. Amplifications of 10,000 were claimed but there is some doubt about this figure.

2. Work at the Electrotechnical Laboratory:

Dr. OKADA of this laboratory had worked on the magnetic amplifier. The work was first undertaken for the purpose of developing relays for automatic telephone circuits. Later Dr. OKADA was requested by Rear Admiral T. MIYAZAWA to cooperate with the Second Naval Technical Institute. The work did not progress beyond the experimental stage. The cores used were silicon steel and Japanese nicalloy made by Nippon Electrolytic Iron Works. OKADA stated that permalloy (78% Ni) would have been better, but was not available. However, the sample which he submitted had a core of American-made permalloy. The amplifier circuits used are shown in Figure 1. No practical application has been made.

The current amplification obtained when the core was silicon steel was from six to eight. To improve the amplification, three stages were tried. Theoretically, the amplification should be 216, but the amplification obtained was lower, about 200. Four stages were tried, but did not work. With Nicalloy cores and one stage, the amplification was about 60.

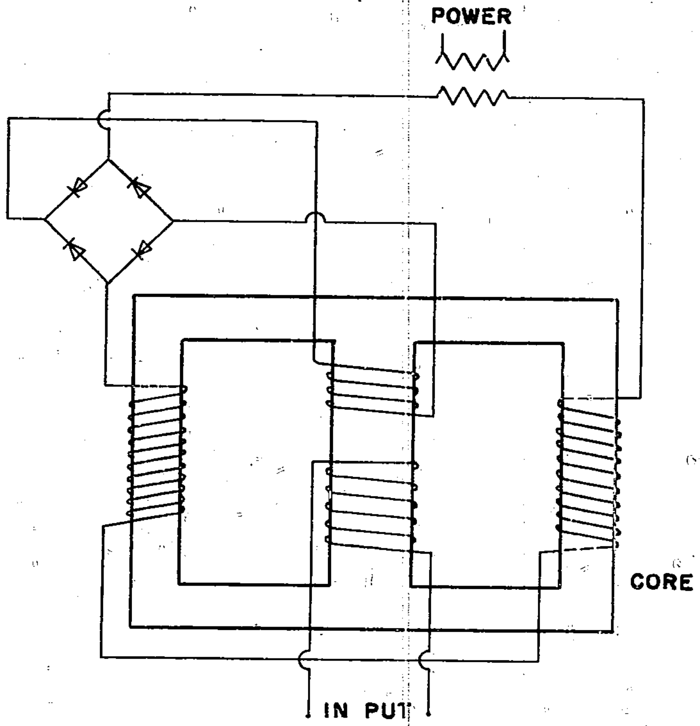


Figure 1
AMPLIFIER CIRCUITS

Work on magnetic amplifiers was carried on by Prof. K. HARADA, of the Electrical Engineering Department, Kyushu Imperial University. He started work on the magnetic amplfier about 1940 without knowledge of any previous work on the subject. He later learned of the work of Geyger in Germany. During the war he was requested by T. OSAKI of the Naval Technical Laboratory, TOKYO, to do further work, but he was not told what use would be made of the results. A report of the work on the amplifier was privately printed in September, 1944. Enclosure (B) is a translation of this report. A report was also made to the Navy in October, 1942. A number of reports not printed, and laboratory notes, were inspected. Enclosure (C) is a summary of those relating primarily to modifications of the amplifier for special uses.

B. UNDERGROUND VIBRATORS AND RECEIVERS

The magnetostrictive alloy, Alfer, was developed to replace nickel for the cores of such apparatus.

For this purpose, three types of punchings were used. Two of these were rectangular and the third was a ring type. The punchings are stacked into cores of proper dimensions and wound with 40 to 50 turns of wire. They are designed for 14 to 16 kc per second. The input is 40 to 50 watts but in practice as much as 2 kw may be used. The design generally provides for 2 to 3 watts/cm^2 of vibrating surface for intermittent use or 0.3 watts/cm^2 for continuous operation.

For the ring type, a conical reflector is used consisting of two cones of brass separated by sponge rubber.

The core is polarized with a steady field of several oersteds. As used, the effective initial permeability is from 70 to 80. The magnetostriction is 0.3 to 0.4 x 10^6 dynes/cm^2 oersted.

The same apparatus is used for receiving with tube amplification of 100 to 130 db. Two coil units are sometimes connected in series for transmitting, and in parallel for receiving.

ENCLOSURE (A)

LIST OF TITLES OF RESEARCH PROJECTS
CARRIED OUT SINCE JANUARY, 1941

A. SENDAI UNIVERSITY AND METAL INDUSTRIES, LTD.

Magnetostriction Activity in Highly Reduced Plates of Nickel - Y. KIKUTI and K. FUKUSIMA, 1942.

Special Magnetostriction Quality of Magnetic Silicon-Iron Sheet in Different Directions - Y. KIKUTI and NISHIKAWA, 1943.

Magnetostriction of Iron-Aluminum Alloys and a New Alloy "Alfer" - K, HONDA, H. MASUMOTO, Y. SHIRAKAWA, and T. KOBAYASHI, 1945.

Dynamical Characteristics of the Magnetostrictive Alloy "Alfer" - H. MASUMOTO, and G. OTOMO, 1945.

Charts of Curves of Wiedemann Effect of Iron-Aluminum Alloy - 1945.

Magnetostriction of the New Constant Permeability Alloy - T. YAMAMOTO, 1944.

Limiting Path of Mechanical Work Depending on Magnetostriction - Y. KIKUTI, Part I and II, 1945.

Theoretical Composition of Special Magnetostriction Qualities in Polycrystalline Metals - Y. KIKUTI, 1943.

Research on Rate of Magnetostriction - Y. KIKUTI, 1942.

Elastic Constants of Iron Single Crystals - M. YAMAMOTO, 1943.

Elastic Constants of Nickel Single Crystals - M. YAMAMOTO, 1942.

ΔE Effect in Iron, Nickel, and Cobalt - M. YAMAMOTO, 1943.

Dynamic Measurement of Δ E(Young's Modulus)Effect in Nickel-Iron Alloys - M. YAMAMOTO, 1944.

ΔE Effect in Iron-Nickel Alloys - M. YAMAMOTO, 1943.

Determination of Young's Modulus and Density in Iron-Cobalt and Iron-Nickel Alloys - M. YAMAMOTO, 1942.

Young's Modulus of Elasticity and its Change with Magnetization in Iron Cobalt Alloys - M. YAMAMOTO, 1941.

Young's Modulus of Iron-Cobalt Alloys and its change Accompanying Magnetization - M. YAMAMOTO, 1941.

Dynamical Measurement of ΔE Effect in Iron-Cobalt Alloys - M. YAMAMOTO, 1942.

Young's Modulus and its Temperature Coefficient, of a Cobalt-Iron-Chromium Alloy, and a New Alloy "Co-elinvar" - H. MASUMOTO and H. SAITO, 1944.

Young's Modulus, its temperature Coefficient, and Coefficient of Thermal Expansion of Nickel-Copper Alloys - H. MASUMOTO and H. SAITO, 1943.

Young's Modulus of Elasticity and its Variation with Magnetization in Ferromagnetic Nickel-Copper Alloys - M. YAMAMOTO, 1942.

ENCLOSURE (A), continued

Change of Electrical Resistance Due to Magnetization of Single Crystals of Iron and Nickel - T. HIRONE and N. HORI, 1942.

Abnormality in the Thermal Expansion of Iron-Platinum Alloys - H. MASUMOTO and T. KOBAYASHI, 1945.

Densities of Nickel-Cobalt Alloys - M. YAMAMOTO, 1942.

On the Magnetic Properties of Iron-Aluminum Alloys - H. MASUMOTO and H. SAITO, 1942.

Effect of Heat Treatment on the Magnetic Properties of Iron-Aluminum Alloys, Parts I and II(Alperm) - H. MASUMOTO and H. SAITO, 1945.

Special Magnetic and Electric Properties of Strongly Magnetic Iron-Silicon-Aluminum Alloys - T. YAMAMOTO, 1944.

Studies of Magnetic Dust Cores - T. YAMAMOTO, 1942.

Magnetic and Electric Research on New Constant-Permeability Alloys - T. YAMAMOTO, 1944.

Experimental Research on Special Magnetic and Electrical Qualities of Iron-Silicon-Nickel Ternary Alloys, New Sendai Alloys, and Constant-Permeability Alloys - T. YAMAMOTO(Doctor's Thesis), 1944.

Magnetic Properties of Hardened Iron-Molybdenum-Tungsten Alloys - Y. SHIRAKAWA, 1945.

Large Barkhausen Jump and Internal Stress in Perminvar - T. HIRONE, 1943.

Mechanism of Discontinuous Magnetization of Single Crystals of a Magnetic Circuit - T. OKAMURA, T. HIRONE, and S. MIYAHARA, Part I, 1941; Part II, 1943.

Large Barkhausen Effect, Part III, Growth and Disappearance of Reverse Magnetization Nuclei - S. OGAWA, 1943.

Expansion and Contraction of Magnetic Reversal Nuclei by a Large Single Barkhausen Jump - T. HIRONE and N. HORI, 1942.

Discontinuous (180°) Wall Displacement Between the Elementary Domains Due to External Stress - T. HIRONE, 1944.

Effect of Adding a Third Element on the Ordering of a Lattice of Binary Alloys - T. HIRONE, 1942.

Speed of Transformation of Iron-Nickel Alloys - T. HIRONE, 1942.

Special Magnetic Qualities of Nickel - N. HORI, 1940.

Determination of Crystal Orientation by Light Figures - M. YAMAMOTO, 1943.

Optical Figures of Single Crystals of Nickel-Iron Alloy - M. YAMAMOTO, 1944.

Further Studies on Light Figures of Nickel Single Crystals - M. YAMAMOTO, 1942.

Ferromagnetism of Semi-Conductors - T. HIRONE, 1943.

B. <u>TOKYO IMPERIAL UNIVERSITY</u>

The Influence of Outer Strain on the Initial Permeability of Iron Crystals -

ENCLOSURE (A), continued

S. KAYA, T. TAOKA and T. IKI, 1942.

Effect of Strain on Resistivity of an Fe-Ni Alloy (75% Ni) - S. KAYA and T. MUTO, 1944.

Superstructure Formation in Fe-CO Alloys and Their Magnetic Properties - S. KAYA and H. SATO, 1943.

Superstructure in Fe-Ni-Mn Alloys - S. KAYA, M. NAKAYAMA and H. SATO, 1943.

Effect of Cold Rolling on Magnetic Properties of Silicon Iron - S. KAYA and K. TAKAHASHI, 1945.

Use of Sendust in Magnetic Mines - S. KAYA, 1945.

C. <u>NAGOYA IMPERIAL UNIVERSITY, NAGOYA</u>

Structure of Fe-Si-Al Alloys - S. TAKEDA and K. MUTUZAKE, 1941.

D. <u>KYUSHU IMPERIAL UNIVERSITY, FUKUOKA</u>

Magnetic Amplifier - K. HARADA, 1945.

E. <u>TOKYO UNIVERSITY OF ENGINEERING, TOKYO</u>

Magnetostriction and Properties of Some Ferrites - T. TAKEI, 1945.

F. <u>FURUKAWA INSTITUTE, TOKYO</u>

Magnetic Properties of High Purity Iron - K. MIHARA, 1945.

Effect of Annealing Pure Fe-Si in Magnetic Field - K. MIHARA, 1945.

Magnetic Properties of Fe-Ni-Cu-Cr Alloys - K. MIHARA, 1941.

G. <u>AERONAUTICAL RESEARCH INSTITUTE, TOKYO</u>

Use of Wiedemann Effect in Measurement of Torque - R. KIMURA, 1944.

Wiedemann Effect in Iron Single Crystal - R. KIMURA, 1943.

Non-Destructive Detection of Faults in Ball-Bearing Races - R. KIMURA, 1944.

H. <u>INSTITUTE OF PHYSICAL AND CHEMICAL RESEARCH, TOKYO</u>

On the Neutron Cross-Section by Ni-Fe Alloys - M. KIMURA and R. HASIGUTI, 1943.

Temperature Coefficient of KS, OP and MK Magnets - S. KAYA, 1944.

ENCLOSURE (B)

REPORT OF INVESTIGATION OF MAGNETIC AMPLIFIERS

SPECIAL CHARACTERISTICS OF EXPERIMENTAL SET

by
Prof. K. HARADA,
Kyushu Imperial University, FUKUOKA, Japan.

September, 1944

The wiring of the experimental set is shown in Figure 1. "P" is the primary coil and is connected to an AC source. "S" is the secondary coil and is connected to the control circuit. "T" is the tertiary coil and is connected to the output and can also be used independently as an exciter. The steel cores each consist of 40 laminations of TM3 alloy, 0.3mm thick. The dimensions are specified in Figure 2. The thickness of the coil and coil windings are as follows:

	Size of Wire	Turns per Winding	Resistance
P	28 B.S.	400	20 ohms
S	32 B.S.	2000	372 ohms
T	28 B.S.	400	22 ohms

The special characteristics, shown in the following figures are the results of experiments conducted on the experimental set with the rectifier inserted in the "T" circuit.

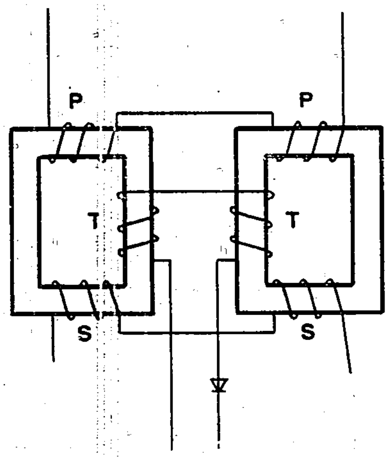


Figure 1(B)
WIRING OF EXPERIMENTAL SET

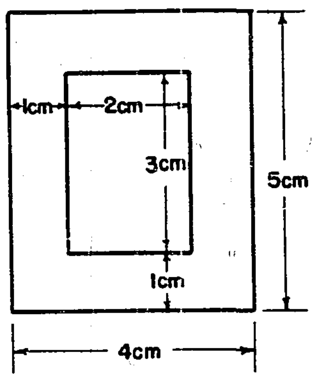


Figure 2(B)
STEEL CORE LAMINATION

ENCLOSURE (B), continued

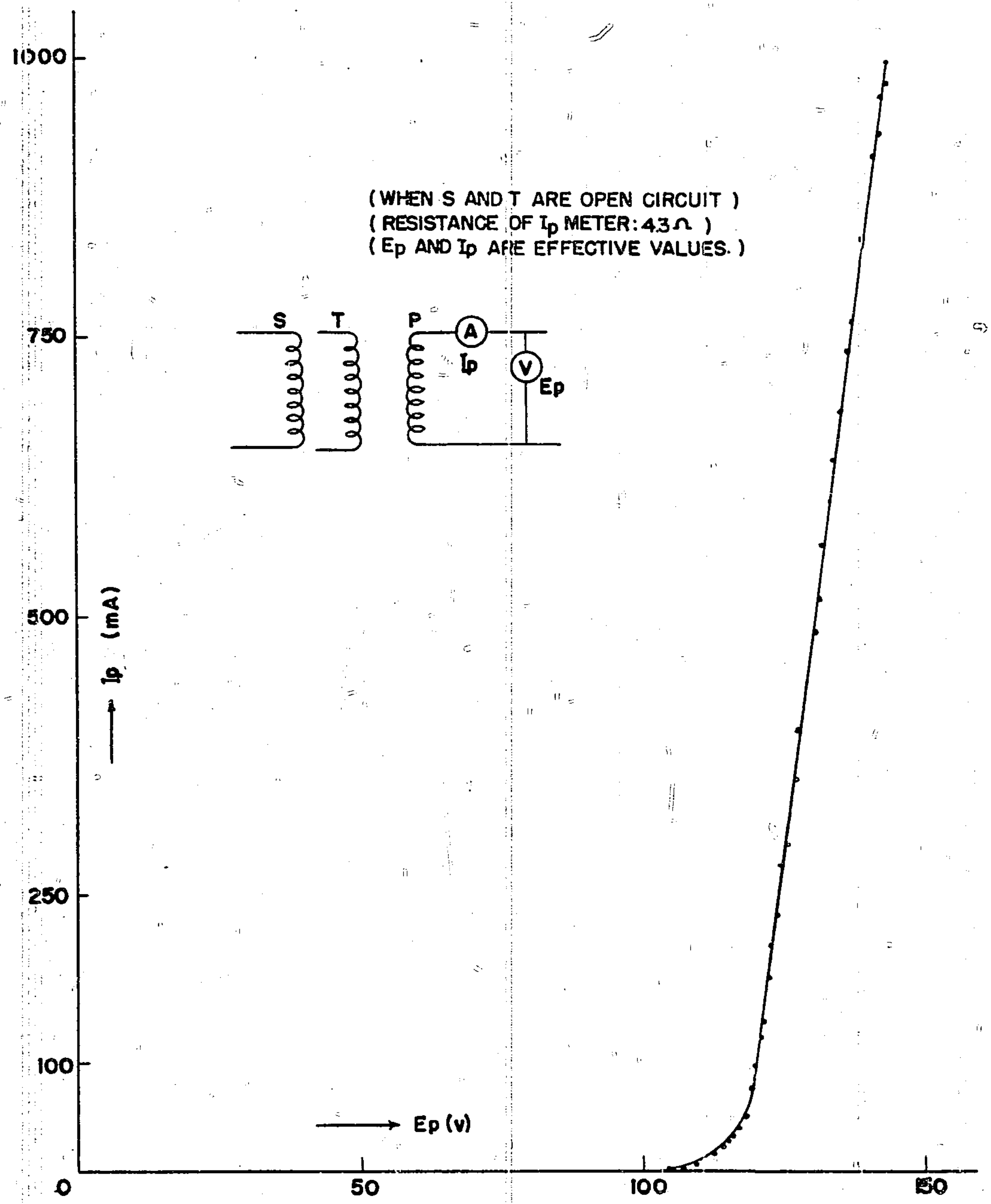


Figure 3(B)
RELATIONSHIP OF Ep TO Ip

ENCLOSURE (B), continued

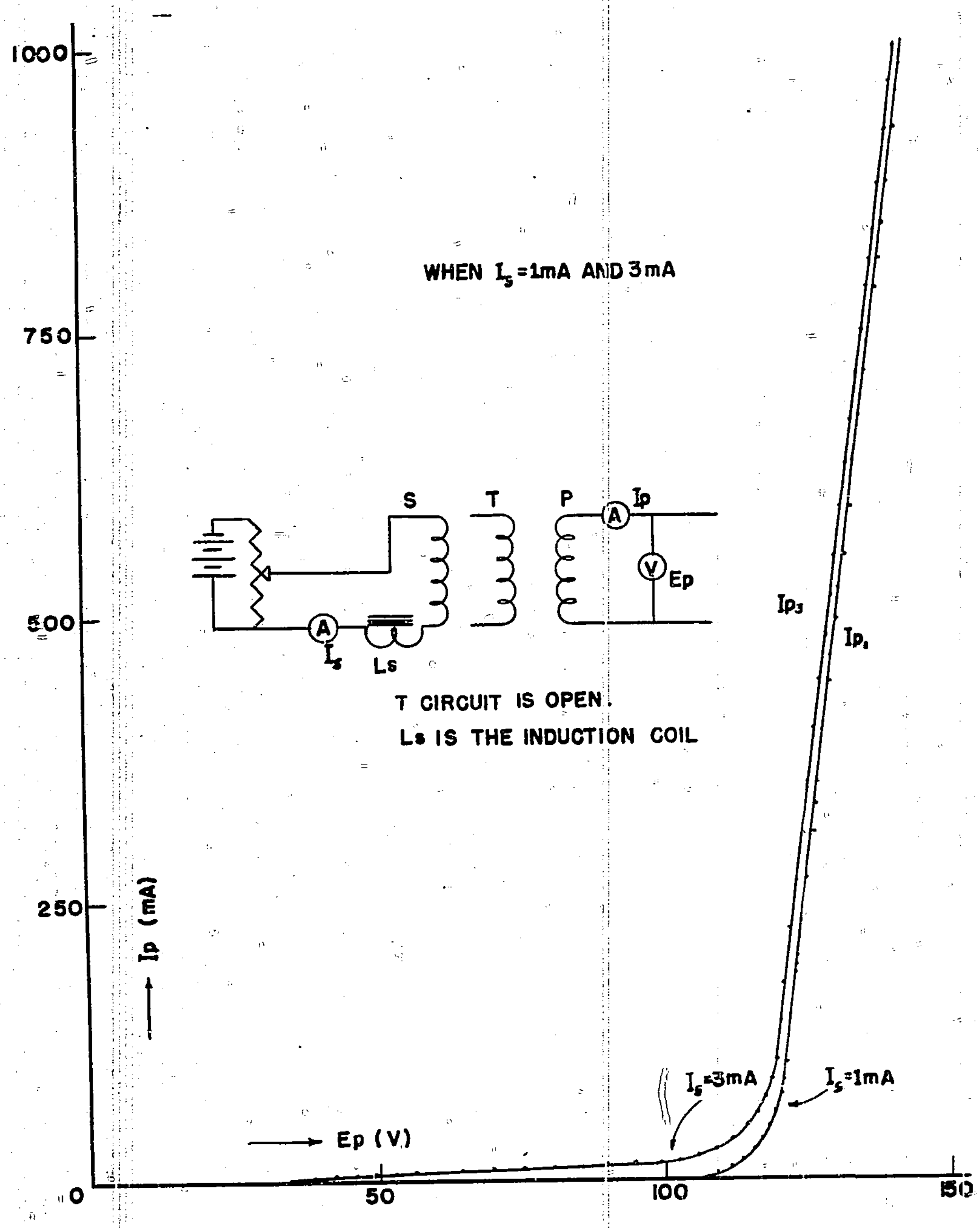


Figure 4(B)
RELATION OF Ep AND Ip

ENCLOSURE (B), continued

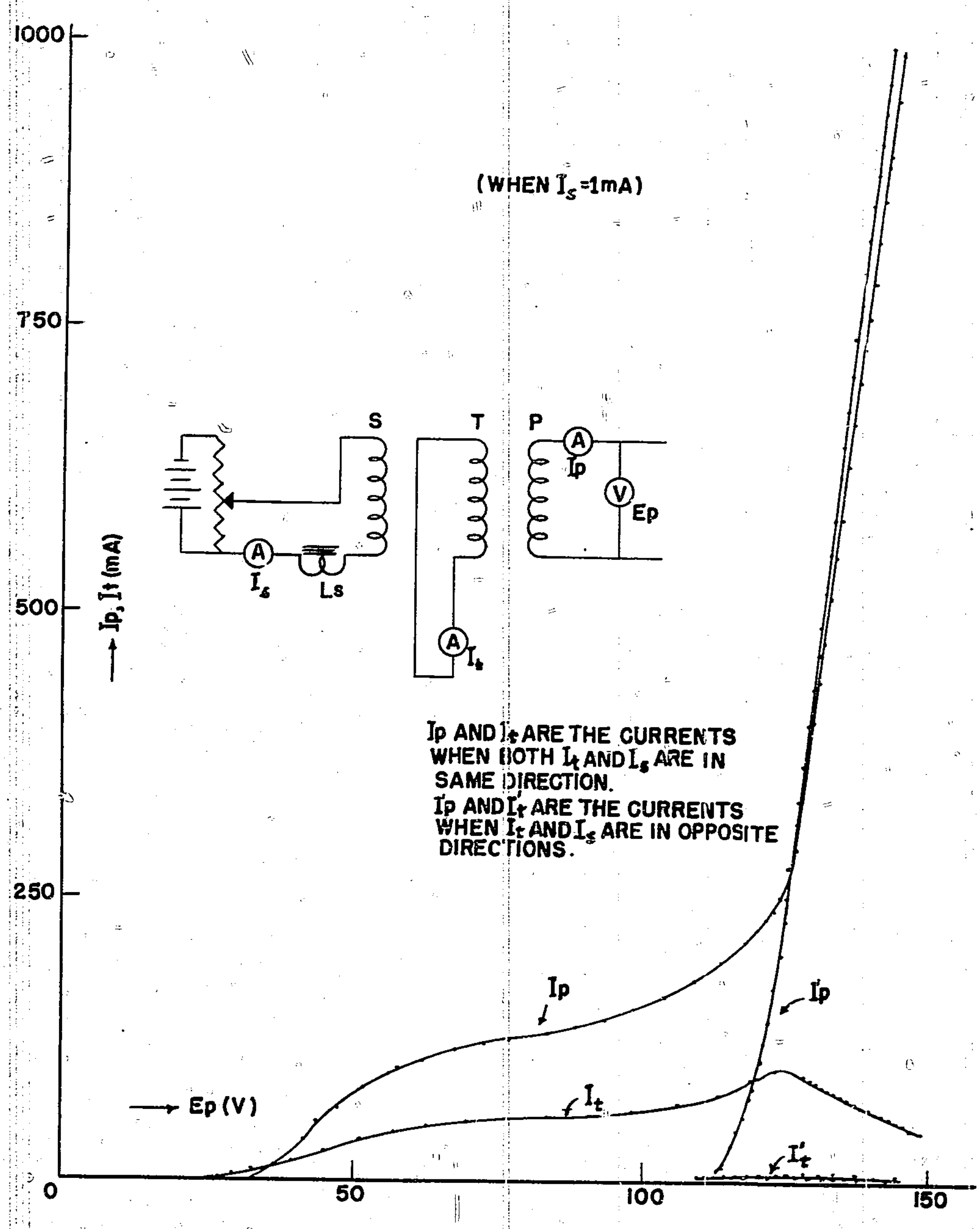


Figure 5(B)

RELATION OF Ep AND Ip

ENCLOSURE (B), continued

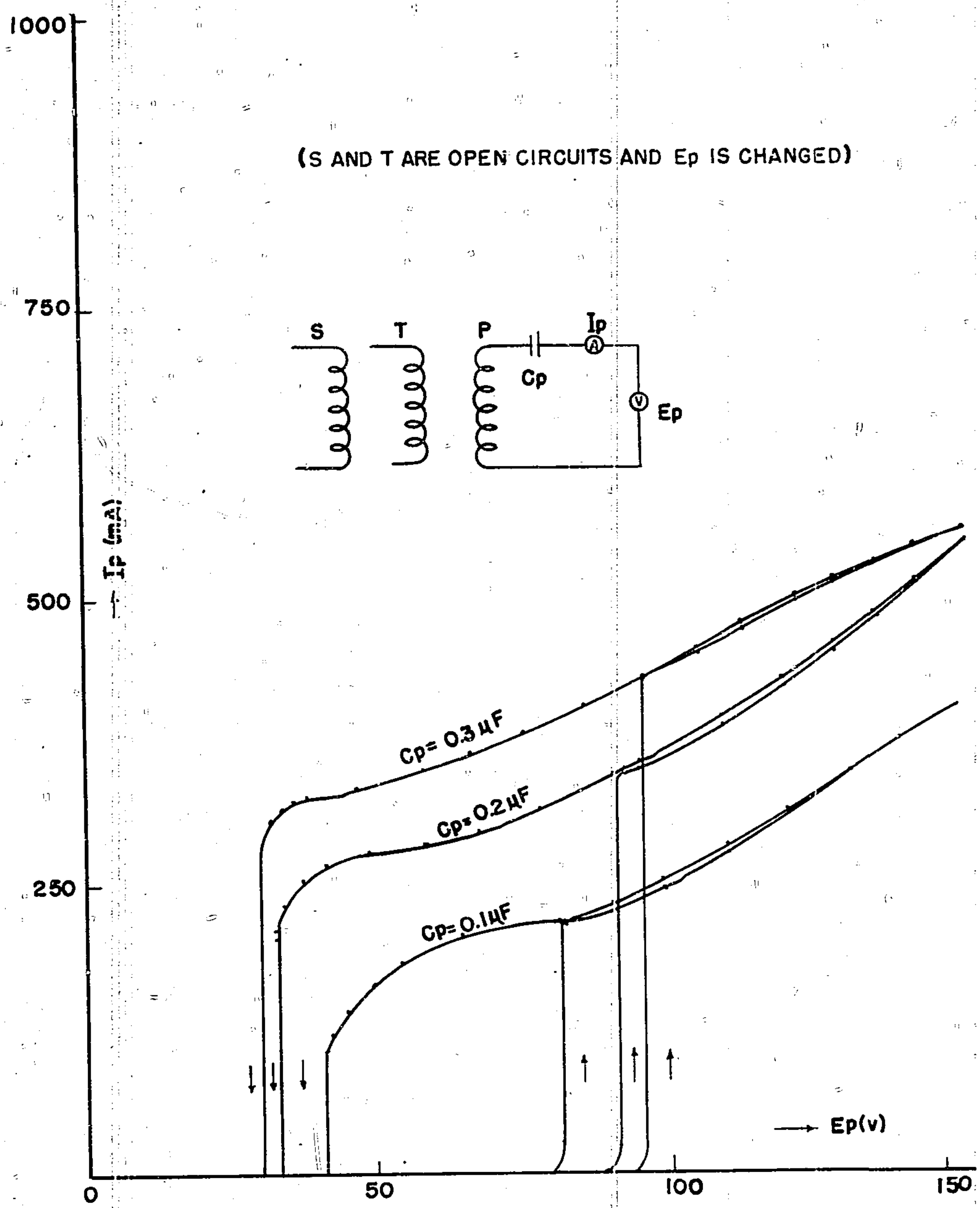


Figure 6(B)

FERRO-RESONANCE: RELATION OF Ep TO Ip

ENCLOSURE (B), continued

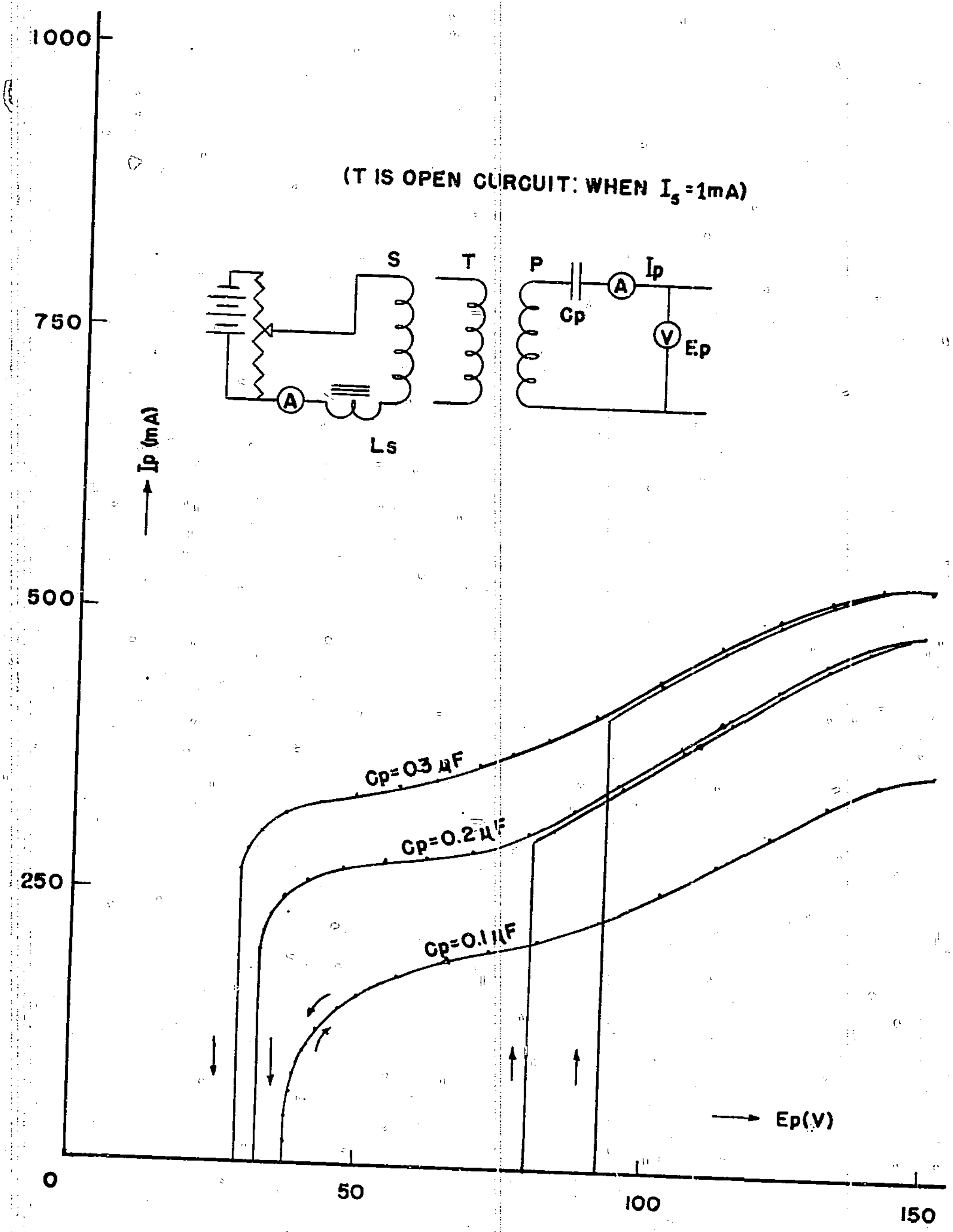


Figure 7(B)
FERRO-RESONANCE: RELATION OF Ep AND Ip

ENCLOSURE (B), continued

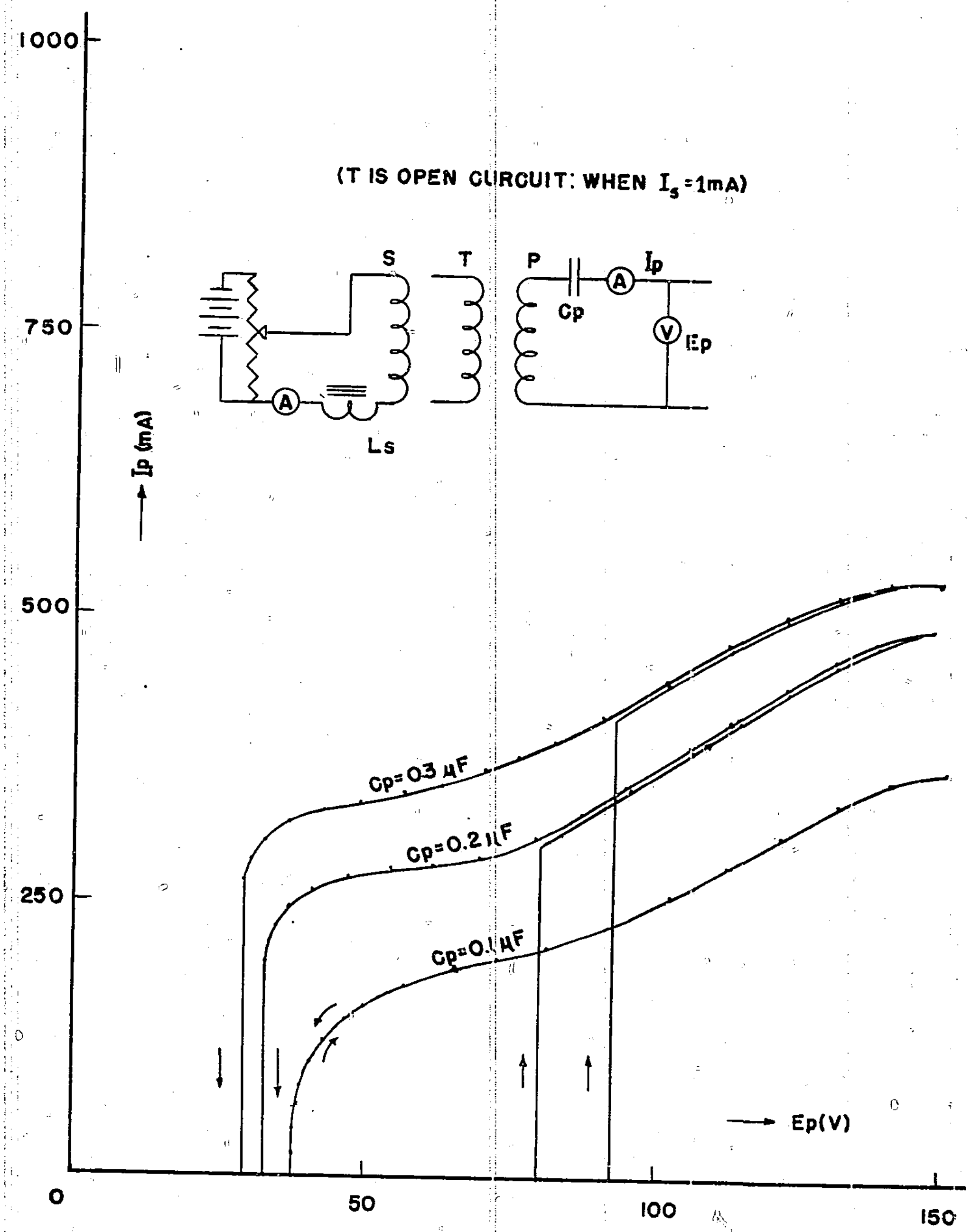


Figure 7(?)
FERRO-RESONANCE: RELATION OF Ep AND Ip

ENCLOSURE (B), continued

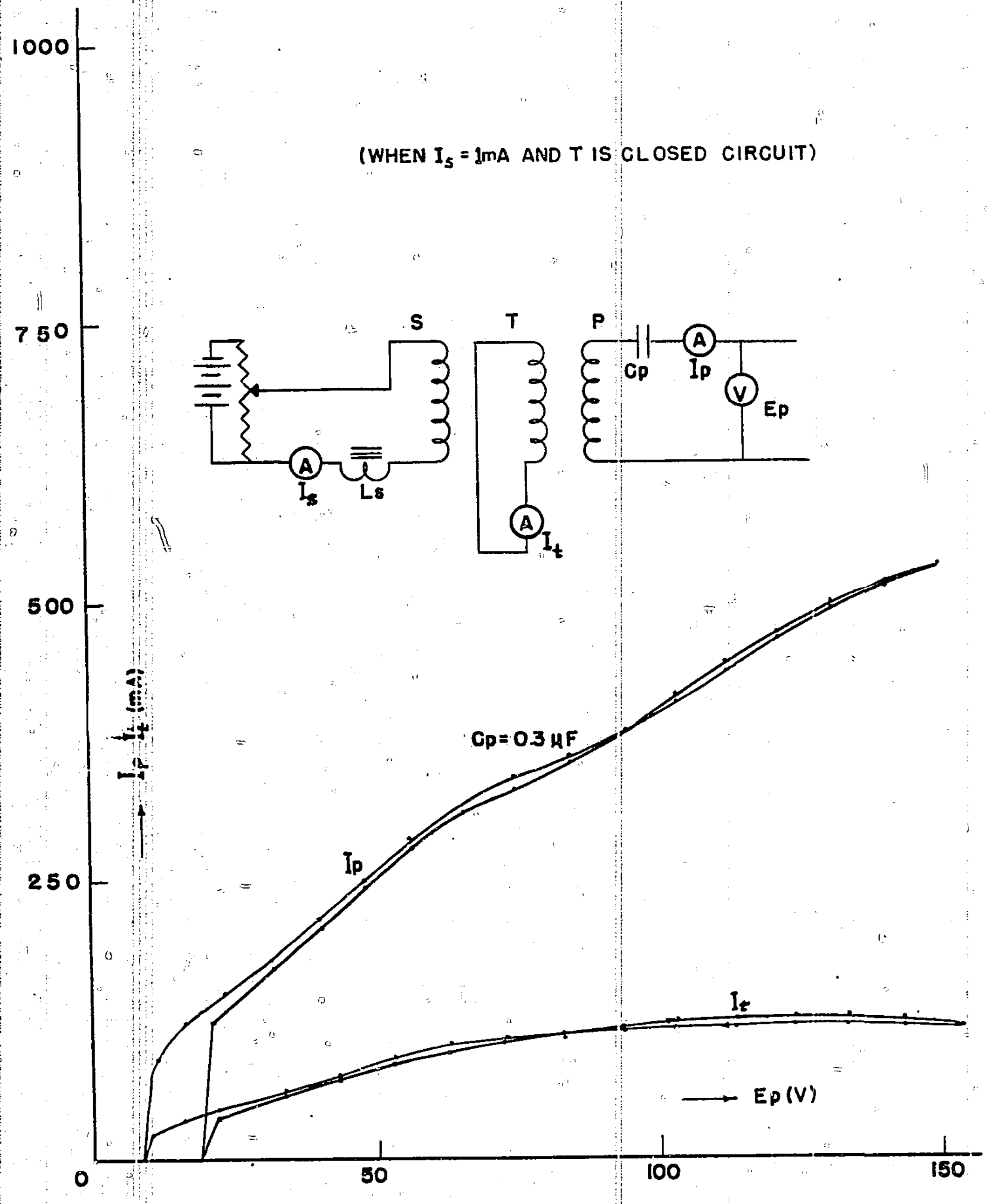


Figure 8(b)
FERRO-RESONANCE: RELATION OF Ep TO Ip

ENCLOSURE (B), continued

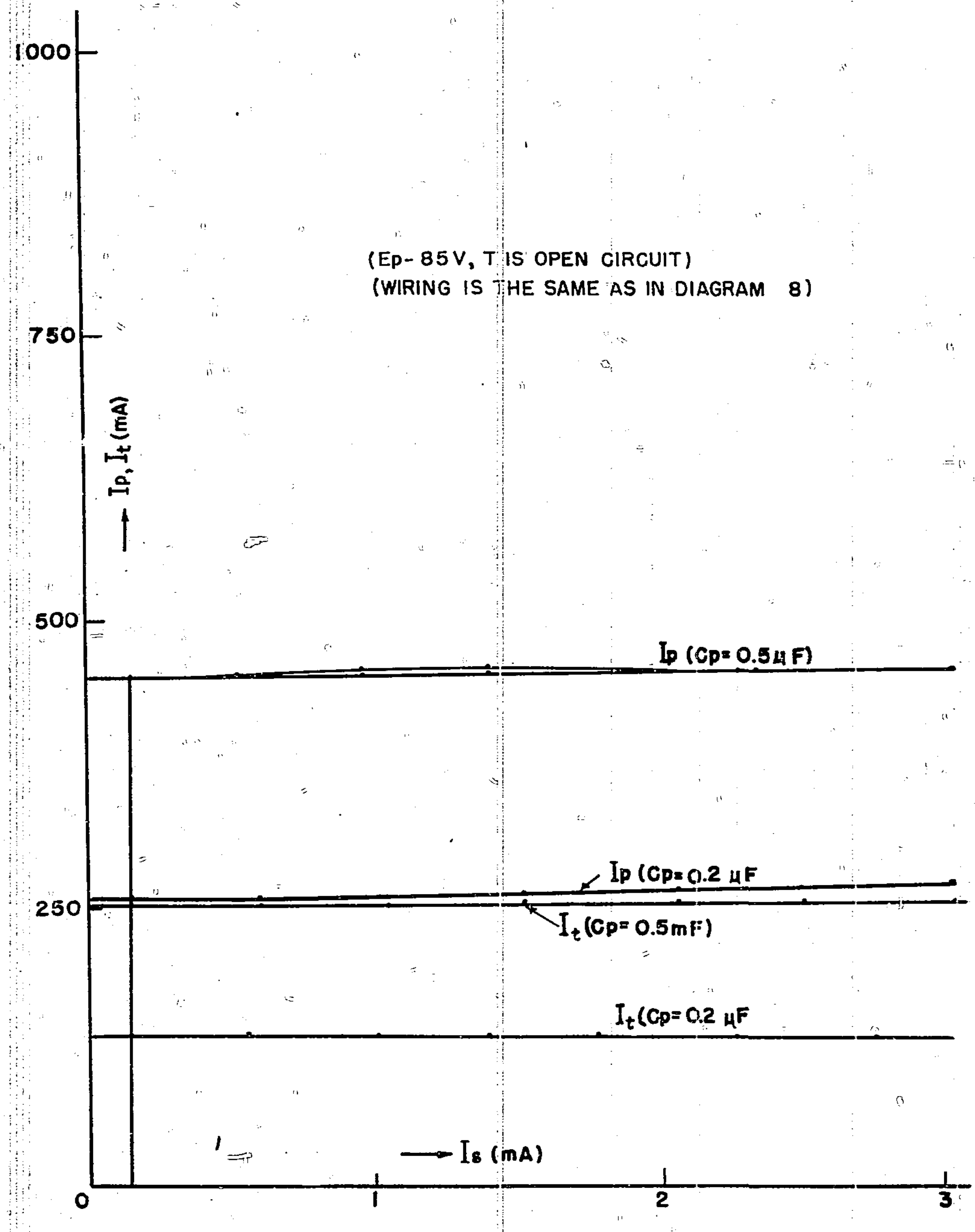


Figure 9(B)
FERRO-RESONANCE: RELATION OF Is AND Ip

ENCLOSURE (B), continued

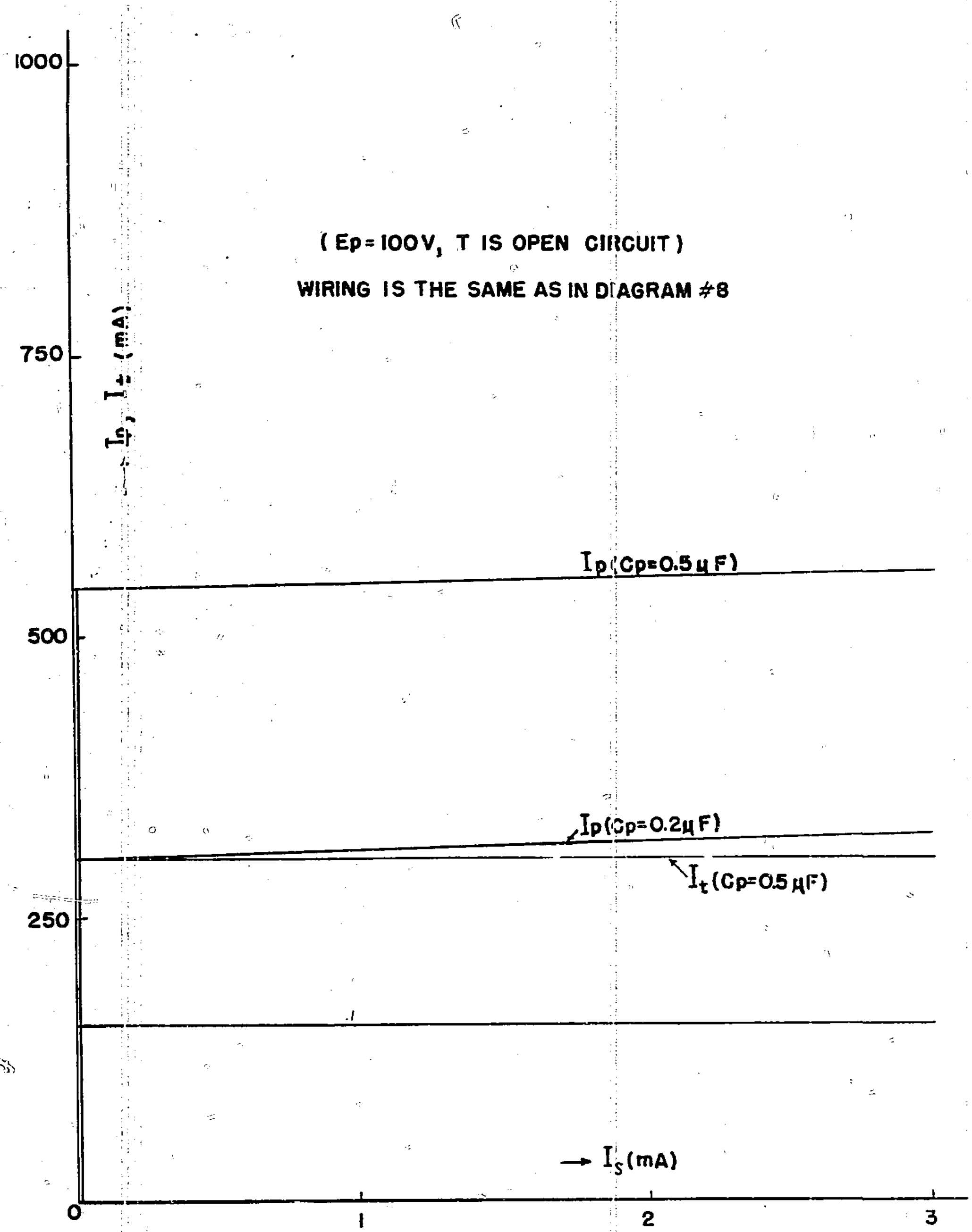


Figure 10(B)

FERRO-RESONANCE: RELATION OF Is AND Ip

ENCLOSURE (B), continued

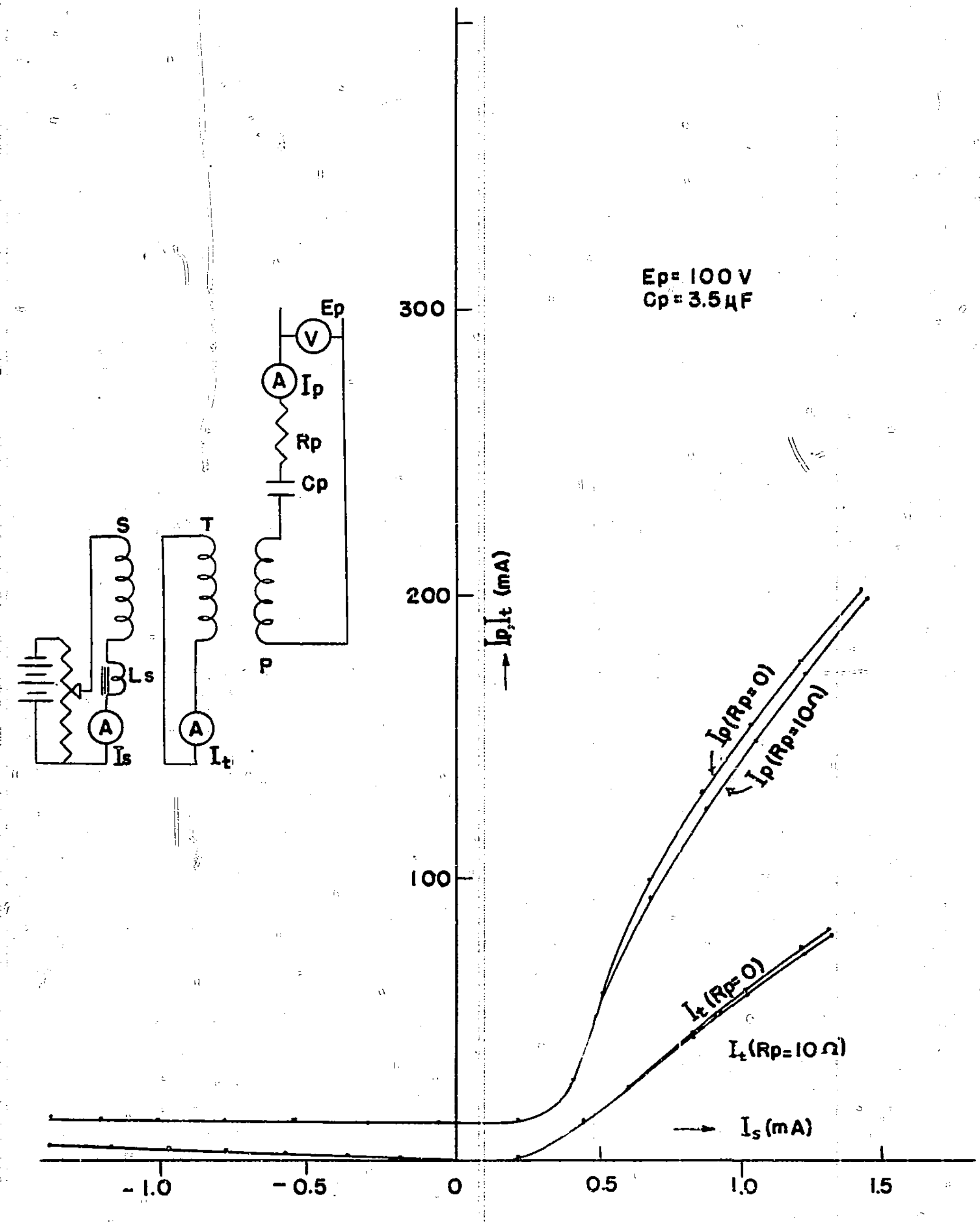


Figure 11(B)
RELATION OF Is TO Ip AND It

ENCLOSURE (B), continued

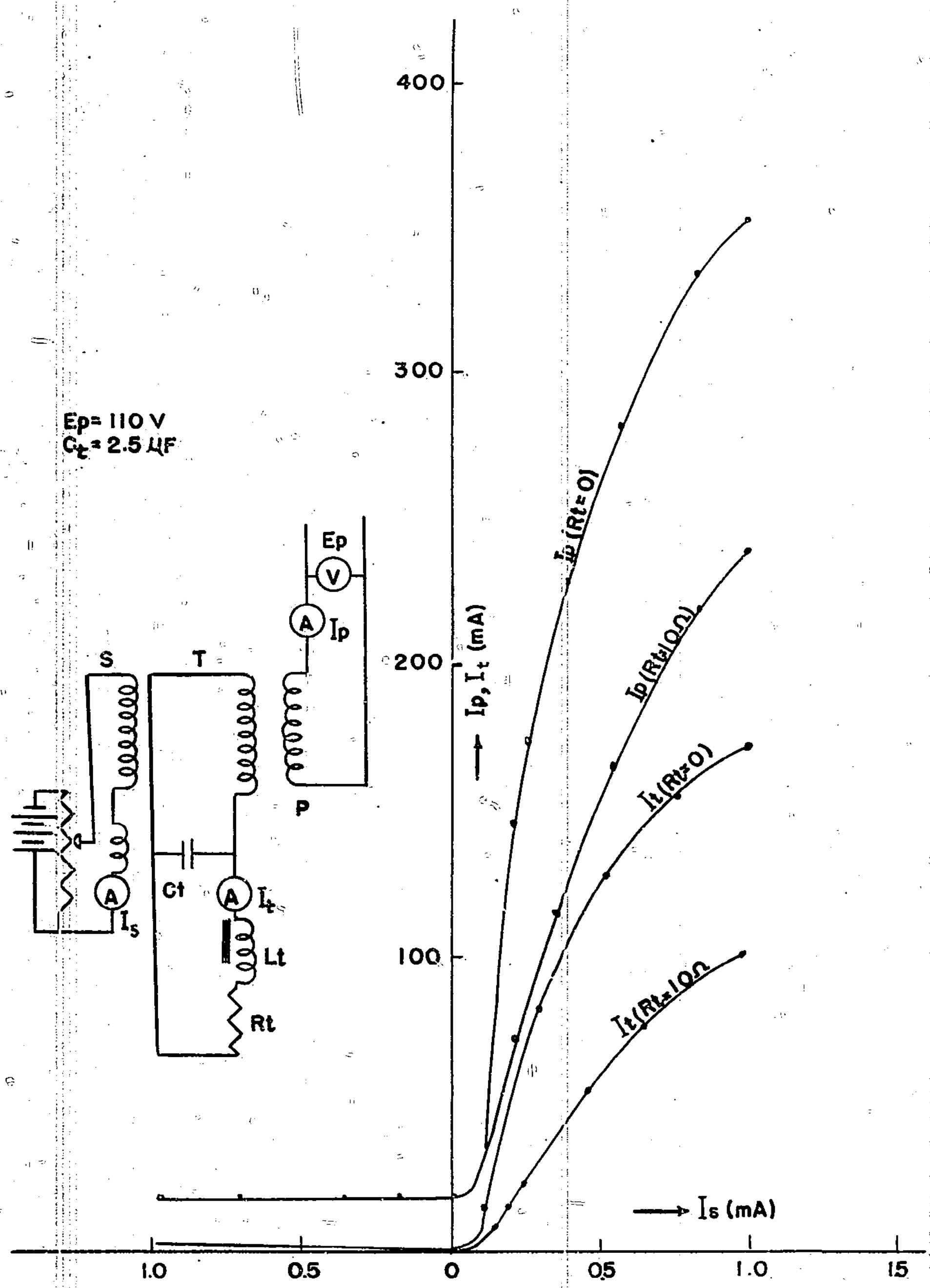


Figure 12(B)

RELATION OF Is TO Ip AND It

ENCLOSURE (C)

SUMMARY OF REPORTS AND LABORATORY NOTES ON APPLICATIONS OF THE MAGNETIC AMPLIFIER

by
Prof. K. HARADA,
Kyushu Imperial University, FUKUOKA, Japan

This is a summary of several reports on the application of the magnetic amplifier as a magnetic field measuring device and as a firing mechanism.

A. INITIAL TEST CONDITIONS

In the preliminary work, the characteristics of the amplifier under varying voltages, frequencies, and loads were investigated. The circuit used is shown in Fig.1(C). In the first experiments, an AC generator was used. The frequencies were 60, 120, 180, 250 and 350 cycles per second. In these tests, $R_t = 0$ and $I_s = 0.5$ ma. It was found that with increase in frequency at the lower frequencies range, I_t increased very rapidly, but at higher frequencies, the increase in I_t was not as rapid. Also, the maximum of I_t for each frequency was obtained at different values of V_p.

The next tests consisted in taking the V_p for the maximum values of I_t for each frequency, and with $R_t = 0$ determine the relation between I_s and I_t. The results of these tests are shown in Fig.2(C). These curves show that the amplification increases with increase in frequency, and that the curves for all frequencies are similar in shape. The I_t values corresponding to those for I_s in opposite direction have no relation to the frequency. This is due to the unbalance of the amplifier coils, but the I_t value with $I_s = 0$ seems to increase with increase in frequency. The amplifier used in these experiments had been adjusted so that the unbalance at 60 cycles was substantially zero, but for frequencies above 250 cycles the unbalance became quite noticeable.

Tests were also made to determine the relation between I_s and I_t for different frequencies when the voltage and the constants shown in Fig.1(C) were varied. The results of these tests are shown in Fig.3(C). These results are of special interest. They show that with suitable adjustment of the voltage, I_s and I_t, a trigger circuit is obtained in which up to a certain value of I_s there is practically no change in I_t. Then, as the current of I_s is increased, an additional small amount, there is a very large jump in the current I_t. At 60 cycles, the sudden increase in I_t occurs at $I_s = 80$ ma when I_t increases to 25 ma. At 180 cycles, I_t jumps to 100 ma when I_s is 7 ma. For higher frequencies, the sudden increase in I_t occurs when I_s is in the reverse direction.

The value of I_s which produces the sudden change in I_t is influenced by the value of I_t when $I_s = 0$. In other words, it is affected by the unbalance existing in the amplifier. Consequently, if the unbalance is increased with an increase in frequency, the value of I_s which causes the jump in the current I_t can be changed at will, to a certain degree, by adjusting the unbalance.

From these experiments, it can be seen that the performance of the amplifier can be modified and the output increased by increasing the source frequency.

B. UNSYMMETRICAL SOURCE-CURRENT

The next experiments were made to determine whether or not an unsymmetrical current could be used. The principle components of the amplifier circuit are shown in Fig.4(C). The cores of the amplifier "AP" were of the same magnetic material used in the cores of the amplifier in Fig.1(C). The windings "P", "S" and "T" were 400, 400 and 200 respectively. The interrupter "IP" is a modification of a buzzer and is the simplest form of this type. The trans-

ENCLOSURE (C), continued

former "TR" is a modified form of the type used in radio receiving sets.

The windings are shown in Fig.4(C). The current source is a six-volt "B" battery. To eliminate sparking of the interrupter, the condenser C_1(1μF) was used. To correct the wave form of Vp, the condenser C_2(2μF) was used. If C_2 is 10 μF the wave form of Vp would be nearly the normal form, but in order to simplify the system, this condenser should be made as small as possible. In the tests, C_2 was made large enough to permit functioning of the system.

It was learned from the experiments of this amplifier system, that the amplifier can function with unsymmetrical AC currents produced by a battery and interrupter, and that a simple circuit can be used.

C. TESTS ON ONE-CORE AMPLIFIERS

Tests also were made on amplifiers in which only one core with three legs was used in place of two cores. The dimensions of the core and the windings are shown in Fig.5(C). The tests on this amplifier showed that this type of core could be used.

D. MAGNETIC FIELD METER

The magnetic core and windings of this meter are shown in Fig.6(C). This is one form of magnetic amplifier and indicates the field strength directly. Attempts were made to apply this for different uses in which the change to be recorded is brought about by a change in the magnetic field. The approximate construction and the wiring are shown in Fig.6(C). In this figure, "C" is a core of the same material as that used in the amplifier previously referred to. Coil "P" is connected to an AC source and the coil "T" is connected to ammeter "A" and rectifier "RC". The windings of "T" on the two legs are arranged so that the voltages induced are in opposition. The magnetic flux produced by "P_1" is indicated by "M". "N" is the magnetic field to be measured. The rectifier is connected so that the rectified current will produce a field in the same direction as "N" by means of coils "T".

Now, for example, if "P" is connected to a proper source of AC and if the meter is placed in a magnetic field, such as the earth's field, at this moment, if there is a component in the direction of N, a double frequency current induced in winding "T" is rectified by "RC" and a magnetic field is produced in the direction "N" and causes a regeneration, thus amplifying current I_t passing through "A". Therefore, even a weak field can be measured with comparative ease by means of the current I_t.

When this instrument is turned in the field until the maximum reading of F_1 is obtained, it is possible to determine the direction and strength of the field.

Because of lack of uniformity of the laminations in the core, the reading never becomes zero even when the field is zero.

When the current in circuit "T" is completely rectified, by using two half-wave rectifiers, the regeneration is not produced. Therefore, the polarity of the field cannot be determined, but the direction and strength of the field can be determined.

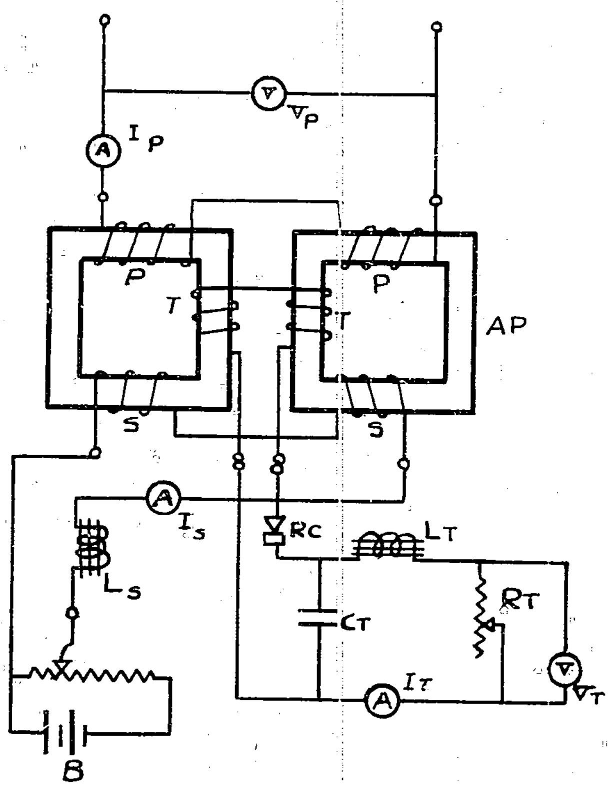
E. MAGNETIC FIRING MECHANISM

As is shown in Fig.1(C), by proper adjustment of the amplifier circuit, it is possible to obtain a trigger circuit in which the amplified current I_t suddenly increases with a small change in the field. The dimensions of the core, the windings, and the circuit used in the tests are shown in Fig.7(C). "NN" is the direction of the outside field, such as the earth.

ENCLOSURE (C), continued

In the tests with the amplifier shown in Fig.7(C), in which L = 0.46 and C = 0.3μf, the sudden rise in the current was so large that it lighted up an incandescent lamp (4.5 volts, 1.2 A). The oscillograph showed that from the time of the increase of the field, which produced the sudden increase in the current I_t, until the time at which maximum current was reached, only 1/25 sec. elapsed.

This arrangement can be used for a firing mechanism or for other apparatus where the operation of the circuit depends on a very small increase in the magnetic field.



AP - Amplifier
RC - Rectifier
L_S, L_T } - Induction Coil
C_T - Condenser
R_T - Rheostat
P - Number of Turns - 400
T - Number of Turns - 400
S - Number of Turns - 200

Figure 1(C)
MAGNETIC AMPLIFIER CIRCUIT

ENCLOSURE (C), continued

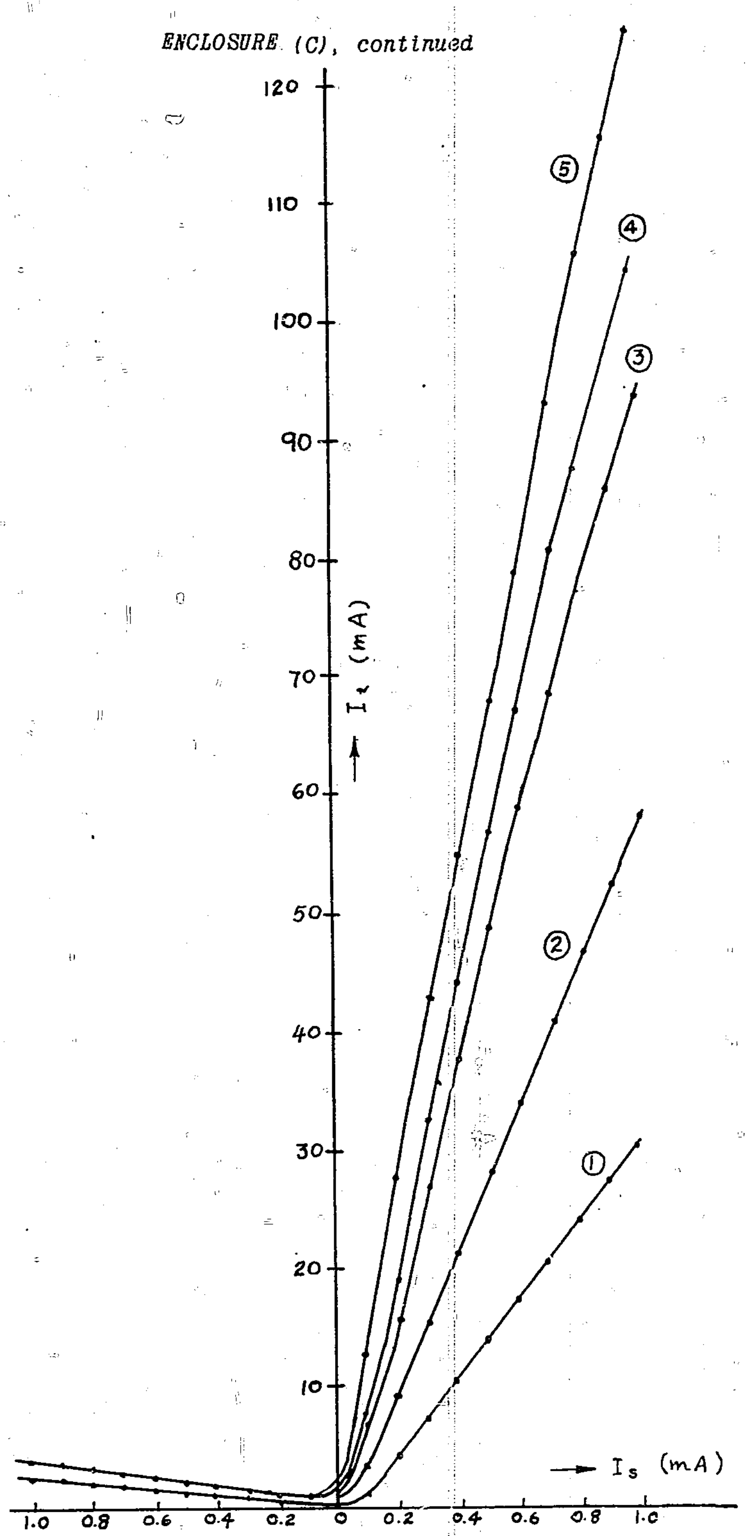


Figure 2(C)

THE EFFECT OF FREQUENCY ON THE RELATION BETWEEN
Is AND It (Rt=Ct=Lt=0)

ENCLOSURE (C), continued

Rt = 10Ω Lt = 1H	(1) f = 60n V_p = 17v Ct = 6mf Is = 60ma	(2) f = 120n V_p = 34v Ct = 5mf Is = 35ma
f = 180n V_p = 48v Ct = 4mf Is = 7ma	(4) f = 250n V_p = 69v Ct = 2mf Is = 30ma	(5) f = 350n V_p = 90v Ct = 1mf Is = 45ma

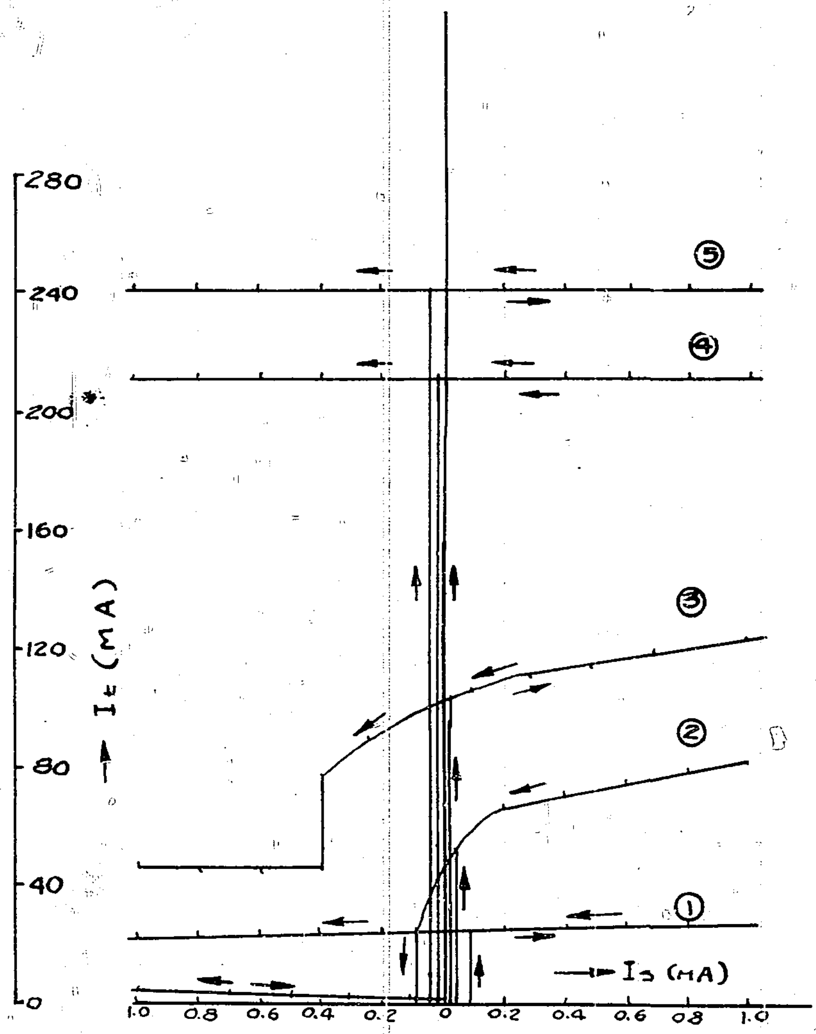
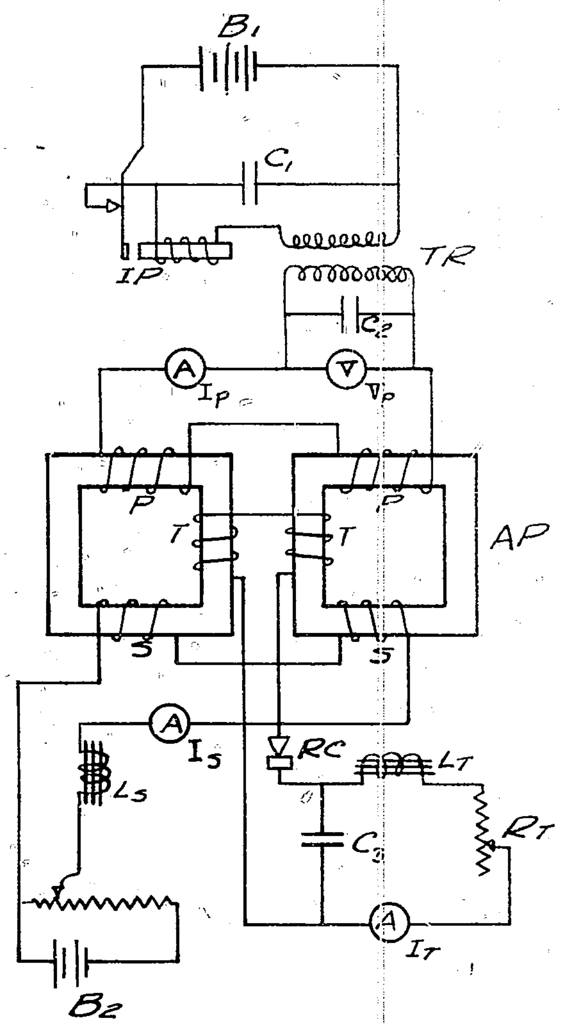


Figure 3(C)
THE EFFECT OF FREQUENCY ON THE RELATION BETWEEN
Is AND It (Rt=10, Lt=1 H)

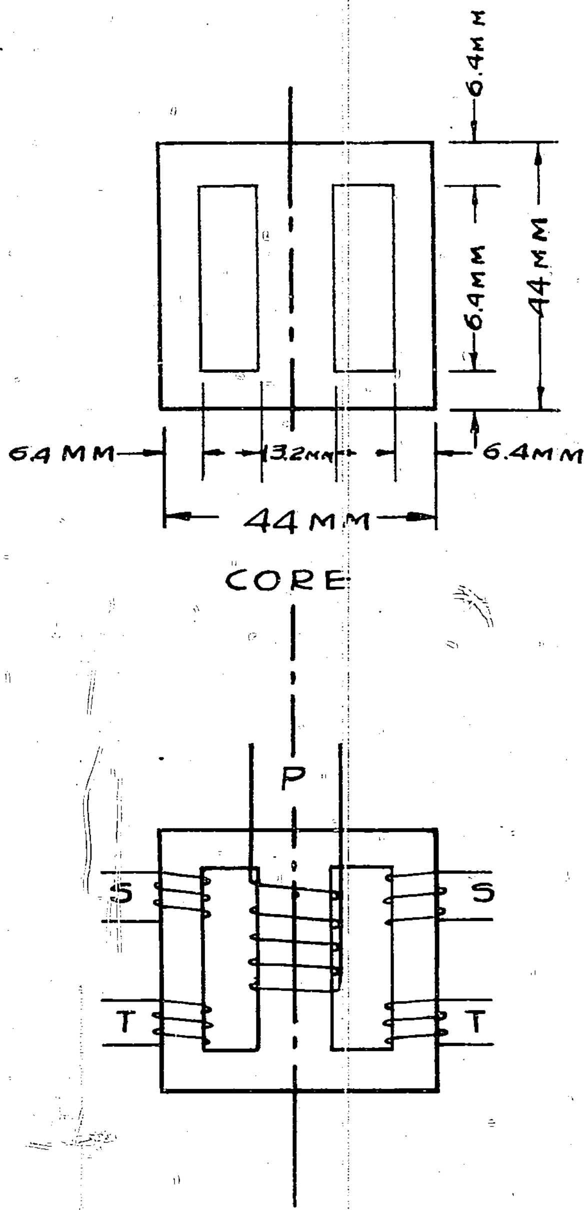
ENCLOSURE (C), continued



A - Ammeter
AP - Amplifier
B_1, B_2 - Batteries
C_1, C_2, C_3 - Condensers
I_P - Interrupter
RC - Rectifier
R_T - Transformer
L_S, L_T - Induction Coils

Figure 4(C)
MAGNETIC AMPLIFIER CIRCUIT FOR USE WITH UNSYMMETAICAL SOURCE CURRENT

ENCLOSURE (C). continued



S = 1000 Turns
T = 500 Turns
P = 400 Turns

No. of Sheets - 34
Thickness of 1 Sheet - 0.4mm
Thickness of Core - 13.7mm

Figure 5(C)
ONE CORE AMPLIFIER

ENCLOSURE (C), continued

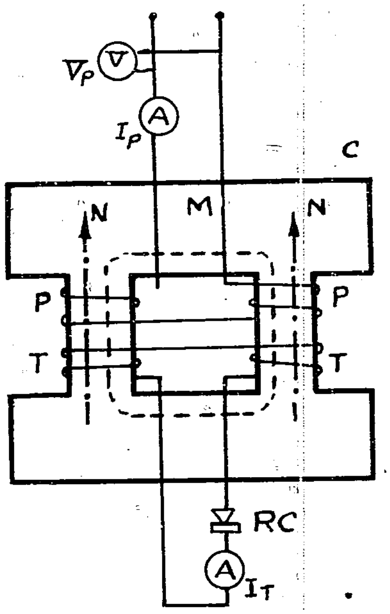
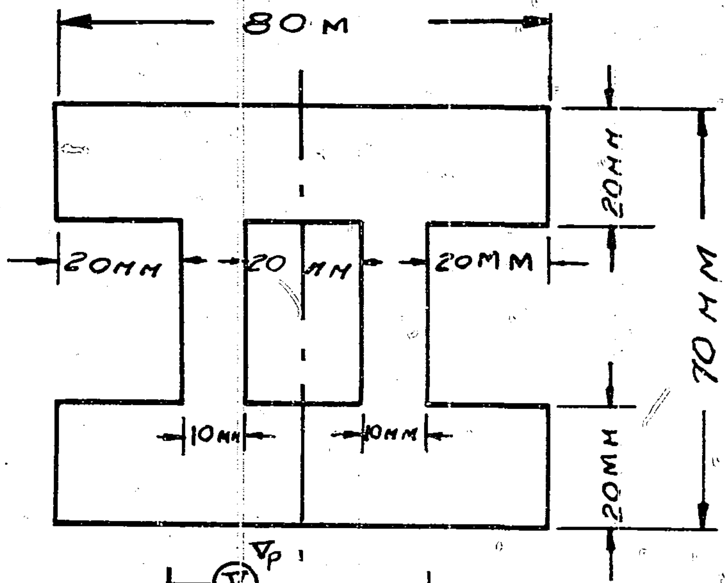
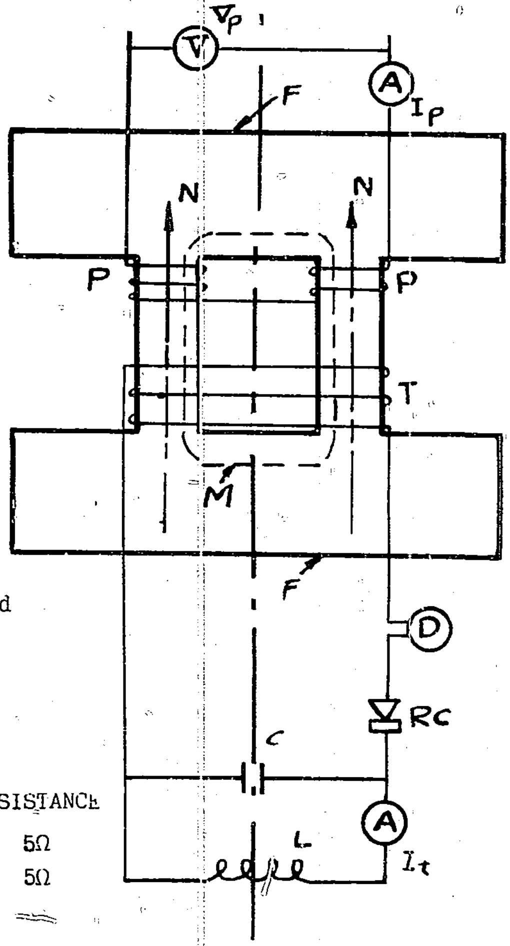


Figure 6(C)
MAGNETIC FIELD METER

ENCLOSURE (C), continued





N - Direction of the Field
V_p - Voltage Applied
C - Condenser
D - Incandescent Lamp
L - Induction Coil

SIZE	TURNS	RESISTANCE
BS #28	400 (200 Each)	5Ω
BS #28	1000	5Ω

Figure 7(C)
MAGNETIC FIRING MECHANISM

ENCLOSURE (D)

REMARKS ON HIGH PURITY SILICON-STEEL SPECIMENS

by
K. MIHARA

Kind of Specimens

Si	Diameter	Height
5.13%	52-48mm	
5.00%	54-50mm	9mm
4.62%	52-48mm	9mm
3.68%	52-48mm	9mm
3.06%	52-48mm	10mm

A. Heat Treatments Supplied

5% Si ring is used for heat treatment in the field, as I formerly reported, and magnetic hysteresis loops are shown in the accompanying Figures.

5.13%, 4.62%, 3.68% and 3.68% Si specimens are used only for a quick-cooling test on magnetic characteristic changes. Maximum permeability of these specimens is a little lower due to high-temperature, prolonged annealing (1200°C for 10 hours) but it is certain that these specimens will also show expected results similar to other specimens tested in my laboratory by cooling in a magnetic field.

B. Preliminary Treatment Required

Polish each specimen or wash in dilute acid and anneal at 1000-1200°C for 2-3 hours either in dry hydrogen or in vacuum. Some specimens will contain thermal strains from quick cooling and others may contain mechanical stresses from handling after the last heating.

As seen, the 5.13% Si ring has pits and small cracks, so, this specimen should be gently reshaved in a suitable machine, avoiding heavy strains in attaching, as the specimen has a coarse grain due to prolonged heating.

I want you to try heat treating in a magnetic field, after preliminary treatments, with these specimens, to confirm my paper.

I should be very glad if these specimens should contribute something to research on cooling in a magnetic field by Dr. Bozorth's ingenious procedures.

Note: This paper was submitted by Mr. K. MIHARA of Fukukawa Research Laboratory, after completion of the report. The Si-Steel samples mentioned are being forwarded to the Naval Research Laboratory under NavTechJap Equipment Number JE50-5217.

ENCLOSURE (D), continued

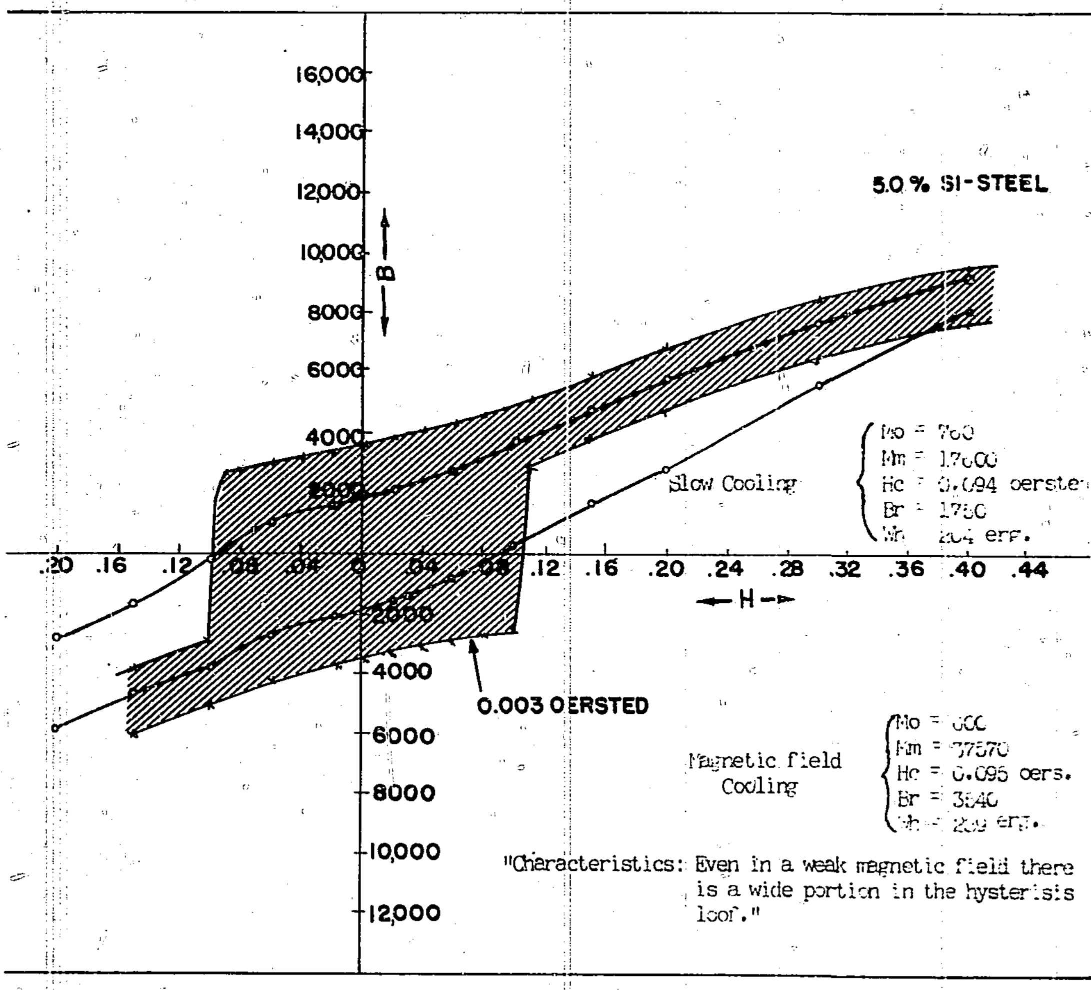


Figure 1(L)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

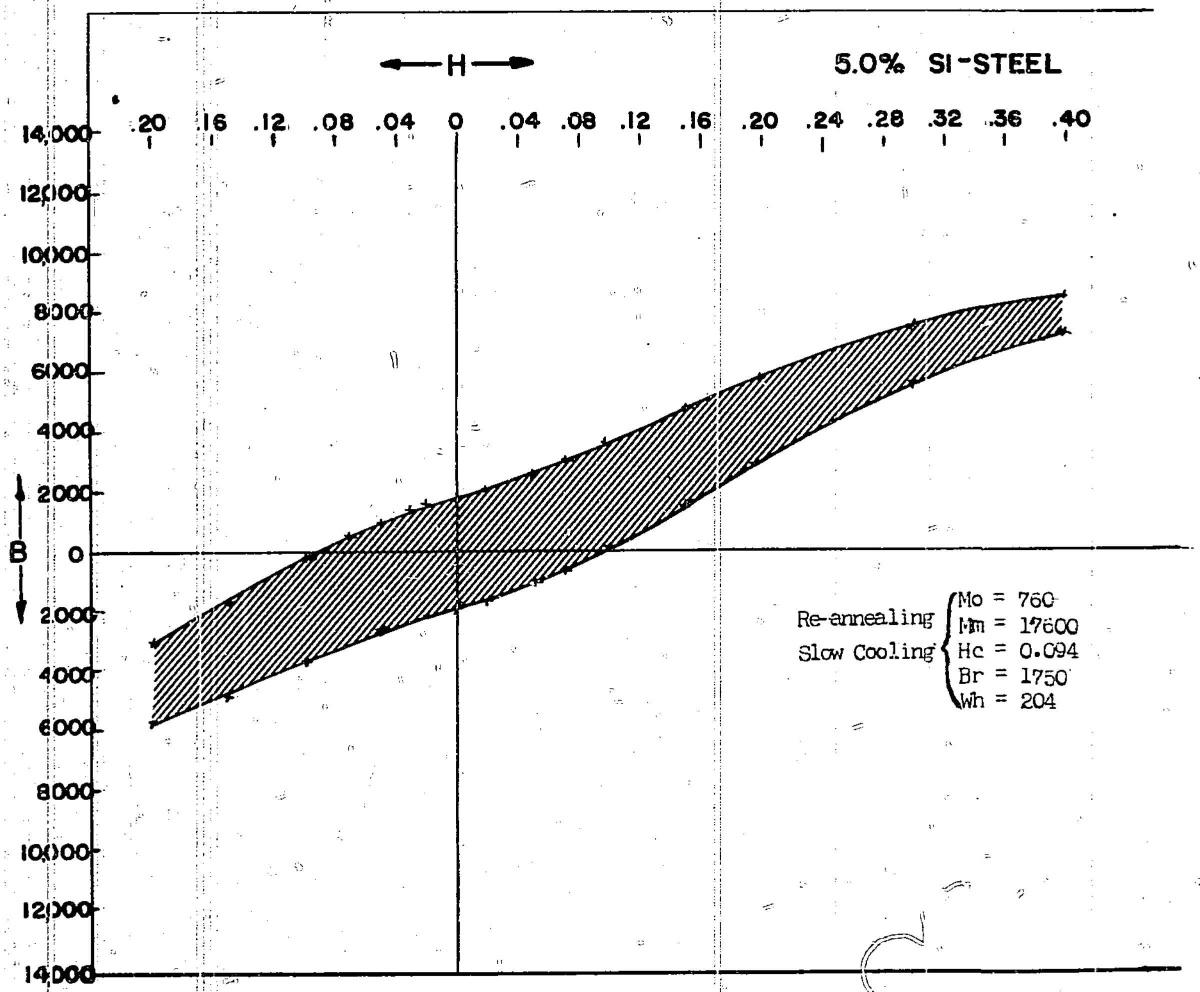


Figure 2(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

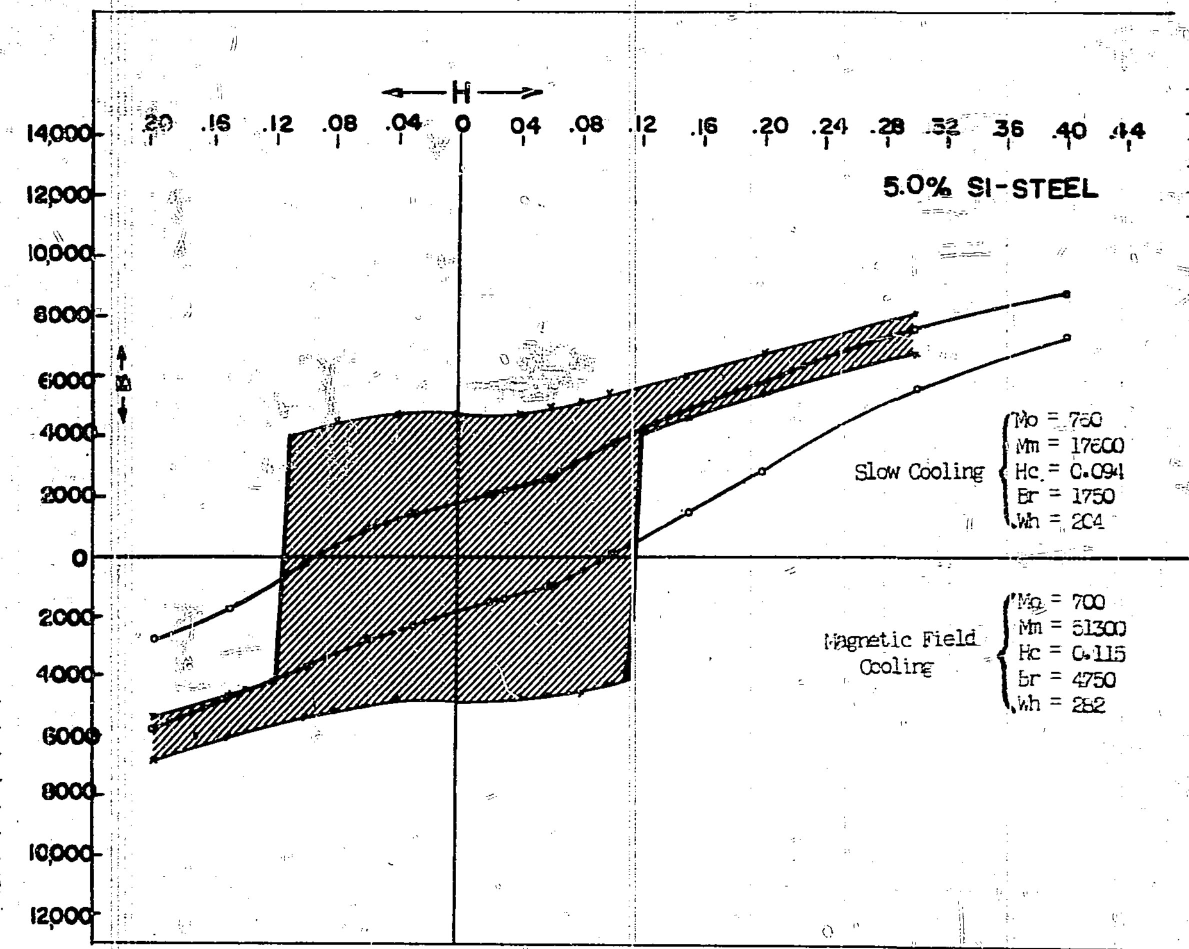


Figure 3(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

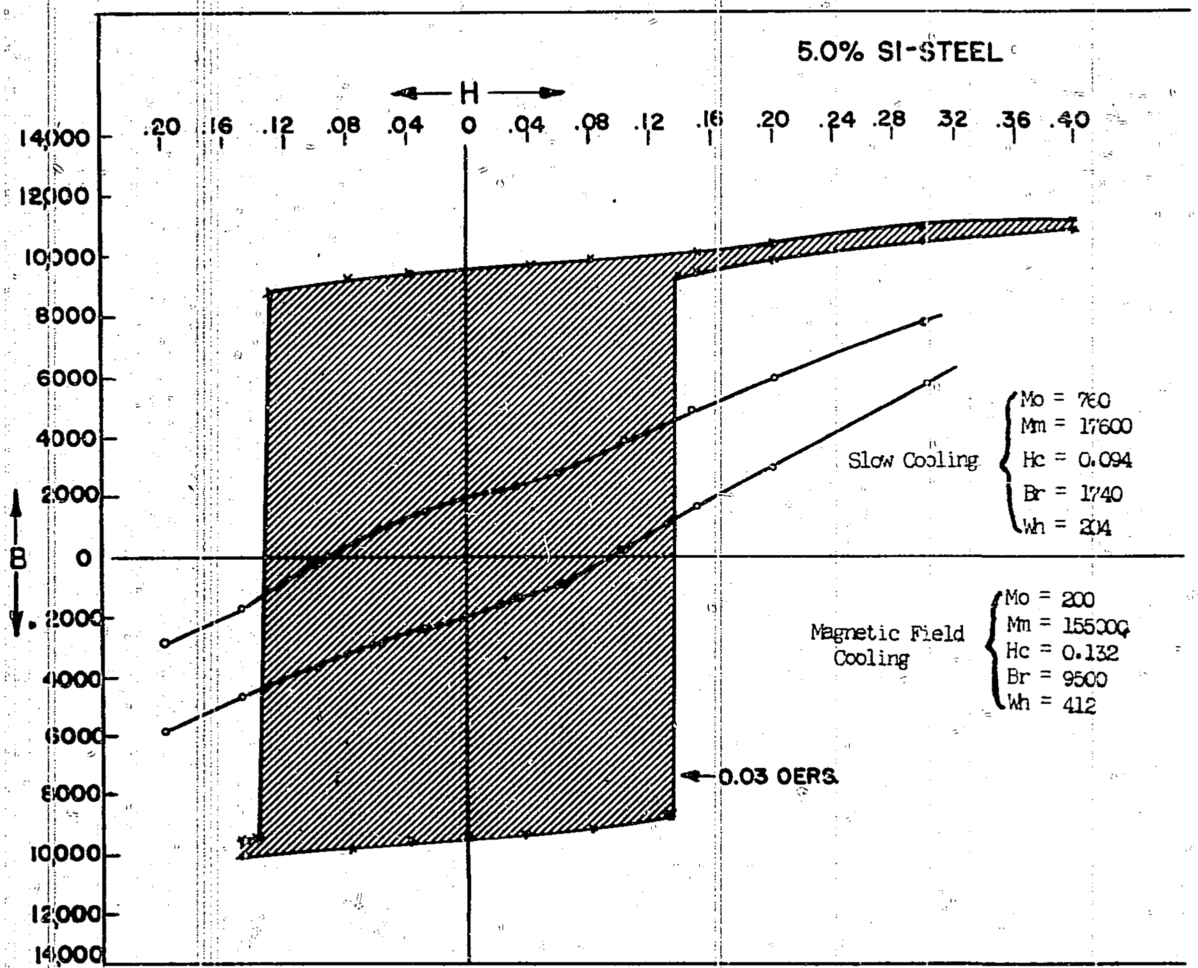


Figure 4(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

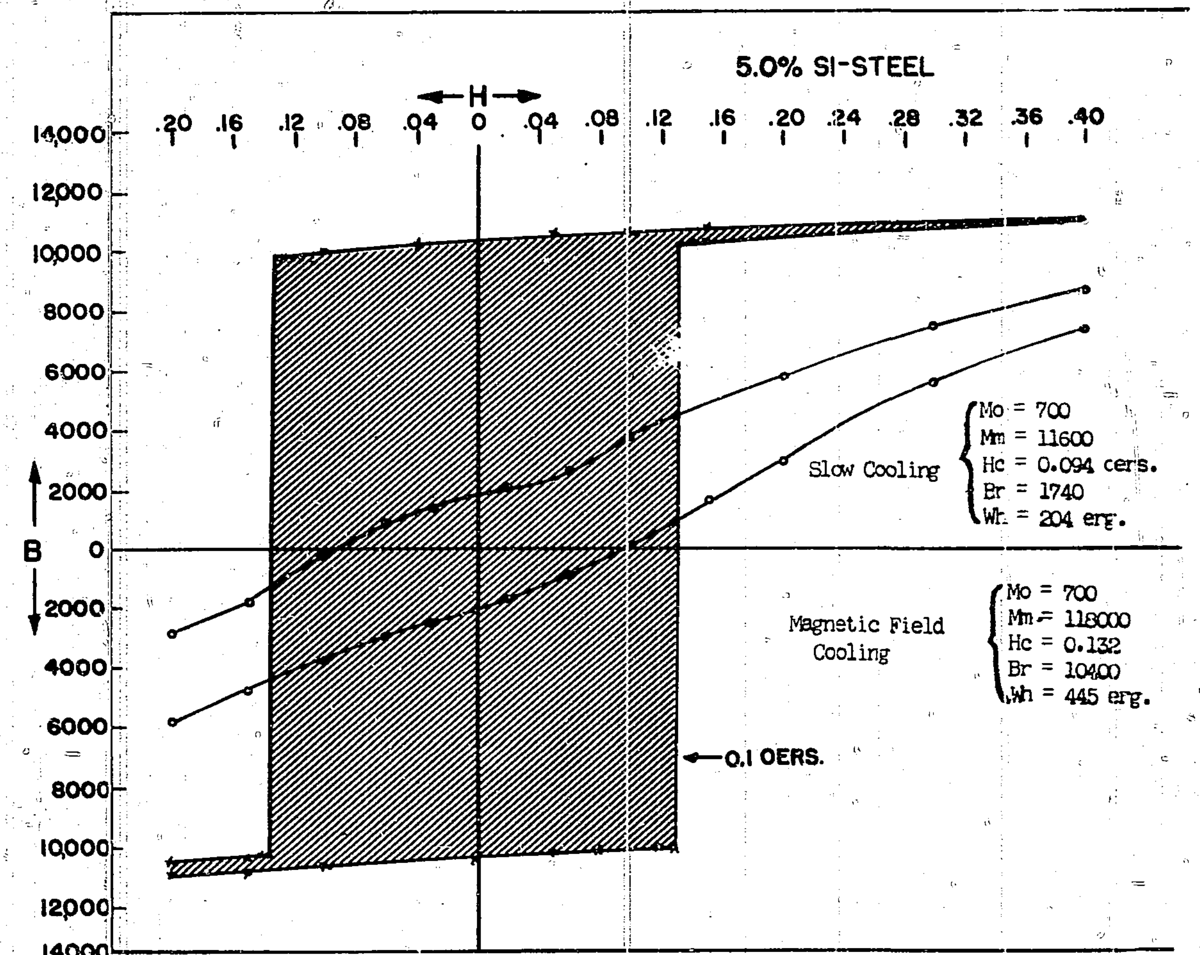


Figure 5(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

'CLOSURE (D), continued

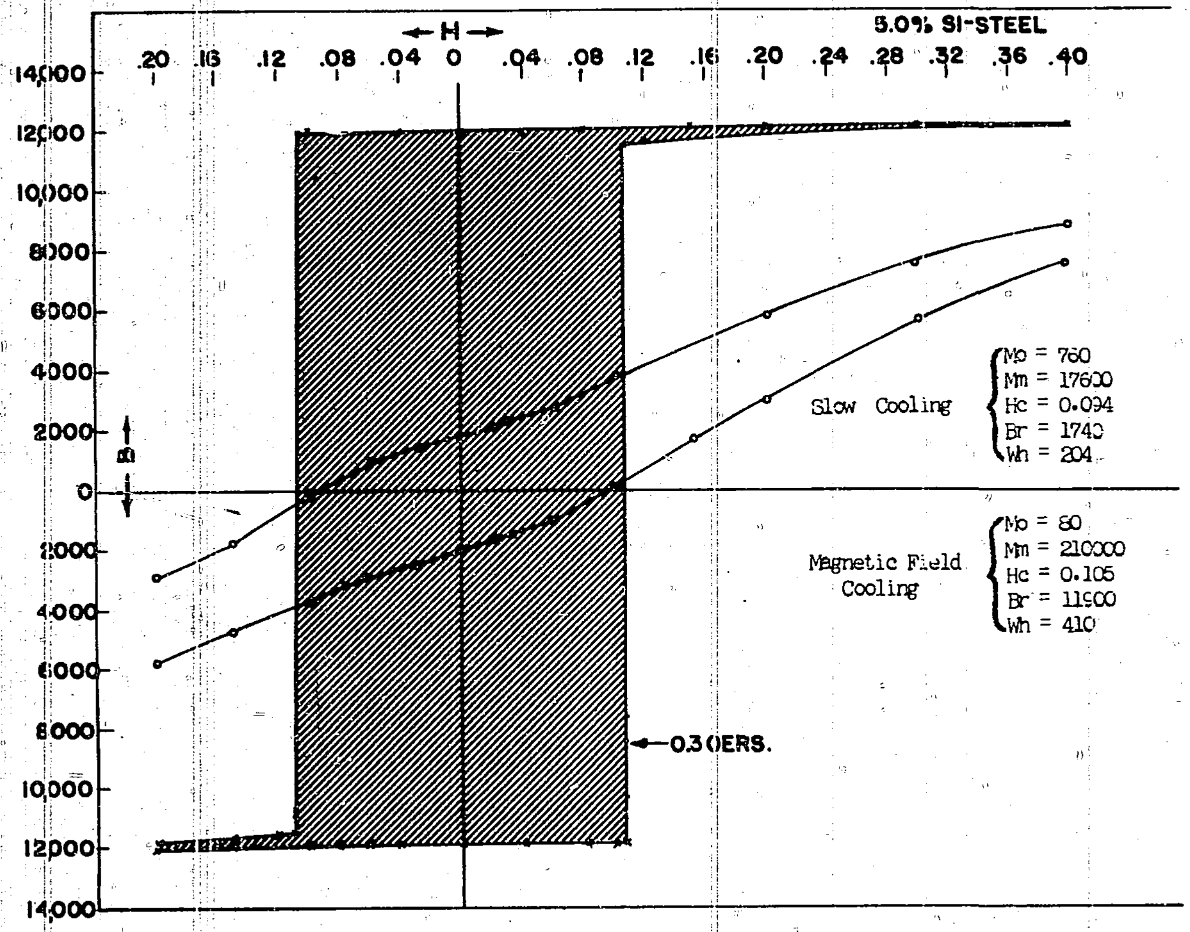


Figure 6(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

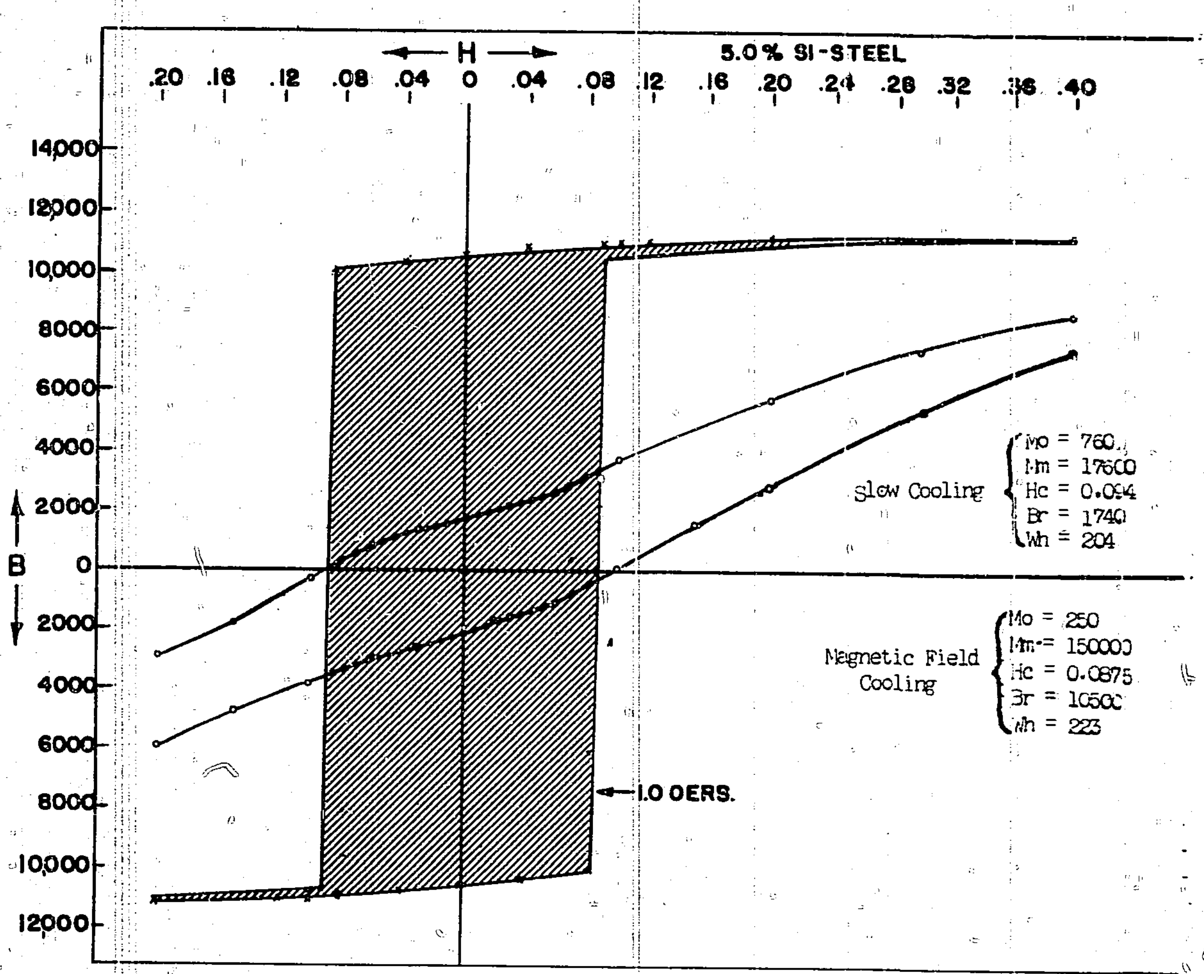


Figure 7(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

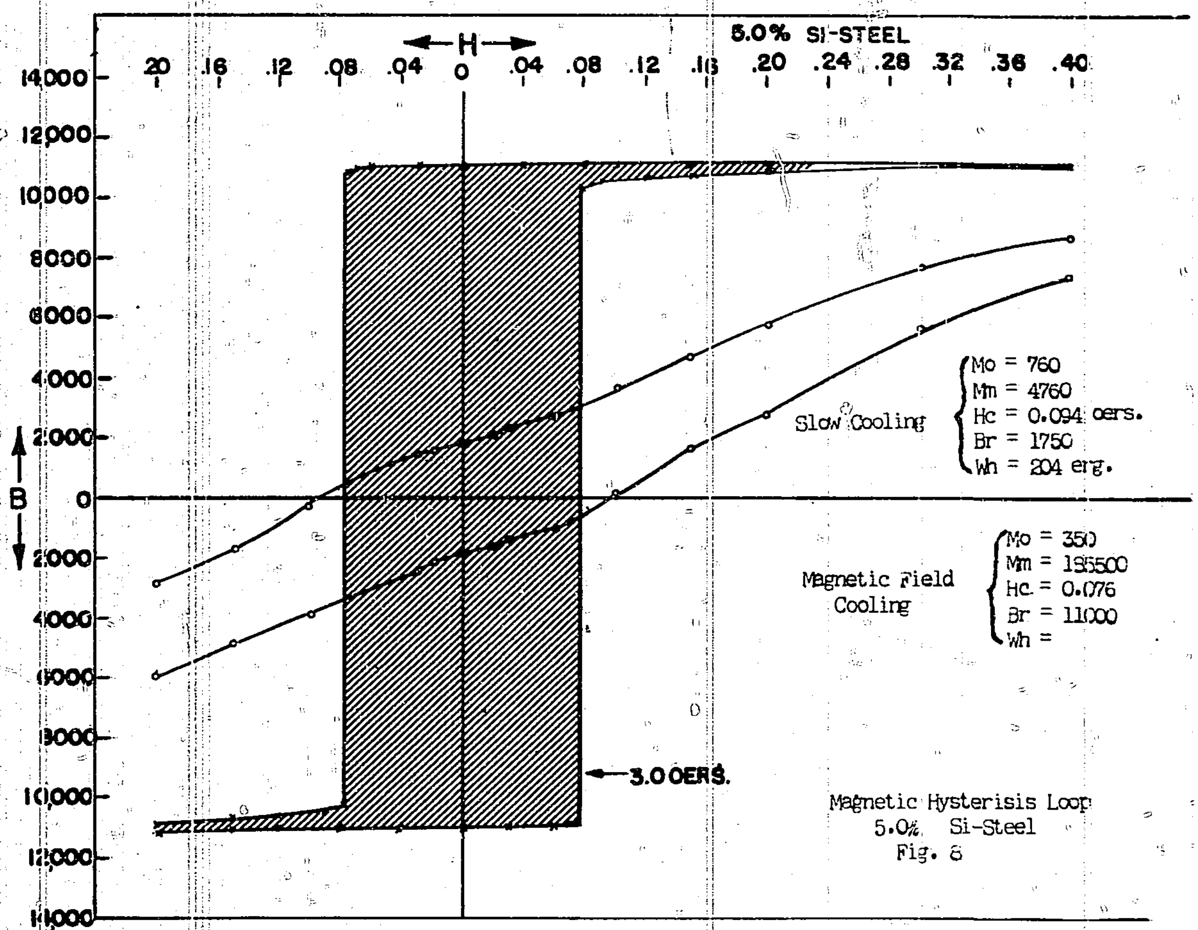


Figure 8(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (D), continued

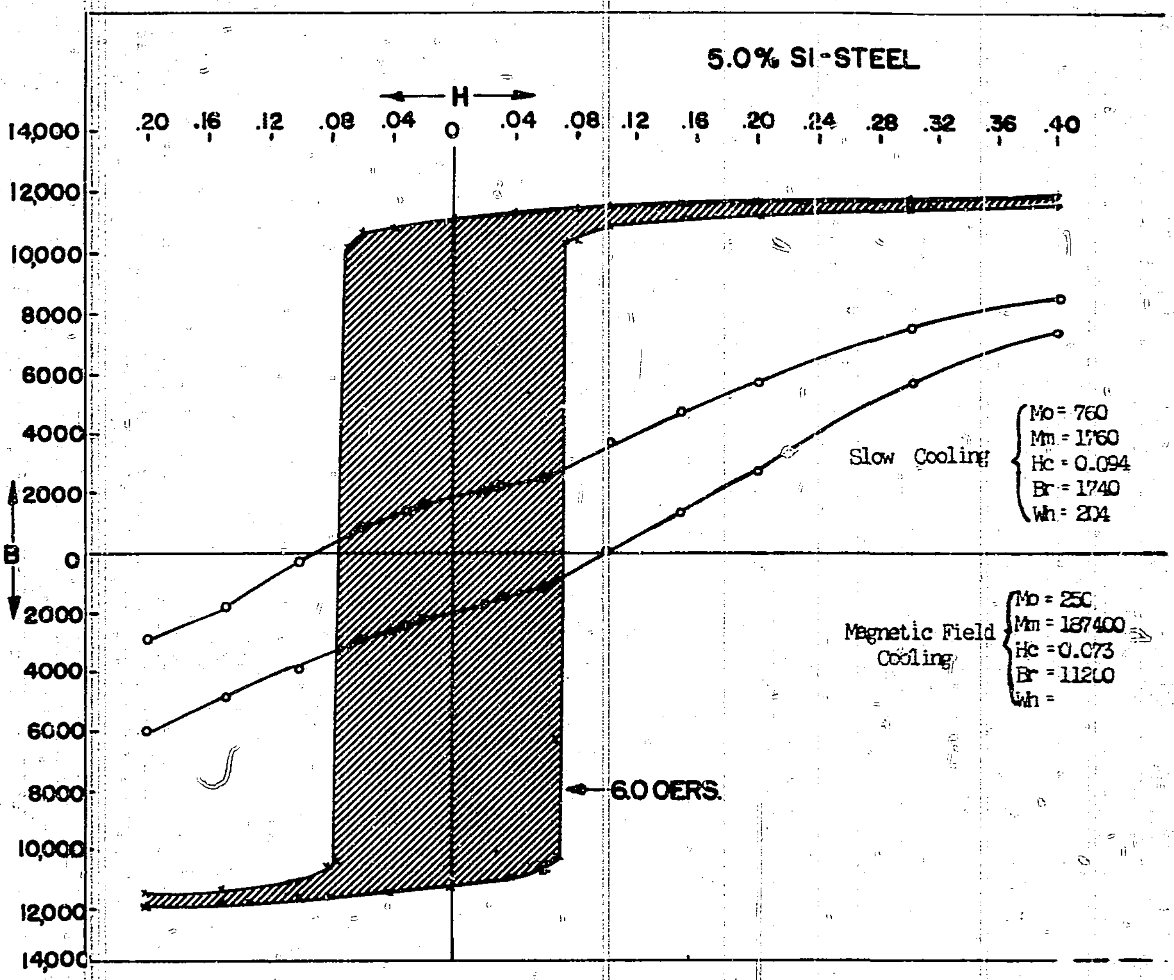


Figure 9(D)
MAGNETIC HYSTERESIS LOOP, 5.0% SI-STEEL

ENCLOSURE (E)

MAGNETIC AMPLIFIER
By Mr. K. MIHARA

Once I tried a magnetic amplifier for weak D.C. charges.

Ring is some 60mm in diameter, 3mm thick, and 20mm wide. The material is permalloy to which slow cooling is preferable, by adding elements other than iron and nickel for high μ_0. The specimen has two necks with 1/120 sectional area of other thick part and 4mm long.

About 10 amperes of D.C. could be amplified and detected, as I remember, with 10 ohms D.C. coil resistance. The defects are: unstable, hysteresis phenomenon, sensitive to earth's field.

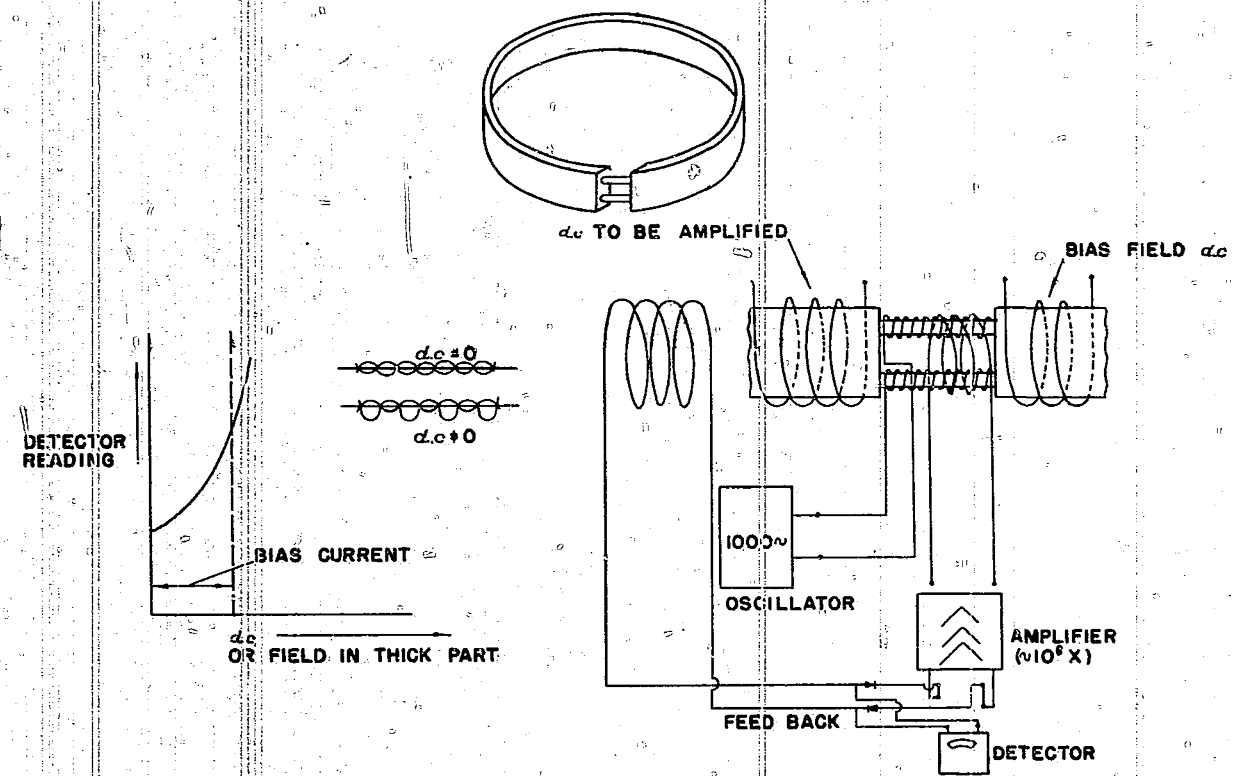
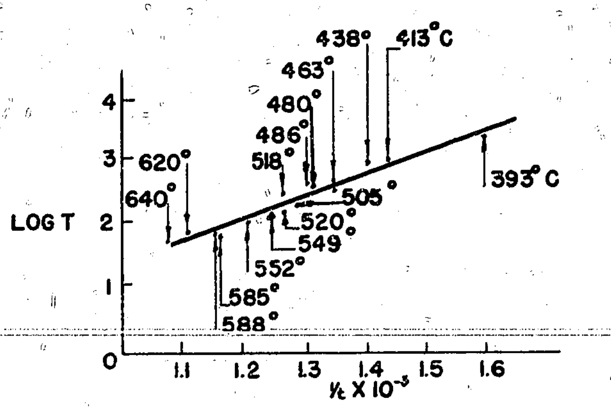


Figure 1(E)
MAGNETIC AMPLIFIER



RELATION BETWEEN RELAXATION TIME AND TEMPERATURE OBTAINED WITH 4% HIGH-PURITY SILICON STEEL

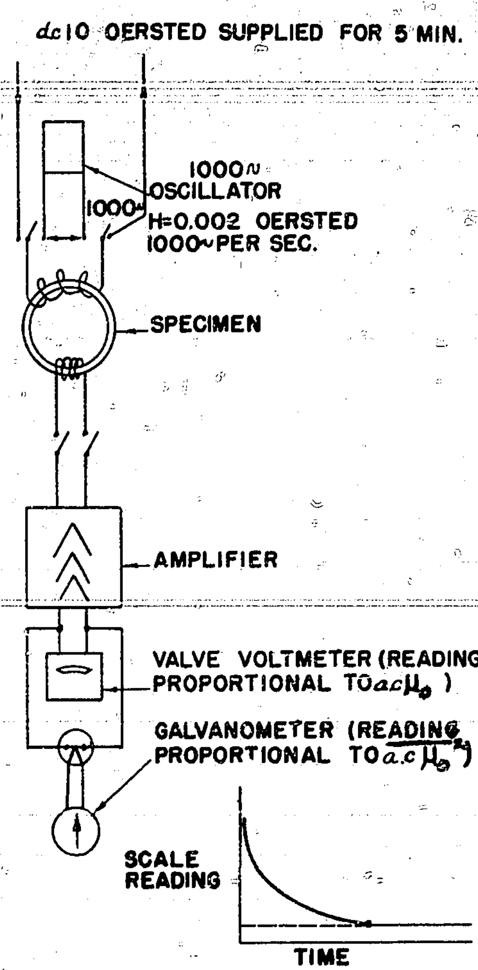


Figure 2(E)

RELATION BETWEEN RELAXATION TIME AND TEMPERATURE OBTAINED WITH 4% HIGH-PURITY SILICON STEEL

ENCLOSURE (F)

PRODUCTION FIGURES OF MAGNETIC ALLOY STEELS
(In Metric Tons)

1940 - 1944

Tohoku Kinzoku K.K., SENDAI

	1940	1941	1942	1943	1944
KS	20	22	34	53	62
Cobalt	18	20	32	58	66
Sendust	20	37	63	104	122
Permalloy	0	0	0	0	0

Mitsubishi Seiko, TOKYO

	1940	1941	1942	1943	1944
MK Magnet Steel	39.0	35.8	41.5	75.5	57.0

ENCLOSURE (G)

LIST OF JAPANESE DOCUMENTS FORWARDED TO THE WASHINGTON DOCUMENT CENTER

NavTechJap No.		ATIS No.
ND50-5040	Experimental Research on Special Magnetic and Electrical Qualities of Fe-Si-Ni Ternary Alloys - T. YAMAMOTO (Thesis), 1944.	3373
5041	On the Magnetostriction of Iron-Aluminum Alloys and a New Alloy "Alfer" - K. HONDA, H. MASUMOTO, Y. SHIRAKAWA and T. KOBAYASHI, 1945.	3374
5042	Magnetic and Electrical Qualities of Fe-Si-Al Magnetic Alloys - T. YAMAMOTO, 1944.	3375
5043	Japan Nickel Review, Vol. 8, No. 4, October, 1940.	3376
5044	Manufacture of Silicon Iron at Yawata Steel Plant, 1945.	3377
5045	Report of Investigation on Cold-Rolled Silicon Steel - S. KAYA and K. TAKAHASHI, 1945.	3378
5046	New High Permeability of Nickel Iron Alloy - K. MIHARA, 1940.	3379
5047	Study on Heat Treatment of Silicon Steel in Magnetic Field - K. MIHARA, 1945.	3380

ENCLOSURE (H)

LIST OF JAPANESE EQUIPMENT SHIPPED TO THE BUREAU OF ORDNANCE

NavTechJap Equipment No.	
JE50-5200	Alfer sheet (2 pieces)
5201	Alperm sheet (2 pieces)
5202	Alfer sheet (2 pieces)
5203	Alfer plate
5204	Magnetostriction vibrator
5205	Laminations for magnetostriction vibrators
5206	Magnetic shield, Sendust (2 parts)
5207	Roll of recording wire
5208	Magnetostriction vibrator
5209	Telephone ringer
5210	NKS magnet receiver
5211	Sendust cores
5212	Alfer or Alperm pieces
5213	Magnetic amplifier (OKADA)
5214	Magnetic amplifier (HARADA)
5215	Receivers using OP magnet
5216	NKS Speaker-magnet

ENCLOSURE (I)

LIST OF JAPANESE PERSONNEL INTERVIEWED

Location of Targets and Japanese Personnel Interviewed:

Japanese Navy Ministry, TOKYO.

Comdr. S. ABE, Engineer.
Capt. Y. ITO, Radio Engineer.
Capt. T. MATSUI.
Adm. T. MIYAZAWA, Engineer.
Mr. T. OTANI.

Tohoku Imperial University and Research Institute for Iron, Steel and Other Metals, SENDAI.

Dr. K. HONDA, President of Research Institute.
Dr. H. MASUMOTO, Professor of Physics.
Dr. T. KUMAGAI, President of the University.
Dr. T. HIRONE, Professor of Physics.
Dr. T. NISHINA, Professor of Physics.
Dr. Y. KIKUTI, Professor of Electrical Engineering.
Dr. K. NAGAI, Professor of Electrical Engineering.
Dr. J. SAMEYOSHI, Professor at the University.

Tohoku Kinzoku, SENDAI.

Dr. H. TAKAGI, President.
Dr. K. SHIMABA, Research Metallurgist.
Dr. T. YAMAMOTO, Research Metallurgist.
C. USHIODA, Engineer (Tungsten Products).

Nippon Electric Co., Tokyo Office and Tamagawa Plant, TOKYO.

Dr. Y. NIWA, Chief Engineer and Director.
Dr. O. ITOH, Superintendent, Tamagawa Plant.
Dr. K. KOBAYASHI, Assistant Superintendent, Tamagawa Plant.
Dr. M. FUKUSHIMA, Engineer.

Tokyo Imperial University, TOKYO.

Dr. T. MISHIMA, Head of Metallurgical Department.
Dr. S. KAYA, Professor of Physics.
Mr. K. TAKAHASHI, Assistant to Dr. KAYA.
Dr. R. HASIGUTI, Assistant Professor of Metallurgy.

Tokyo University of Engineering, TOKYO

Dr. T. TAKEI, Professor of Electrochemistry.

Second Naval Technical Institute, TOKYO.

Mr. ARAKI, Member of Research Staff.

Nippon Electrolytic Iron Works, TOKYO.

T. MASUKO, General Manager.
Y. OKAMURA, Engineer, Tokyo-Shibaura Engineering Co.

ENCLOSURE (I), continued

Electrotechnical Laboratory, Board of Communications, TOKYO.

Dr. S. KOMAGATU, Director.
Dr. S. OKADA, Engineer.
Dr. G. YOSHIDA, Engineer.

Nagoya Imperial University, NOGOYA.

Dr. S. TAKEDA, Professor of Metallurgy.

Sumitomo Steel Works, OSAKA.

Dr. S. YANAGISAWA, General Manager.
Dr. S. HORI, Chief of Research Laboratory.

Suita Plant of Sumitomo Steel Works, SUITA.

Mr. K. NARIAI, Sub-Manager, Planning Department.

Kawasaki Sheet Steel Works, KOBE.

Mr. Y. NISHIYAMA, In Charge of Steel Production and Staff.

Japanese Naval Base, KURE.

Adm. A. YAMAKI, Chief, Administrative Department, Kure Local Repatriation Center.
Mr. M. FUJIKAMI, Engineer at Naval Base.

Kyushu Imperial University, FUKUOKA.

Dr. T. MUTO, Professor of Physics.
Prof. K. MISE, Mechanical Engineering Department.
Prof. K. HARADA, Electrical Engineering Department.

Nippon Iron & Steel Co., Yawata Works, YAWATA.

Mr. I. KOHIRA, Chief of Steel Production.
Mr. T. KITAMURA, Chief in Charge of Operations.
Mr. M. SUNAGA, Chief, Rolling Department.
Mr. M. TAKAHASHI, Engineer.
Mr. I. OKAMOTO.

Aeronautical Research Institute, Tokyo Imperial University, TOKYO.

Dr. R. KIMURA, Professor at Tokyo Imperial University.

Mitsubishi Steel Works, TOKYO.

Mr. R. REISEI, Mitsui & Co., Engineering Department.
Mr. O. HARIMA, Mitsubishi Steel Works.
Mr. M. YOKOTA, Sub-Manager.
Mr. S. Hattori, Director and Superintendent.

Institute of Physical and Chemical Research, TOKYO.

Dr. M. KIMURA, Professor at Tokyo Imperial University.

Furukawa Physico-Chemical Research Institute, TOKYO.

Dr. K. MIHARA, Professor of Engineering.