PHOTOGRAPH THIS SHEET

ADA950217

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

Watertown Arsenal Labs., MA

Rept. No. WAL 020/5

DOCUMENT IDENTIFICATION

12 Feb. 45

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR	
NTIS GRA&I	☒
DTIC TAB	☐
UNANNOUNCED	☐
JUSTIFICATION	
BY (12 Feb. 1945)	
DISTRIBUTION / Per Ltr. on file	
AVAILABILITY CODES	

DIST	AVAIL AND/OR SPECIAL	
A		

DISTRIBUTION STAMP

Released

DTIC
ELECTE
APR 13 1981
S D
D

DATE ACCESSIONED

THIS DOCUMENT IS BEST QUALITY PRACTICABLE.
THE COPY FURNISHED TO DDC CONTAINED A
SIGNIFICANT NUMBER OF PAGES WHICH DO NOT

UNANNOUNCED

81 4 09 113

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 020/5

[illegible]

Magnetic Particle Testing - Control of Magnetization
The General Electric Magnetic Field Gage

BY

Carlton H. Hastings
Pfc., Ordnance Dept.

DATE 12 February 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

DISTRIBUTION

Report No. WAL________________ Total No. of Copies 2

Date Distributed________________ Extra Copies 0

Author

Laboratory Report File

1-oco, ordtr, 11/12/46

Office, Chief of Ordnance

TECHNICAL DIVISION

Ordnance Technical Library
SPOTB - Tech. Reports
SPOTB - For British Army Staff
SPOTR
SPOTM
SPOTT
SPOTC
SPOTS
Others

INDUSTRIAL DIVISION

SPOIR
SPOIM
SPOIS

DETROIT

SPOME - EE
SPOME - EM

Frankford Arsenal

Springfield Armory

Watervliet Arsenal

Rock Island Arsenal

Picatinny Arsenal

Ordnance Research Center

Paint & Automotive Chemical Laboratory

Others

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 020/5

(Problem No. M-4.6)

12 February 1945

~~First Partial Report~~

Magnetic Particle Testing - Control of Magnetization

~~The General~~ Electric Magnetic Field Gage

INTRODUCTION

The report presented herein is an abstract of a report based on experiments performed with the General Electric Magnetic Field Gage by the Magnaflux Corporation. A brief introduction to this work is presented in the following.

A deficiency of the magnetic particle method of inspection at the present time is the lack of uniformity of results when the test is applied to steel of varying thickness or to steels of different compositions. Existing specifications require that the current used for magnetization be metered and maintained between certain limits which may vary depending upon the items to be inspected and the technique employed. It has been acknowledged by workers in this field that measurement of magnetizing current does not insure comparable test results in all cases. For example, when steel is magnetized for magnetic particle inspection, the distribution of current between electrical contacts may vary depending upon the position of these electrical contacts and, thus, the magnetic flux distribution varies. Variations in magnetic flux distribution from one sample tested to another probably account for the difference in powder patterns on these samples. The same difficulty may be encountered when considering only one sample tested by several operators. This deficiency of magnetic particle testing as it is carried out at the present time was pointed out in the unpublished work of Mr. J. F. Cotton* who attempted to evaluate the variation in magnetic flux in samples of varying thickness.

A solution to this problem which has been offered involves the measurement of some quantity such as magnetic flux in the specimen, or magnetic leakage field strength in the air directly above the surface under inspection which would be more directly related to the occurrence of magnetic particle patterns than the current measurement. This quantity should be measured locally at various points on the surface of the casting. A specification might then be written to require a definite minimum magnitude of this quantity, say magnetic flux, for the detection of defects in a type of sample and the inspector may adjust his magnetizing technique to obtain this minimum value at any point on the sample.

In an effort to materialize the above idea, "A" ~~the General Electric Company~~ has attempted to develop a suitable instrument which would be

---

* "Magnetic Powder Inspection of Large Castings", a paper presented by Mr. John F. Cotton at the Annual Meeting of the American Foundrymen's Association, Buffalo, N. Y., April 25-28, 1944. This paper has not yet been published.

adaptable to this problem. As an approach to the problem the above company has altered an instrument already developed as a magnetic film thickness gage. The thickness gage consisted of an inductance bridge calibrated in terms of the thickness of nonmagnetic coatings on magnetic materials. A nickel iron shunt strip was added to the existing gage head arm of the bridge and the calibration of the meter changed to arbitrary "magnetic field units". It is understood that it has been admitted by the General Electric Company that there is no certainty as to just what quantity the Magnetic Field Gage measures. It has, however, been offered as a possible solution to the problem cited above.

Upon completion of the development of the field gage, Watertown Arsenal became interested in its application to specification requirements in the hope that it might be possible thereby to attain more consistent test results. The report of a preliminary investigation of the device by the Magnaflux Corporation has been studied, abstracted, and is discussed in the following pages.

SUMMARY OF RESULTS AND DISCUSSION

1. Theory of Operation of the Magnetic Field Gage.

The theory of operation of the gage which was offered in the original report and which had been formulated before the performance of experiments explained the meter reading on the basis of a change of inductance of one of the arms of the bridge, this being brought about through a change in the magnetic flux in the nickel iron strip shunting the gage head coil. Placing the nickel-iron strip shunting the gage head in contact with a magnetized specimen causes a shunting of at least a portion of the magnetic flux in the specimen through the nickel-iron strip. Thus, the flux through this strip and the meter readings are a function of the flux in the specimen and possibly also a function of the ratio of permeabilities involved in the strip and the specimen beneath the strip. Although the report stated that experiments showed the meter reading to be a function only of flux in the nickel-iron strip and not a function of the ratio of permeabilities, the experiments are not described in such a way that the conclusion is an obvious one. Experiments were performed, however, which showed that the meter reading is proportional to magnetizing force or applied current in the specimen rather than proportional to magnetic flux in the specimen. It is pointed out (see Figs. 7, 8, and 9) that although gage readings are proportional to H (magnetizing force) one still cannot predict flux in a specimen from a knowledge of the gage reading and magnetization curve (H vs. flux) since the constant of proportionality varies from one steel to another.

Tests showed that the gage cannot be used with coil or cable wrapping magnetization since the large leakage field from the magnetizing cables influences the meter reading. A statement is also made to the effect that leakage fields from the current alone when using circular magnetization have negligible effect on meter readings. The experiment leading to this conclusion is not explained in sufficient detail to make the conclusion evident.

It is pointed out that correlation between gage readings and magnetic powder patterns is good for surface defects but the correlation in the case of subsurface defects is not very good. Here again, for subsurface defects, the experiment performed is not explained clearly enough to permit an understanding of how the conclusion was reached.

In view of the uncertainty of this work it is contemplated that a program of investigation will be undertaken by this Arsenal in an attempt to more clearly define the usefulness of the General Electric Magnetic Field Gage to the Ordnance Department.

C. H. Hastings

C. H. Hastings
Pfc., Ord. Dept.

Approved:

MAM 4/24/45

H. H. Lester

H. H. Lester
Chief, Research Division

020/5

Summary of
Experiments Performed With the
General Electric Magnetic Field Gage
By ~~the~~
Magnaflux Corporation
Chicago, Illinois

The purpose of the work summarized herein, as reported by the Magnaflux Corporation, was to determine, if possible, the advantages and limitations of the General Electric Magnetic Field Gage, Catalog No. 5920230G6.

A schematic diagram of the gage is shown in Fig. 3. In operation, the gage head (Coil FE) is placed on the specimen or metal surface to be magnetized in such a position that the magnetic shunt (nickel-iron strip) is in contact with the metal surface. Adjustment of the meter to zero balances the bridge circuit for the high or low range as selected. The magnetizing current (D.C.) is then passed through the metal and the meter reading noted. According to theory, the D.C. flux passing through the shunt strip on the gage head causes a change in the permeability of this strip and thus a change in the inductance of the coil in the gage head. This change in inductance unbalances the bridge and causes a deflection of the meter. The A.C. bridge current is rectified before application to the meter. Since the nickel-iron shunt strip acts as a shunt for the D. C. flux in the metal immediately below it, the flux through this shunt and thus the meter reading is a function of the flux in the specimen being examined or possibly also a function of the ratio of permeability of the strip to the sum of the permeability of the strip and the permeability of the metal beneath the strip.

To test this theory of operation as offered in the report*, experiments were performed using a set up as depicted in Fig. 4. "CD" represents the metal to be examined; "B" a magnetizing coil; "A" a coil associated with a flux meter; and "FE" the gage head coil. The shunting effect of any material directly below the nickel-iron strip has been eliminated by using an air gap. The nickel-iron strip simply shunts the flux across this gap. The flux through the strip was measured for various magnetizing coil currents (three coil "B") by means of the flux meter. The gage was turned off during this measurement to prevent inductive pick up in the flux meter coil "A" from the gage coil FE through which alternating current passes when the gage is in operation. The relation between flux in nickel-iron strip vs. gage readings is shown in Fig. 5, Curve 1. The relation between magnetizing current through coil "B" and flux in nickel-iron strip is shown in Fig. 5, Curve 2. Fig. 6 shows a plot of magnetizing current through coil "B" against gage readings. An inspection of these curves indicates that the gage readings are proportional to magnetizing current or magnetizing force for one piece of steel tested.

To determine the shunting effect of material beneath the nickel-iron strip, a similar test was performed using a hot-rolled steel cylinder as a specimen. A gage reading of 4.4 was taken against a flux meter reading of 720 maxwells in the nickel-iron strip. From curve 1 of Fig. 5, a gage reading of 4.4 corresponds to a flux of 725 maxwells in the

---

***NOTE**: It is believed that this is ~~the Magnaflux Corporation's~~ "B"'s theory of operation of the instrument.

nickel-iron strip, thus indicating that idea of ratio of permeability in the strip to the permeability of the specimen is not valid as influencing the gage reading. It is the change in permeability of the strip alone that gives rise to the gage readings.

Fig. 7 shows a plot of G. E. gage readings vs. flux in cylindrical specimens. Flux was measured by wrapping several turns of wire through the cylinders. Magnetizing current was passed through a central conductor. For curves 1, 3, and 4 the flux was measured with a fluxmeter. For curve #2, flux was read from a magnetization curve for the material after calculating $H = 2I/10r$. Oersteds, knowing current and radius of rods. Fig. 8 shows gage readings plotted against H as calculated from above formula. It is obvious that gage readings are proportioned to H and not B for any one composition or type of steel. However, the slope of the curves in Fig. 8 is different. Thus, one cannot predict flux from gage reading and magnetization curve since the curves for gage reading vs. flux and H vs. flux do not always coincide (See Fig. 9).

Fig. 11 shows an irregularly shaped part. Gage readings were taken at different points on the surface when the prods were placed at 8 and 0.

Tests were made to determine what ~~the~~ effect ~~of~~ leakage fields from parts being magnetized would have. The G. E. gage cannot be used with coil magnetization because of large leakage field. If the gage head is placed on a copper rod carrying 1600 amps, the meter reads off scale. However, the leakage fields from the current alone in circular magnetization has negligible effect on meter readings; e.g., if gage head is placed on a 1-1/2" radius steel rod carrying 700 amps parallel to its axis, the meter reads 4.6. If the gage is held in the air 1-1/2" from the center of a small copper rod carrying 700 amps, the meter reads the same as it does at an infinite distance from the rod (or nearly so). Checks were made on a railroad rail and on an angle iron. No effect of leakage from fillets was noticed with the railroad rail; however, the meter read higher on the inside of the angle iron than outside. Angle iron was magnetized by passing current through between contact heads which should give uniform flux through the section. The effect of leakage at the fillet was noticeable in this case.

To ascertain correlation between gage readings and magnaflux indications, the following was reported. At position 3, Fig. 11, is a surface lamination which can be found when using the residual method with 500 amps. D.C. with prods spaced 2" on either side of the defect. At position 3u, is a defect which is detected with similar ease by the same method. However, gage readings are very much different (See reading for 3 and 3u - Fig. 11 for 465 amps.) When magnetized in the same manner and powder applied, the correlation between gage readings and powder indications is good (See Fig. 13). For subsurface defects, threshold powder indications do not correlate very well (See Fig. 13).

The comparison between gage readings at points 1 and 2 with 3 and 4 of Fig. 11 was at first questioned with regard to detectability at these points. Further consideration of the shape of the part led to the belief that the gage might not be so far off at that. This lead to data shown in Fig. 14; Gage readings vs. thickness. Note sharp increase of gage readings between 5/8" and 3/4" thickness. This variation seems improbable. It might be related to the length of the magnetic shunt which is 3/4" between contact points.

G/020

Advantages

1. "G.E. gage gives approximate idea if conditions are right to show defects."

2. "Gives direction of flux"

3. "Indicates excessive current, thus prevents overheating of part being examined."

4. "Standardization based on G.E. gage could be definitely helpful for certain parts."

Limitations

1. Not good for A.C. magnetization
2. Not good for half wave rectified current
3. Readings depend on surface condition and cleanliness.
4. Gage head is fragile.
5. Care and pressure required in placing gage head to get consistent readings.
6. Not good with coil or cable wrapping method.
7. Leakage sometimes interferes when circular method is used.
8. Gage doesn't have high enough range for subsurface defects.
9. Not good for residual method.

Questions Raised by Work

1. Does a gage reading of 2 on cast iron mean that a crack can be found as well as in hot-rolled steel with a reading of 2? (See Figs. 9, 15, and 16). Flux data in Fig. 16 calculated from curves of Fig. 9. Gage readings correlate O.K. with magnaflux pattern but not with flux. Possible that the flux values were calculated using wrong curve for the subject material.
2. What determines the detectability of a defect?
3. How does flux in a bar vary with thickness?

The original report was signed by Mr. Grant W. Coon, dated September 22, 1944.

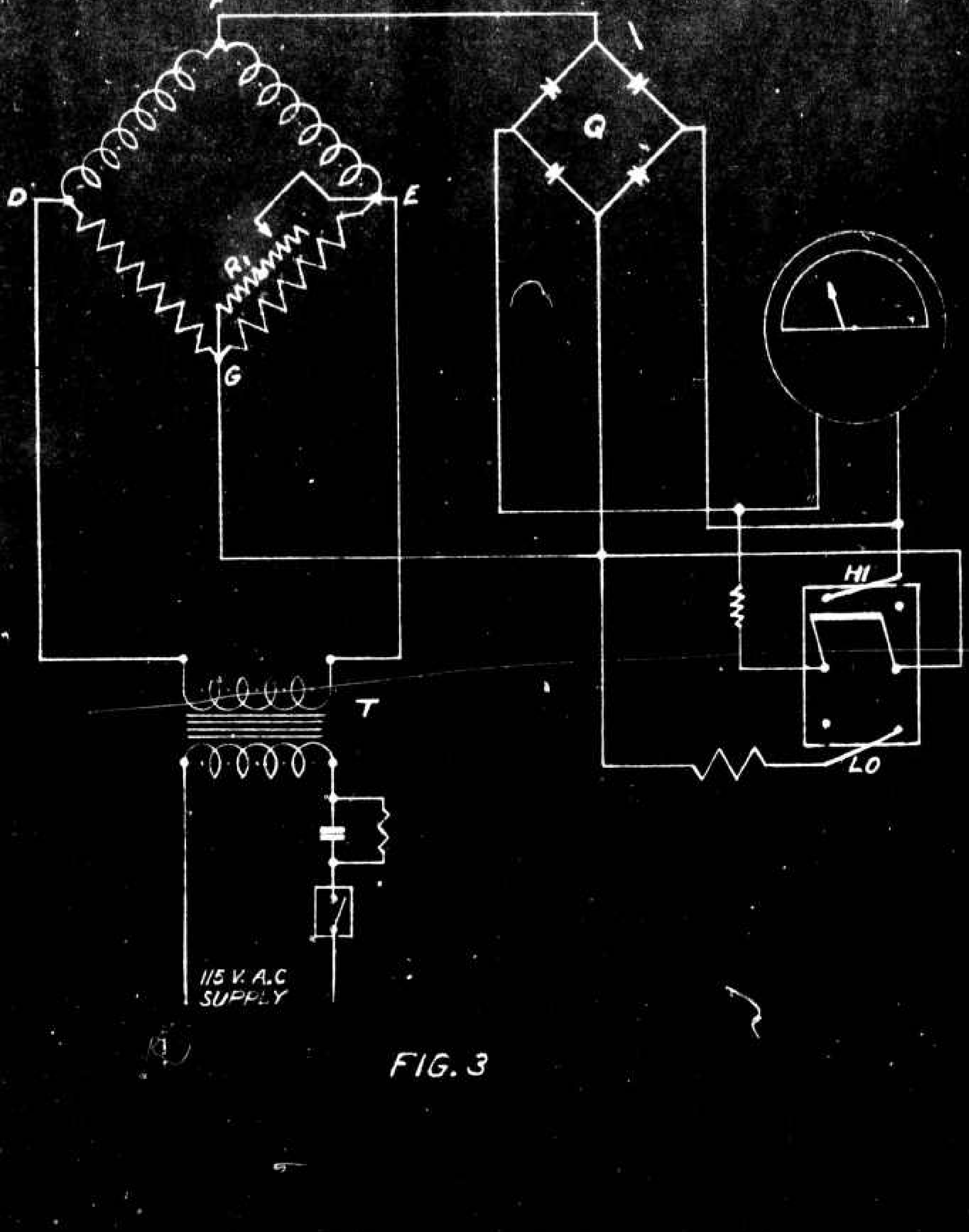


FIG. 3

R.A.B. 9-16-44

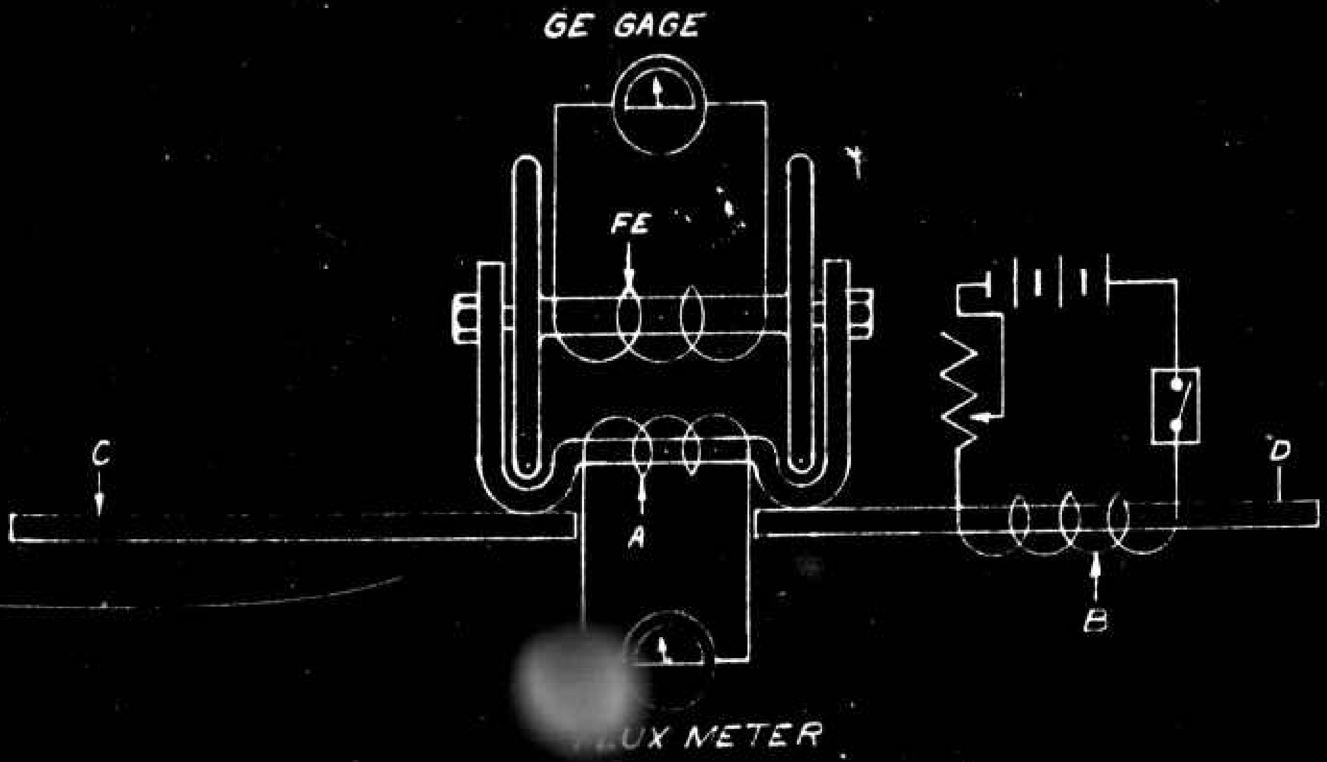


FIG. 4

R.A.B. 9-16-44

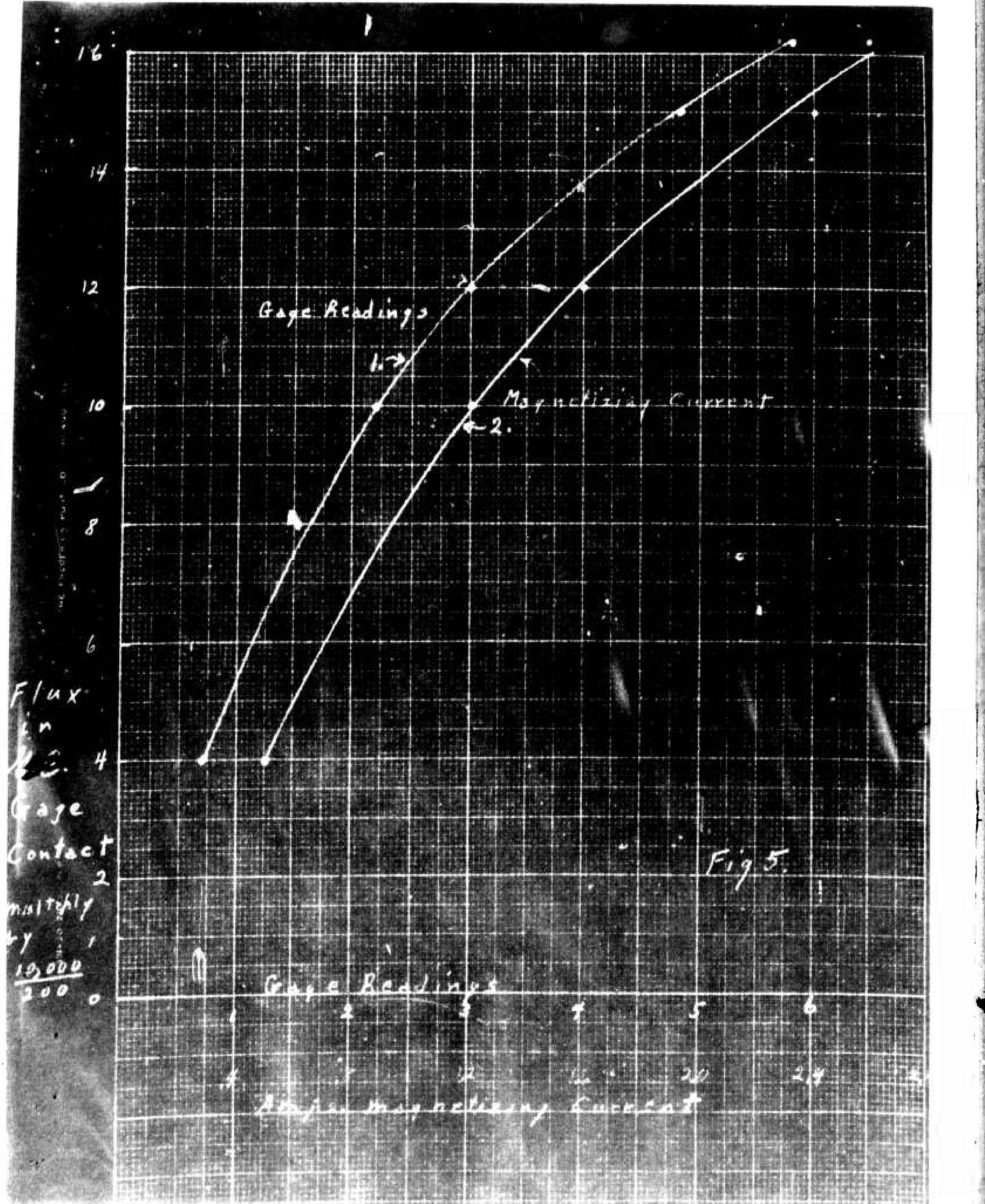

16
14
12
10
8
6
4
2
1
0
Flux in [illegible] Gage Contact multiply by 10,000 / 200
Gage Readings
1.
Magnetizing Current
2.
Gage Readings
1
2
3
4
5
6
4
8
12
16
20
24
Amperes magnetizing Current

Fig 5.

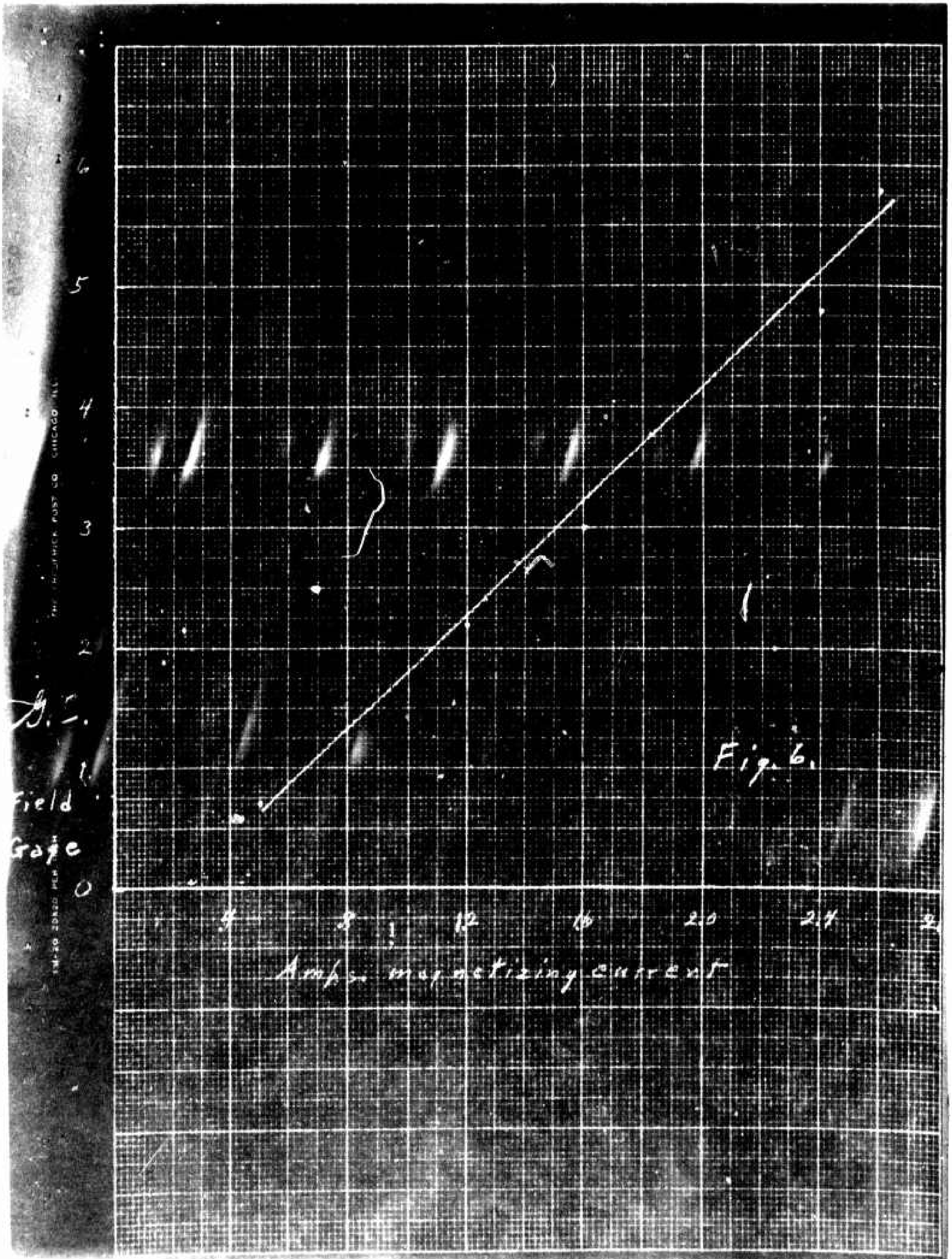
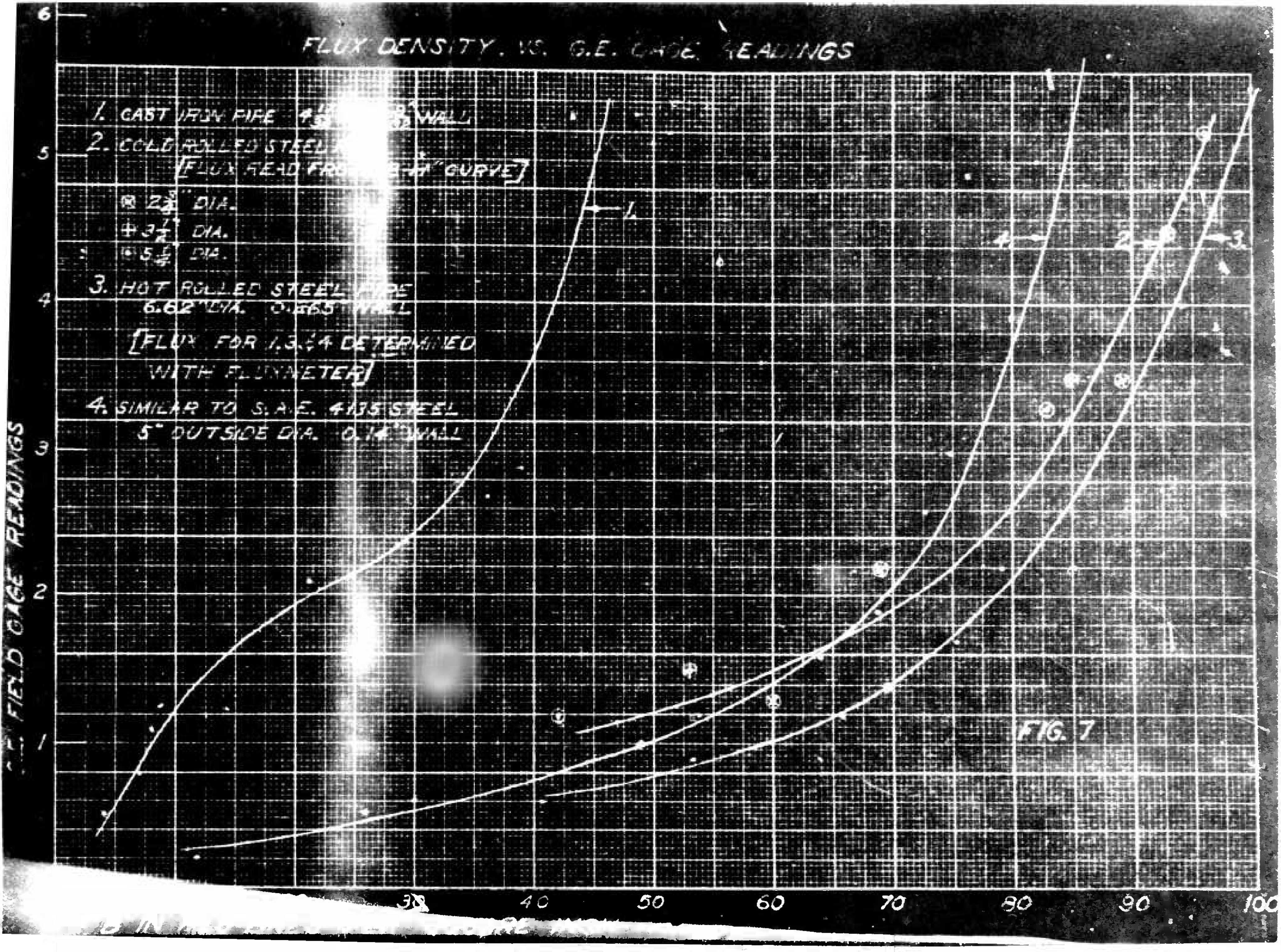


Fig. 6.



FLUX DENSITY . VS. G.E. GAGE READINGS

FIG. 7

MAGNETIZING FORCE VS. [illegible] GAGE READINGS

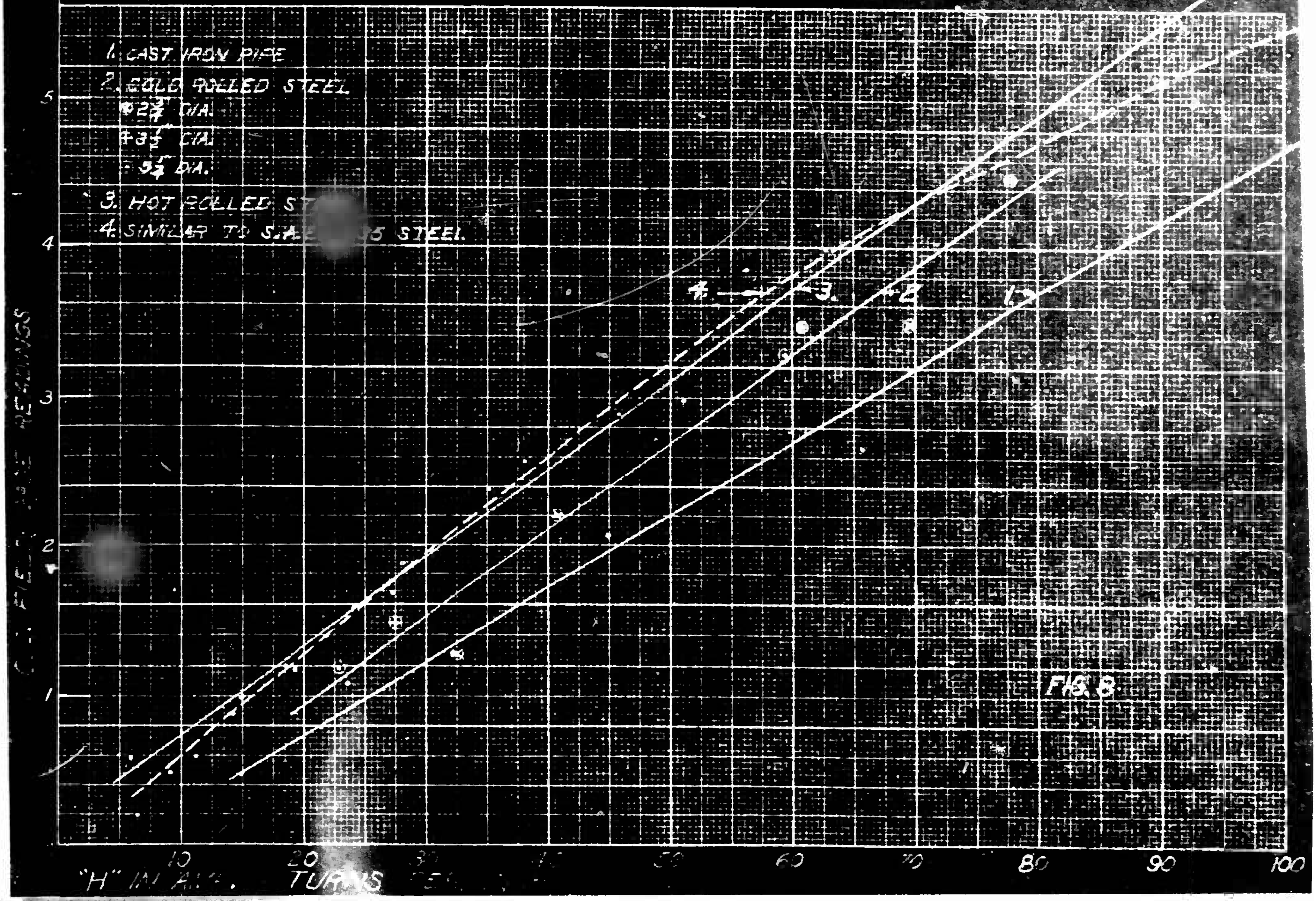


FIG. 8

COMPARISON OF MAGNETIZATION CURVES WITH GAGE READINGS

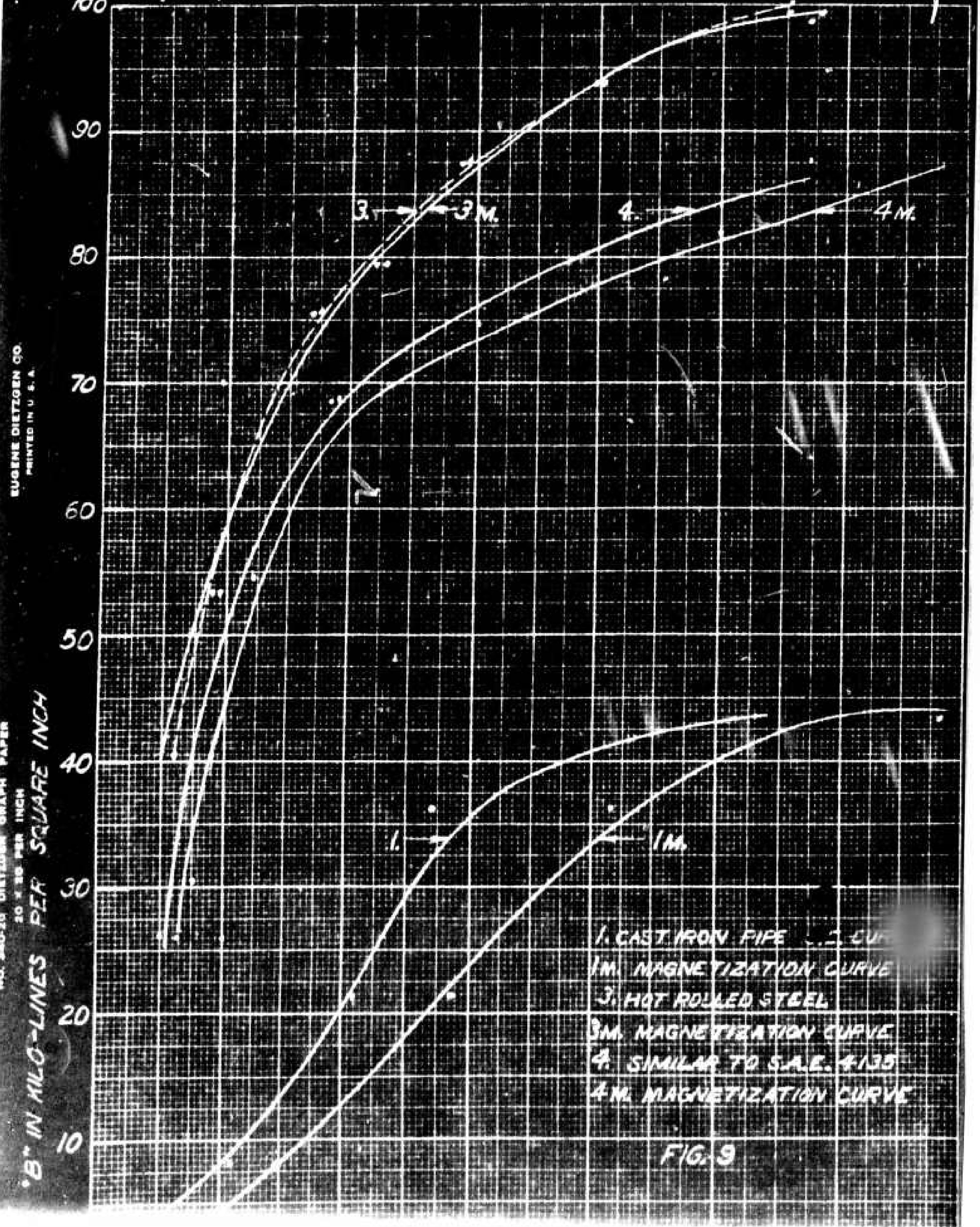
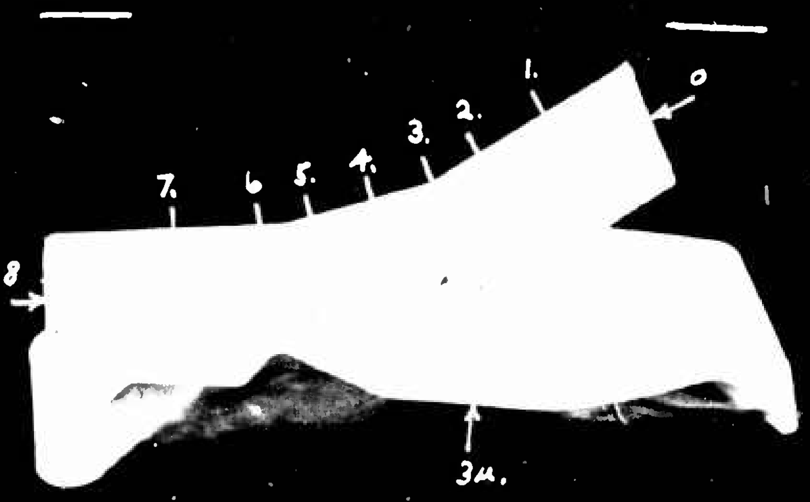


FIG. 9

(FIGURE 11)



Magnetized at 245 amps.

Position Number	Inches from right hand prod at 0	thickness of plate	[illegible] gage readings top side	under side
1	2-1/4"	3/8"	1.05	
2	4-7/8	17/32	1.1	
3	6-1/2	3-5/8	1.4	.4
4	7-1/2	3-1/8	1.4	.6
5	9-1/4	1-3/4	1.2	.7
6	10-3/4	3/8, 1/4, 5/8	1.2	
7	13	1-1/8	1.1	.7

465 Amps. Magnetizing Current.

Position Number	thickness of plate	[illegible] gage	[illegible] on under side (thickness the same)
1	3/8"	4.	
2	17/32"	3.8	
3	3-5/8	5.2	.7
4	3-1/8	4.8	1.7
5	1-3/4	4.2	2.4
6	3/8, 1/4, 5/8	3.8	
7	1-1/8	4.3	2.7

(FIGURE 13) CORRELATING GAGE READINGS WITH MAGNAFLUX INDICATIONS

AMPS.	Magnetizing Current at position 0 & 8	G. Reading	MX Indication (continuous method)
150	" 3	1.2	good
150	" 3u	.1	none
600	" 3	6. plus	very good
600	" 3u	1.0	small
900	" 3u	1.4	good

CORRELATION ON WELD DEFECTS

C.R. S bar 2-3/4 x 7/8 x 12" long

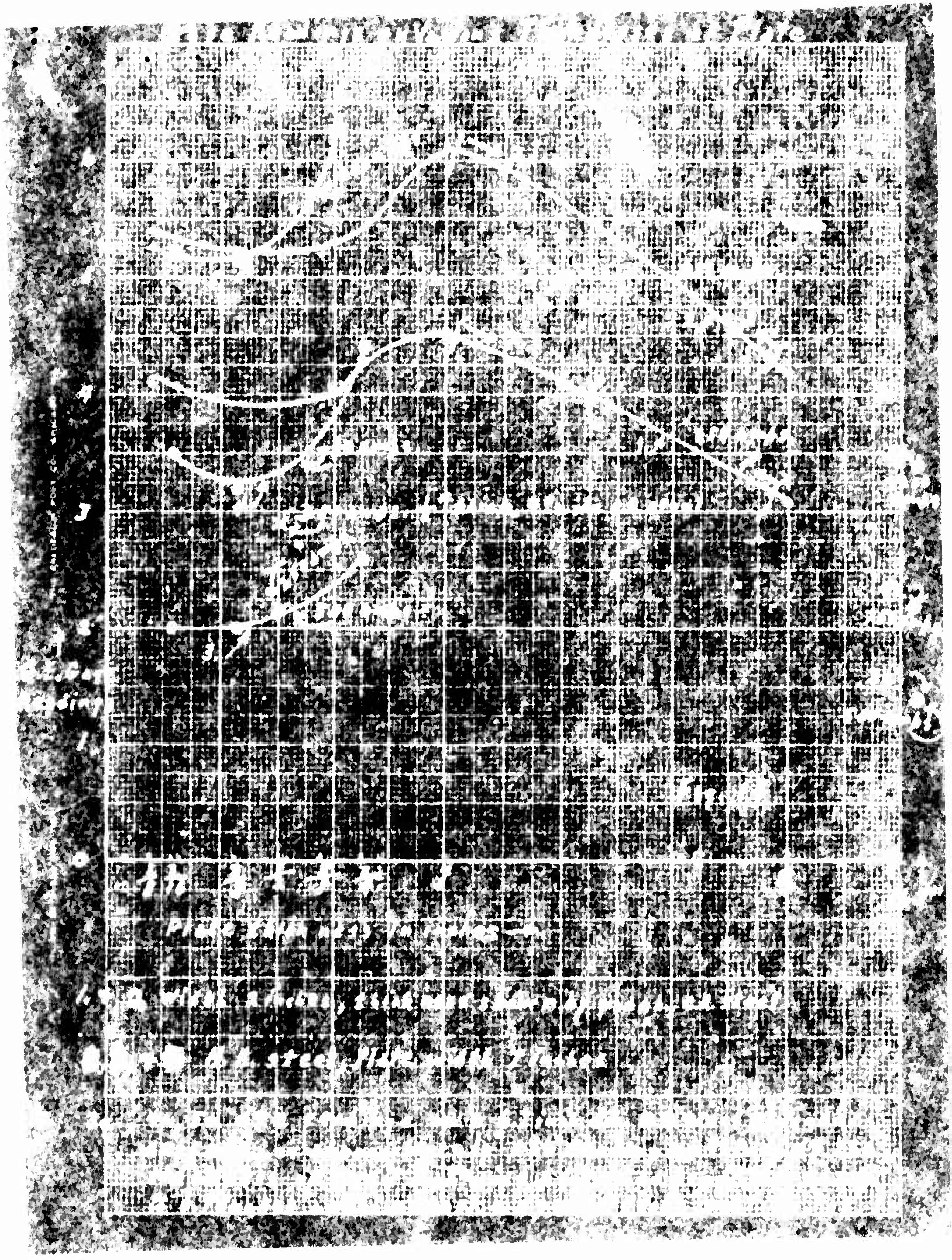
600 amps. necessary to show up a subsurface, artificial inclusion about 1/4" deep. 400 amps. gives an off scale reading (6 plus)

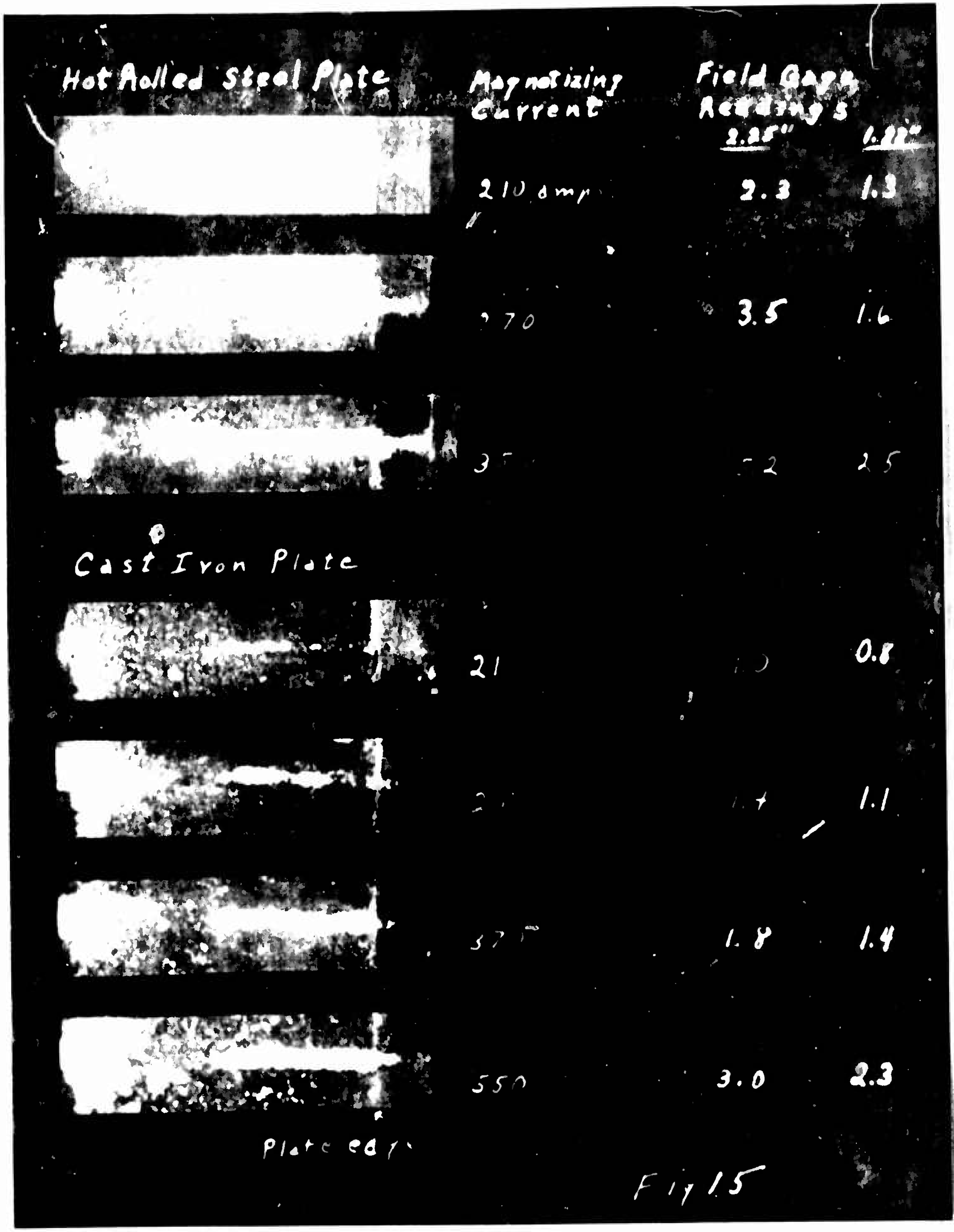
A different placing of prods brought out indication where defect was about 1/8 inch deep using 260 amps.

Prod Position	Magnetizing Current	G. Reading	MX indication
1 prod 2½" away 1 prod 9" away	260 amp.	5.0	threshold indication
both prods 2½" away	200 amp.	3.8	threshold indication

A 3/8" subsurface weld defect at center of 7½ inch long plate, 12 inch wide.
Prods placed along line of weld.
Defect parallel to weld.

Prod Positions	Magnetizing Current	Gage Readings	Indication
4" away from defect	600 amps.	2.7	threshold
3½" " " "	" "	"	"
1¼" " " "	300 "	1.9	threshold
3½" " " "	" "	"	"





Magnetizing Current	Field Gage Readings 2.25"	1.88"
210 amps	2.3	1.3
270	3.5	1.6
3[illegible]	[illegible]2	2.5
21	1.0	0.8
2[illegible]	1.4	1.1
375	1.8	1.4
550	3.0	2.3

Fig 15

(FIGURE 16) COMPARISON OF FLUX IN H. R. STEEL PLATE & CAST IRON PLATE

H.R. STEEL PLATE

[illegible] Readings at 1.875" from rod	Magnetizing Current	Amp. turns per inch	[illegible] lines per sq. inch x 1000
1.3	210 amps.	17.9	57.0
1.6	270	23.0	[illegible].
2.0	[illegible]	29.8	76.

[illegible]

.8	21[illegible] amps.	17.9	5.2
1.1	[illegible]	23.0	[illegible]
1.4	[illegible]	31.5	12.9
2.3	[illegible]	4[illegible].2	25.0