T H E S I S

THE DESIGN OF A TESTING MAGNET

Submitted by

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This paper deals with the design and construction of an electromagnet capable of producing a flux density of 100,000 lines per square inch across an air gap of .3 inch for use in the laboratory of the Department of Physics at the Virginia Polytechnic Institute. There are various styles of testing magnets on the market and after due consideration of the advantages and disadvantages of the several types, it was decided to build one of the type shown in the accompanying blue print.

The size of a testing magnet is to a certain extent arbitrary. However it is well to have the area of cross section as large as possible because upon this area depends the value of the total flux or total number of lines flowing through the magnetic circuit and if the total flux is high it is possible to increase the flux density in the air gap by varying the shape of the pole pieces.

Assume the magnet cores to be cylindrical and 4 inches in diameter giving a cross section area of 12.6 square inches. In order to adapt the magnet for optical experiments it is necessary to have a .75 inch hole through the center of the magnet blocks, magnet cores, and pole pieces. This reduces the area to 12.1 square inches. The other parts of the circuit must have such an area that the total flux will remain constant. The pole pieces can be made with the same diameter and area as the cores since they are to be constructed of the same material.

The magnet blocks must be at least 8 inches square to support the cores and winding. The area of cross section would then be 64 square inches. Cast iron has a lower permeability than steel and in the majority of cases it is assumed that the density in cast iron is half that in steel. If this be true, the area of cast iron should be twice as great as that of steel so as to maintain the total flux. From the area of the cores, the area of the blocks should be at least 24.2 square inches. This makes it possible to round the top of the blocks thereby reducing both the area and the weight. The area will still be in excess of the required value but it is doubtful if the flux will thoroughly saturate the entire area and a mean value of 30 square inches can be assumed.

The base must be as wide as the magnet blocks and can be made of either steel or cast iron. For steel the area of cross section will have to be 12.1 square inches giving a thickness of 2 inches provided there is a slot 1 inch wide through it for fastening the magnet blocks to it. For cast iron the area of cross section will have to be 24.2 square inches giving a thickness of 3.5 inches with a similar slot through it. The magnet as built in the shops will have a cast iron base since it impossible at the present time to secure the steel.

The length of the several parts is also arbitrary. Suppose the cores to be 6 inches long, the pole pieces to be made conical with a 45° slope making their length 2 inches. The blocks are 8 inches square and will have a mean path approximately 8 inches long. Since the mean path of the flux will follow approximately the center of the circuit, the length of the mean path through the base will be about 24.3 inches. Naturally the base will be made longer than this to allow for a variety of experiments.

From any standard text on electricity it can be found that $R = \frac{l}{\mu a}$ where R is the reluctance, l the length and a the area of cross section of the circuit. μ is the permeability of the material and can be obtained from the curves accompanying this paper. (These curves were taken from Christie: Electrical Engineering.) In this formula, however, l and a are in metric units. To use inches instead of centimeters, it is necessary to multiply l by 2.54 and a by $(2.54)^2$ which is equivalent to dividing the right hand member of the equation by 2.54 making the formula for use with English units $R = \frac{l}{2.54\mu a}$.

The values of l and a obtained above and the value of μ for each part of the circuit are tabulated for convenience.

Part	l	a	μ	R
Air gap	0.3	12.6	1	.0094
Pole pieces (2)	2.0	12.1	300	.0004
Magnet cores (2)	6.0	12.1	300	.0013
Magnet blocks (2)	8.0	30.0	150	.0014
Base	24.3	24.5	150	.0026
	Total Reluctance			.0151

The values for R in the above table were calculated as follows:

$$R = \frac{l}{2.54\mu a}$$

$$R_g = \frac{.3}{2.54 \times 1 \times 12.6} = .0094$$

$$R_p = \frac{2 \times 2}{2.54 \times 300 \times 12.1} = .0004$$ (For two pole pieces)

$$R_c = \frac{2 \times 6}{2.54 \times 300 \times 12.1} = .0013$$ (For two cores)

$$R_m = \frac{2 \times 8}{2.54 \times 150 \times 30} = .0014$$ (For two magnet blocks)

$$R_b = \frac{24.3}{2.54 \times 150 \times 24.5} = .0026$$

Total reluctance of circuit = .0151 oersteds

Assuming a flux density of 100,000 lines per square inch and with a cross section area of 12.6 square inches for the air gap, the total flux, Φ, will be 1,260,000 lines.

The magnetomotive force, M, is found from the relation $M = R\Phi$

$\therefore M = .0151 \times 1{,}260{,}000 = 19{,}000$ gilberts

Now M is also equal to $.4\pi NI$ where N represents the number of turns of wire in the magnetizing coil and I the current in amperes flowing through the coil.

The Department of Physics has a direct current generator capable of delivering

20 amperes at 110 volts. Using 20 amperes as the value of I

$M = .4\pi N \times 20 = 8\pi N$

But $M = 19,000$

$8\pi N = 19,000$

and $N = 755$ turns = number turns required for magnetizing coil.

To allow for any losses that might enter into the circuit, it will be safe to increase the number of turns to 1000 divided into 8 coils of 125 turns each situated 4 on each core. This will have a tendency to increase the flux density and the reluctance.

For a current of 20 amperes the coils should be wound of No. 12 double cotton covered wire having a diameter of approximately .1 inch. On each core there are four coils of 125 turns each. The cores are 6 inches long with .25 inch on each end occupied by walnut end pieces for finish, leaving 5.5 inches as the length of the winding space. This gives 1.4 inches as the width of each coil. Allowing .1 inch for insulation reduces this value to 1.3 inches as the winding space which is equivalent to 13 turns per layer. It will take 10 layers to complete the 125 turns. The thickness of 10 turns will be 1 inch with an additional .1 inch for insulation giving a mean radius of 2.5 inches. The length of a mean turn will be $2\pi \times 2.5 =$ 15.7 inches. The length of 1000 turns will therefore be 15,700 inches or 1310 feet, say 1325 feet which at .03 pound per foot will weigh about 40 pounds.

The terminals of each coil are to be brought out to separate binding posts located on a terminal board on top of the magnet blocks so that greater flexibility in operation can be obtained.

The approximate cost of the magnet as built in the V. P. I. shops is as follows:

The steel for the cores and pole pieces was secured from a second hand dealer in Norfolk, Va. for $6.30 plus $1.00 for drayage and $.75 for freight.

The castings for the magnet blocks and base were made in the V.P.I. foundry, the patterns being made in the wood shop, at a total cost of $34.10.

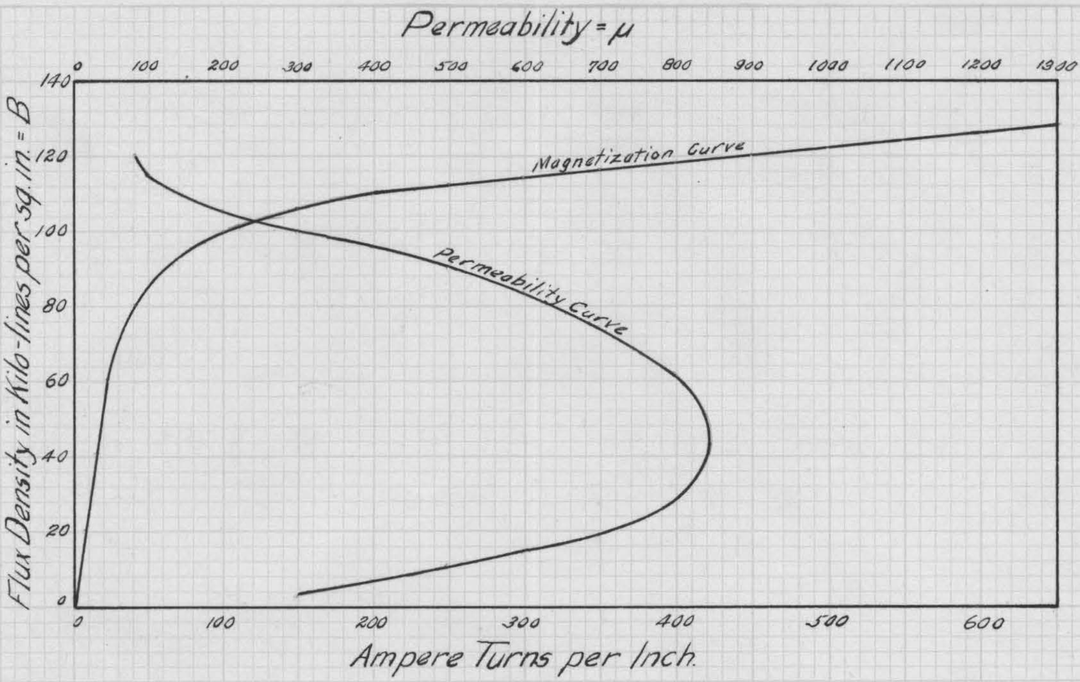
The wire for the magnetizing coils was ordered through the Electric Light Department from the Southern Electric Company, Baltimore, Md., the cost being $25.00

The linen tape to be used in insulating the coils was purchased from the Hope Webbing Company, Providence, R.I. for $4.00.

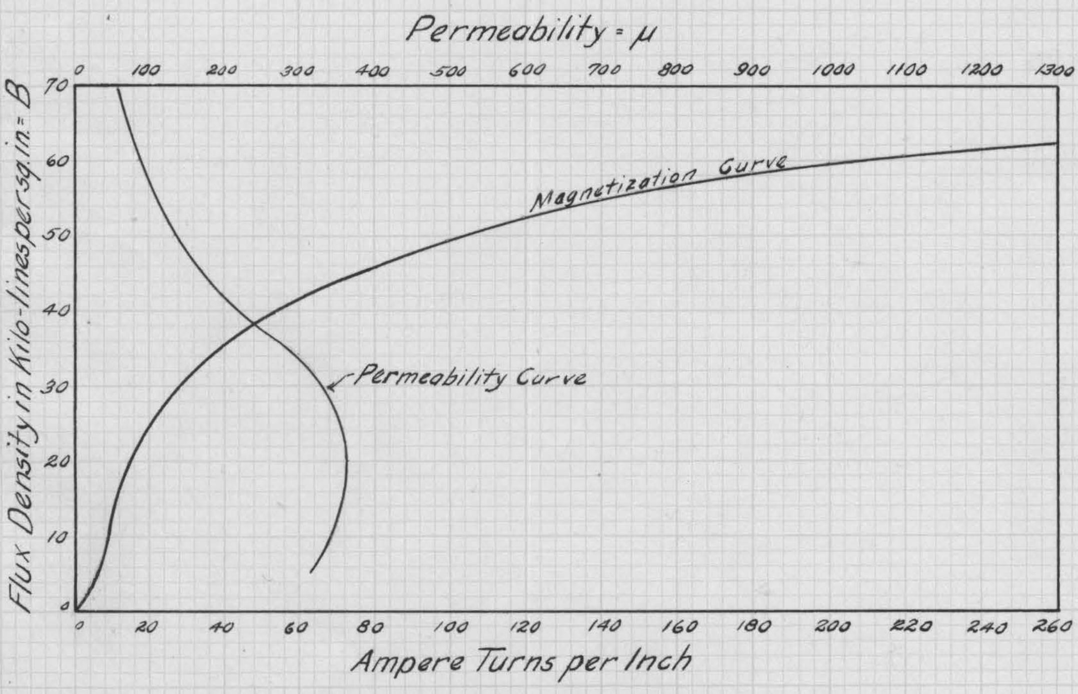
The binding posts, varnish, walnut end pieces and terminal boards will bring the total cost of the magnet up to approximately $80.00.

The weight of the magnet assembled will be about 600 pounds.

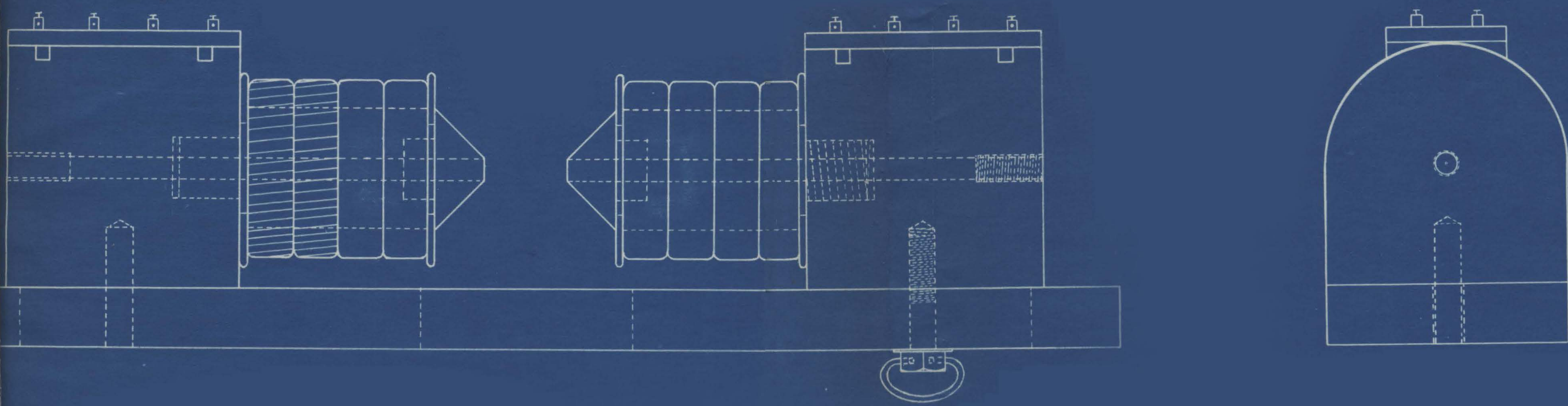
References - Christie: Electrical Engineering; Ewing: Magnetic Induction in Iron and Other Metals; Hudson: The Engineers' Manual.



Magnetic Characteristics of Cast Steel



Magnetic Characteristics of Cast Iron



TESTING MAGNET

Designed for

DEPARTMENT of PHYSICS

VIRGINIA POLYTECHNIC INSTITUTE

Scale: 1/4" = 1"

May 25, 1920. A.W. Fairer, Jr.