THESIS

EPSTEIN APPARATUS FOR DETERMINING CORE LOSSES

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** T H E S I S **

Construction and Testing of an Epstein Apparatus for the Determination of Magnetic Losses.

A Thesis Submitted to
The Faculty of
MICHIGAN AGRICULTURAL COLLEGE

By

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Candidates for the Degree of
Bachelor of Science.

June 1916.

** DEDICATION **

* TO *

The Electrical Engineering Department of the

Michigan Agricultural College for

Increasing and Bettering

the Laboratory

Equipment

and the Benefit

to the Course therefrom

this Work is heartily Dedicated

by the Authors

** PREFACE **

This book is a collection of notes and details for the construction and use of an Epstein apparatus for the determination of magnetic losses, especially in sheet iron and steel such as is used in transformer and armature laminations;

We selected the construction of this apparatus in view of the fact that it is a standard instrument and much needed to better the equipment of the department. Also, we considered the benefit to ourselwes derived from the working out of the details of construction, the pleasure of seeing it materialize and work out under test after completion.

The general specifications were taken from the 1913 year book of the American Society for Testing Materials, as per their requirements for the Standard Magnetic Tests for Iron and Steel, with such changes as were recommended by the committee A6 on that subject.

In the course of our work we received much help from various departments and persons connected thereto and we wish to express our deep indebtedness to;

Prof. W. L. Lodge and Prof. A. R. Sawyer for advice on construction, general information and supervision.

The Phisics Department for the use of laboratory and apparatus.

A. P. Krentel and C. N. Rix for material, use of tools and benches and also personal help.

C. A. Evans for the use of the machine shop in the winding of the coils and the machining of the metal parts.

F. Mitchel, college electrician, for the contribution of various articles of brass which entered into the apparatus.

A. B. Howard for finish used on the base and other wooden parts.

Barker Cole Electric Co. for extension of credit on our wire bill.

Everybody with whom we came in contact for general good will, readiness to help, and interest in the work.

We feel that we are well repaid for our efforts to make this work a success, and hope that the instrument which we have constructed will be of use and value to the Department. We will be glad if these notes, as the benefit of our experience, may be of use to any one considering the same or a similar project.

H.J.Knowlton.

W.B.Brown.

M.A.C. May, 1916.

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* * INTRODUCTION. * *

The manufacturers of electrical apparatus using sheet steel laminations require from the Steel Companies, material of guarenteed quality as regards the magnetic losses. Some means had to be provided for the determination of these losses and the apparatus formerly used required the use of the balistic galvanometer. The sample were put up in ring form and the magnetizing coils had to be wound on by hand. The samples being in the ring form required the expenditure of money for special machinery to punch them accurately from the sheets as they had to be either punched accurately to size, or turned to size after being punched. The winding of the magnetizing coils had to be very carefully done in order to obtain the correct number of turns. Before making the test the sample had to be carefully demagnetized, as a slight amount of magnetism would cause much error in the deflection of the galvanometer. A very careful test was then run, taking readings of the galvanometer deflection and current through the coil. From this data the hysteris loop was plotted and from the area of this curve the loss in joules could be calculated. This loss in joules had then to be transformed into loss in watts, either per lb. or per Kg.

This made a slow and expensive process of the test and for this reason it was not suited for commercial work. In an effort to better these conditions, Epstein brought out his apparatus for the determination of magnetic losses, which, with some modifications was adopted by the American Society for Testing Materials. The following notes pertain to an apparatus of this type.

STANDARD MAGNETIC TESTS OF IRON AND STEEL.

Chapter 1.

Core Loss.

The power consumption in electtical sheet steel when subjected to an alternating magnetization is known as the core loss. The standard core loss is the total power in watts consumed in each kilogram of the material at a temperature of 25°C., when subjected to a harmonically varying induction having a maximum of 10,000 gausses 10,000 Maxwells per sq. C. M.) and a frequency of 60 cycles per second, when measured as specified below. It is represented by the symbol $W_{10}/60$.

The ageing coefficient is the percentage change in the standard core loss after continued heating at 100°C for 600 hours.

Chapter 2.

Conditions of Test.

The Standard core loss shall be measured under the following conditions:

The magnetic circuit shall consist of 10 kg. (22 lbs) of the test material, cut with a sharp shear into strips 50 cm, (19 11/16 ins.) long and 3 cm. (1 3/16 ins) wide, half parallel and half at right angles to the direction of rolling, made up into four equal bundles, two containing material parallel and two containing material at right angles to the direction of rolling, and finally built into the four sides of a square with butt joints and opposite sides consisting of material cut in the same manner. No insulation other than the natural scale of the material (except in the case of scale-free material) shall be used between the laminations, but the corner joints shall be separated by a tough paper 0.01 cm. (0.004 in) thick.

Chapter 3.

Specifications.

The magnetizing winding shall consist of four solenoids surrounding the four sides of the magnetic circuit and joined in series. A secondary coil shall be used for energizing the voltmeter and the potential coil of the wattmeter.

These solenoids shall be wound on a form of any non-magnetic non-conducting material of the following dimensions:

Inside cross-section	4 by 4 cm.
Thickness of wall	not over 0.3 cm.
Winding length	43 cm.

The primary winding on each solenoid shall consist of 150 turns of copper wire wound uniformly over the 43 cm. length. The total resistance of the magnetizing winding shall be between 0.3 and 0.5 ohm. The secondary winding of 150 turns on each solenoid shall be similarly wound beneath the primary winding. Its resistance shall not exceed 1 ohm.

The voltmeter and the voltage coil of the wattmeter shall be connected in parallel to the terminals of the secondary winding of the apparatus. The current coil of the watt meter shall be connected in series with the primary winding.

A sine wave electromotive force shall be applied to the primary winding and adjusted until the voltage of the

secondary is given by the equation:

$$E = \frac{4fNnBM}{4lD10^8} = \frac{4.44NnBM}{4lD} 10^{-8}$$

in which

f....form factor of primary E.M.F.... 1.11 for sine wave
N....number of secondary turns 600
n....number of cycles per second 60
B....maximum induction 10,000
M....total mass in gramms 10,000
l....length of strips in cm. .... 50, 4l = Total length
D....specific gravity .... 7.5 for high resistance steel.
7.7 for low-resistance steel.
E... 106.6 volts for high resistance steel for sine voltage.
E....103.8 volts for low-resistance steel for sine voltage.

A specific gravity of 7.5 is assumed for all steels having a resistance of over 2 ohms per meter-gram, and 7.7 for all steels having a resistance of less than 2 ohms per meter gram. These steels are designated as high and low resistance steels, respectively.

The wattmeter gives the power consumed in the iron and in the secondary circuit. The loss in the secondary circuit is given in terms of the total resistance and the voltage. Subtracting this correction term from the total power gives the net power consumed in the steel as hysteresis and eddy current loss. Dividing this value by 10 gives the core loss per kilogram.

Chapter 4.

Procedure.

The core loss material shall be cut from two or more sheets taken at random from the shipment. The strips should be distributed symetrically over the sheet, as nearly as may be practicable. For example, see plate No.1.

Cut from the test material a number of strips 3 by 50 cm. half at right angles and half parallel to the direction of rolling.

Place on the balance a pile of strips weighing 2.5 kg, (5.5 lbs). Add a second pile of the same kind, bringing the weight up 5 kg, (11 lbs). In each case the weight is taken to the nearest strip. Add in succession two piles of 2.5 kg, (5.5 lbs) each, of the other kind of strips, bringing the weight up to 7.5 kg (16.5 lbs) and 10 kg (22 lbs) respectively.

Secure each bundle by string or tape (not wire) and insert in the apparatus as indicated.

Apply the alternating voltage to the primary coil and tap the joints together until the current has a minimum value, as shown by the ammeter in series. Then clamp the corners firmly by some suitable device.

Shunt the ammeter and adjust the primary current until the voltmeter indicates the proper value. This adjustment may be made by an auto-transformer, by varying the field of the alternator, or by both, but not by inserting

resistance or inductance into the primary circuit. Simultaneously the frequency must be adjusted to 60 cycles.

Read the wattmeter.

Calculations. Subtract from the wattmeter reading the instrument losses, which will be constant for any set of instruments and voltage, and divide by 10. The result is the standard core loss.

Chapter 5.

Details of Construction.

The first detail considered was the construction of a form on which to shape the cores and wind the coils. This form was made of hardwood, according to the dimensions given on the detailed drawing, sheet #3. It was parted diagonally and held together by screws, one in each end. This construction allowed the form to be removed from the finished coil without binding, as after the screws were withdrawn the two parts could be taken out separately.

The core was made of two layers of horn fiber, held together with glue, the joints being butted and on opposite sides of the core. This core was made about 1-1/2 in. longer than the winding length so that when the fiber ends were glued on none of the glue would work between the core and the wooden form, and thus cause difficulty in withdrawing the latter.

The secondary winding was wound on first. The form, with the core on it, was placed in a lathe set to cut nine threads per inch, and the wire was fed over a smooth groove in a tool set in the tool post. The ends of the wire were brought out through holes in the fiber next to the core. After wrapping one layer of thin fish paper on the secondary coil, the primary wires were wound on in the same manner. Care was taken to have the winding smooth and in the same direction on each of the four coils. Each coil was

covered with a wrapping of heavy paper and shellaced. The inside surface of each core was also shellaced to provide protection against injury from the samples.

The base was made from 5/8" redwood lumber, glued up in two layers of strips approximately five inches wide and twenty six inches long, the direction of the grain in the two layers being at right angles. Holes were drilled for wires, binding posts and screws. Blocks were made to support the ends of the samples so that they would lie centrally in the coils, the bbocks being fastened to the base with brass screws.

The next detail was the providing of suitable means for clamping the ends of the samples during the test. The clamping device selected consisted of two arms fastened at right angles to each other with a half lap joint in the center. Blocks were placed on the ends of the arms to bear on the ends of the samples. The clamping was effected by means of an eccentric lever which acted on the center of the cross arms. Adjustment of the pressure was obtained by means of thumb nuts, which raised or lowered the eccentric. A helical brass spring was provided to hold the arms up when the clamp was not in use. All of the metal entering into the construction of the apparatus was either brass or copper, so as not to interfere with the magnetic action. The coils were held onto the base by means of brass screws which were forced up through the base into the fiber on the ends of the coils.

To protect the base while working on it, it was given a good filling of oil. When it was ready to finish it was sanded and given two coats of varnish. The hard wood parts were finished by the application of a coat of filler and two applications of wax. This gave a very satisfactory finish.

When assembled, the terminals of the coils were soldered to the binding posts and the coils were connected in series by flexible connectors.

Chapter 6.

Wiring computations.

Secondary Winding.

The resistance of the secondary winding of each coil is required to be under 0.25 ohm, and there are to be 150 turns, evenly distributed over the winding length of 16.53".

Size of wire required:

Approximate length of wire.

Inside of core,.............	1.57"
Thickness of core,..........	0.04"
Outside dimension of core,..	1.65"

$$L = \frac{1.65 \times 4 \times 150 + 16.53}{12} = 83.8 \text{ ft.}$$

Approximate resistance of wire:

$$R = \frac{0.25 \times 1000}{83.8} = 0.00298 \text{ ohms /ft.}$$

Size of wire required:

Resistance of # 14 wire is 0.002525 ohms/ft, which is within the limits and was selected.

Length of wire required.

Outside dia.of #14 wire,DCCis,....	0.0731"
Around coil at center of wire, $(1.65 + 0.0731)4 =$	6.89"

$$L = \frac{6.89 \times 150 + 16.53}{12} = \text{.............} \quad 87.5 \text{ ft.}$$

Resistance of the wire.

$R = 0.002525 \times 87.5 =$	0.2209 ohms
R for four coils	0.8836 ohms.

The resistance as measured on the Kelvin Double Bridge,after the coils were assembled was, ... 0.8974 ohms, which is below the limit of 1 ohm.

Primary Winding.

The resistance of the primary winding of each coil is required to be between 0.075 and 0.125 ohms, and there are to be 150 turns evenly distributed over the winding length of 16.53"

Size of wire required:

Approximate length of wire.

Outside of secondary wire........	1.796"
Thickness of fish paper..........	0.01"
Outside dimension of secondary...	1.816"

$$L = \frac{1.816 \times 4 \times 150 + 16.53}{12} = ..\ 92.3\ \text{ft.}$$

Required resistance of wire.

Using . 1 ohm as the desired resistance,

.1 ÷ 92.3 = ... 0.00108 ohms/ft.

The resistance of #10 wire is 0.00104 ohms/ft. and this would have been used but the desired number of turns could not be put on the winding length. We therefor selected #11 and used #17 on parallel with it to keep the resistance well within the limits.

Length of the wire at the center line.

Outside dimension of secondary....	1.816"
Dia. of #11 DCC wire.............	0.106"

$$L = \frac{(1.816 + 0.106)4 \times 150 + 16.53}{12} = 97.4\ \text{ft.}$$

Resistance.

#17 and #11 in parallel.

#17,.........................	0.00527 ohms/ft
#11	0.00131 ohms/ft

$$R = \frac{0.00527 \times 0.00131}{0.00527 + 0.00131} = ...\ 0.00105\ \text{ohms/ft}$$

Resistance of the coil,.00105 x 97.4 = .102 ohm

Resistance of the four coils,...... 0.408 ohms

As measured on the Kelvin Double Bridge after being assembled,the resistance was, 0.3936 ohm.

Chapter 7.

The Test.

The sample which were used in the test were some that had been on hand for some time and had gone through the fire at the time of the burning of the Engineering building. The identification tags were burned off them and they were rusted to such an extent that they had to be cleaned with oil and emery cloth. Of the four samples, we had core loss data on only two and not knowing which of the four these were, we had no check on the accuracy of the apparatus, except, as from the results of the test, the sample might be assumed to be one of the two on which we had data.

The set up for the test was made according to the wiring diagram, sheet #5. The machine used to supply the alternating current to the apparatus was a three phase generator, direct connected to a D.C. series motor. The generator was a four pole machine, operating at 1800 R.P.M. to supply the current at 60 cycles. The speed was indicated by a tachometer, which we calibrated by means of a revolution counter.

The wattmeter used was a Weston, indicating type, with a 150 watt scale. Its reading was checked up with a Westinghouse precision wattmeter and found to be low. We then calibrated the Weston meter and plotted a calibration curve from which we could correct the readings. We took the wattmeter reading at the voltages for both high and low resistance steel,

Results:

Test on Sample #1.

Esec.	Epri.	Ipri.	R.P.M.	Watts	Wcor.
103.8	104	1.475	1800	40.65	41.5
"	"	"	"	40.50	41.4
"	"	"	"	40.40	41.25
"	"	"	"	40.50	41.40
"	"	"	"	40.50	41.40
"	"	"	"	40.45	41.33
				Average...	41.38

Res. voltage coil of wattmeter .... 2653 ohms.
Res. current coil of wattmeter .... 0.26 ohms.

Watts lost in voltage coil;

$W = E^2/R = 103.8^2/2653 = 4.06$ watts.

Watts loss in current coil:
$W = I^2R = 1.475^2 \times .26 = 0.565$ watts. ([illegible])

Instrument losses ...... 4.625 watts.

$W_{10/60}$ = loss per lb. = $\frac{41.38 - 4.625}{22} = \underline{1.67}$

$E_{sec.}$	$E_{pri.}$	I_{pri}	R.P.M.	Watts	Wcor.
106.6	107	1.5	1800	42.70	43.60
"	"	"	"	42.65	43.55
"	"	"	"	42.65	43.55
"	"	"	"	42.55	43.50
"	"	"	"	42.50	43.30
"	"	"	"	42.50	43.30
				Average	..43.46

Watts loss in voltage coil:
$W = E^2 = 106.6^2/2653 = 4.29$ watts.

Watts loss in current coil:
$W = I^2R = 1.5^2 \times .26 = 0.585$ watts.

Instrument losses ...... 4.879 watts.

$W_{10/60}$ = loss per lb. = $\frac{43.46 - 4.879}{22} = \underline{1.75}$

Results:

Test on sample #2.

E_{sec}	$E_{pri.}$	$I_{pri.}$	R.P.M	Watts	W_{cor}
103.8	104	1.50	1800	21.50	22.75
"	"	"	"	21.55	22.78
"	"	"	"	21.65	23.00
"	"	"	"	21.50	22.75
"	"	"	"	21.60	22.80
"	"	"	"	21.60	22.80
				Average ..	22.81

Watts loss in voltage coil:
$W = E^2/R = 103.8^2/2653 = 4.06$ watts

Watts loss in current coil:
$W = I^2R = 1.5^2 \times 0.26 = 0.585$ watts

Instrument losses .... 4.645 watts

$W_{10/60} =$ loss per lb. $= \frac{22.81 - 4.645}{22} = \underline{0.825}$

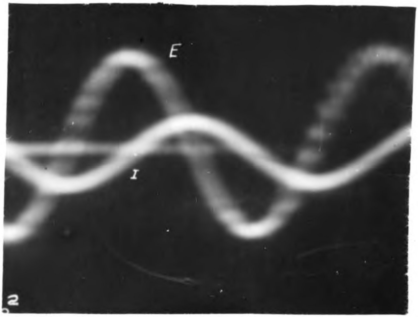
E_{sec}	$E_{pri.}$	I_{pri}	R.P.M.	Watts	W_{cor}
106.6	107	1.55	1800	22.50	23.70
"	"	"	"	22.40	23.65
"	"	"	"	22.45	23.68
"	"	"	"	22.50	23.70
"	"	"	"	22.55	23.75
"	"	"	"	22.50	23.70
				Average ..	23.70

Watts loss in voltage coil:
$W = E^2/R = 106.6^2/2653 = 4.29$ watts.

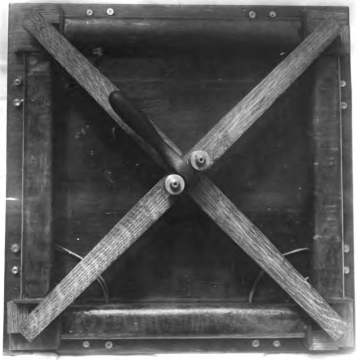
Watts loss in current coil:
$W = I^2R = 1.55^2 \times .26 = 0.625$ watts.

Instrument losses ...... 4.915 watts.

$W_{10/60} =$ loss per lb. $= \frac{23.70 - 4.915}{22} = \underline{0.864}$



The specifications require that a sine wave of E.M.F. be applied to the primary of the instrument. For information as to the voltage wave form of the various generators in the laboratory we are indebted to W. C. Knickerbocker and I. N. Reed, who were testing the various wave forms by means of the oscillograph. They furnished us with the Oscillogram shown above, which was taken from the generator we used.



** APPENDIX **

The detailed cost of material for the apparatus was as follows:

7/8 lb. fiber board	.35
Charge for cutting board	.15
4 lbs. #10 magnet wire	1.73
5 1/2 lbs. #14 magnet wire	2.56
1/4 lb. fish paper	.10
110 1/2 lbs. #11 D.C.C. magnet wire .	4.62
Screws	.10
2 3/4 lbs. #17 D.C.C. magnet wire...	1.38
Horn fibre 40" x 36"	.25
16 binding posts	.60
2 rolls tape	.50
	$12.34

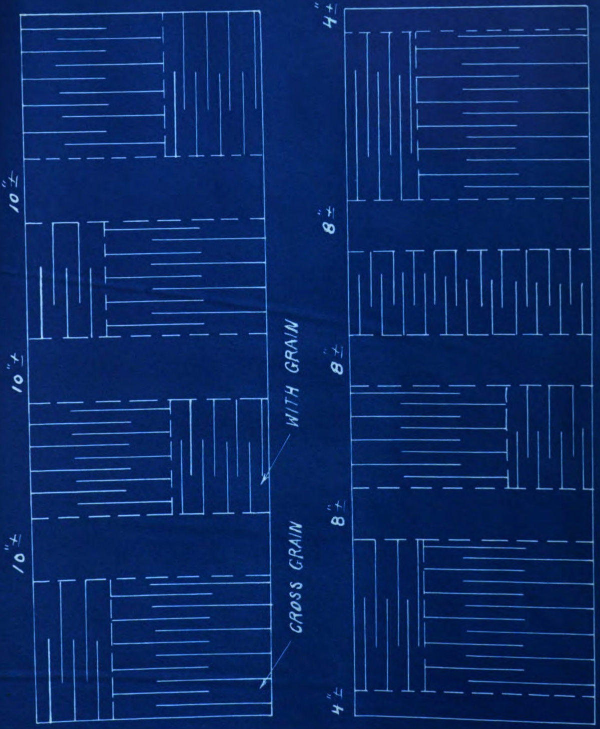
Comments:

We recommend that a larger wire than #14, either #11 or #12, be used on the secondary, as it would give a much more even winding surface for the primary and the resistance would be brought farther within the limits. Also, that #10 enamelled or single cotton covered wire be used on the primary if it is available, otherwise #11 in parallel with #17 gives excellent results.

In our opinion the ideal winding would be square wire on both primary and secondary.

MATERIAL FOR SAMPLES

SHEETS 37 1/4" × 111 3/4"



EPSTEIN CORE LOSS TESTER

SAMPLES

H. J. KNOWLTON — W. B. BROWN

SHEET No 1. MAY 29, 1916.

General Electric Com

Schenectady, N Y

SUPPLY DEP

January, 1914