DESIGN AND CONSTRUCTION OF A MAGNETIC ABSORPTION DYNAMOMETER

BY

H. P. SCHREIBER
M. J. GRILL

ARMOUR INSTITUTE OF TECHNOLOGY
1921
AT 602
Schreiber, H. F.
The design and construction of a magnetic absorption
THE DESIGN AND CONSTRUCTION OF A MAGNETIC ABSORPTION DYNAMOMETER

A THESIS

PRESENTED BY
H. F. SCHREIBER AND M. J. GRILL

TO THE
PRESIDENT AND FACULTY
OF
ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
ELECTRICAL ENGINEERING

JUNE 2, 1921

APPROVED

E.H. Freeman
Professor of Electrical Engineering

Dean of Engineering Studies

Dean of Cultural Studies


10. J. D. Good. 1864-1865.


# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Object</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>The Electric Absorption Dynamometer</td>
<td>3</td>
</tr>
<tr>
<td>The Rotor</td>
<td>4</td>
</tr>
<tr>
<td>The Field Structure</td>
<td>4</td>
</tr>
<tr>
<td>Use of Cast Iron in Dynamo Electric Machinery</td>
<td>9</td>
</tr>
<tr>
<td>Design and Construction of the Electric Absorption Dynamometer</td>
<td>11</td>
</tr>
<tr>
<td>Bill of Material</td>
<td>22</td>
</tr>
<tr>
<td>Theory of the Dynamometer</td>
<td>23</td>
</tr>
<tr>
<td>Conclusion</td>
<td>29</td>
</tr>
</tbody>
</table>
## LIST OF ILLUSTRATIONS AND DRAWINGS

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Illustration</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Photograph of Dynamometer</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Photograph of Dynamometer</td>
<td>7</td>
</tr>
<tr>
<td>#1</td>
<td>Assembly of Dynamometer</td>
<td>8</td>
</tr>
<tr>
<td>#2</td>
<td>Assembly of Rotor</td>
<td>25</td>
</tr>
<tr>
<td>#3</td>
<td>Plan View of Field Structure</td>
<td>26</td>
</tr>
<tr>
<td>#4</td>
<td>Cross-section Elevation of Field Structure</td>
<td>27</td>
</tr>
<tr>
<td>#5</td>
<td>Sketch for Determination of Pole-face Area</td>
<td>17</td>
</tr>
<tr>
<td>#6</td>
<td>Assembly of Frame</td>
<td>28</td>
</tr>
</tbody>
</table>
THE OBJECT.

The object of this thesis is the design and construction of an Electro-magnetic Absorption Dynamometer to facilitate the testing of fractional horse-power motors. This will include either A.C. or D.C. motors.

Our investigation shows that a few attempts have been made in the design and construction of an electro-magnetic absorption dynamometer, but no commercially successful machine has been put on the market up to date.

In our experiences in motor testing and the use of the Prony brake, we have noticed that for fractional horse-power motors the Prony brake method of testing is rather cumbersome. Therefore, we are endeavoring to design and construct a machine which can be directly coupled to the shaft of the motor to be tested, this machine to serve the same purpose as the Prony brake.

The pull which is exerted by the dynamometer can be measured by a simple scale, which is
within the limit of the machine. This scale is supported by special frame work attached directly to the frame of the dynamometer. The object of this is to eliminate the use of platform scales and small weights, which are very easily misplaced.
INTRODUCTION.

THE ELECTRIC ABSORPTION DYNAMOMETER.

This machine was designed and constructed at the Armour Institute of Technology. Views of the machine are shown by the photographs on pages (6 & 7). In appearance it resembles a fractional horse-power motor. The overall dimensions are 5\(\frac{1}{2}\) inches in diameter, and 4 inches wide. It is supported in a frame made adjustable to accommodate motors up to one-half horse-power. The journal supports are made of cast iron, as are the frame and field structure. The rotor is made up of concentric rings of mild steel and brass. A number of copper pins are inserted radially around the periphery, connecting the brass rings electrically. These pins also aid in keeping the rings in place.

In designing this machine, an attempt has been made to get something better than the Prony brake has proven itself to be, for the testing of small or fractional horse-power motors. Due to the size of the machine, and
the small output, it was thought a good plan to do away with external resistances or other absorption apparatus usually employed with an electric dynamometer used in the same manner. Therefore the rotor was designed to absorb within itself the power generated.

In the design of the rotor we have attempted to use as small an amount of material as possible, taking into consideration the electrical and mechanical requirements. Our object in doing this was to obtain a rotor which would be comparatively light, thereby keeping the coefficient of friction small, and reducing the fly-wheel effect of the rotor.

The field structure is made up of two similar parts, which, when placed in position are held by brass plates. There are two field coils, one for each field structure. The two coils are connected in series, and their magneto-motive forces act in the same direction.

The structure is supported on a set of ball bearings the race being fastened to a bushing or sleeve. This sleeve in turn rests on another
set of ball bearings which rest on the rotor shaft. By this means the rotor and field structure are free to rotate independently.
PLATE #1

ASSEMBLY OF DYNAMOMETER
SCALE = FULL SIZE

GRILL & SCHREIBER
1927
USE OF CAST IRON IN DYNAMO ELECTRIC MACHINERY.

Cast iron is used for yokes and spiders on account of its cheapness, the ease with which it is cast into complicated shapes and the ease with which it is machined. Though of much poorer magnetic quality than steel, it sometimes pays to use a heavy section of it instead of a light section of steel. Sometimes it happens that in big frames a great depth of material would in any case be necessary in order to obtain sufficient mechanical stiffness and the magnetic qualities of cast iron are then sufficiently good. For this reason cast iron is used to a great extent in the yokes of large continuous-current machines. Very often in slow speed A.C. generators it is necessary to provide a certain amount of fly-wheel effect, and the fly-wheel effect can be obtained most economically by employing deep cast iron rims on the field-magnet wheel. There being a great depth of material, the cast iron is magnetically sufficiently good.
for the purpose. It is only at the root of the poles that one feels the pinch, due to the poor magnetic quality of the iron. Even where the number of ampere-turns on the magnetic circuit is somewhat increased by the use of cast iron instead of cast steel, there may be cases where the saving effected in using the cheaper iron pays for the cost of extra copper.

When cast iron cools, part of the carbon in it is deposited in graphitic flakes, while the remainder is combined with the iron and has the effect of greatly reducing its permeability. Very slow cooling results in a smaller percentage of combined carbon. It thus comes about that two different pourings from the same ladle may have considerably different magnetic properties, according to the way in which the iron is cooled.
THE DESIGN OF THE ABSORPTION DYNAMOMETER.

The complete assembly and detail drawings of the dynamometer are shown in plates #1, #2, #3, and #4, but for convenience reference may be made to the cut in Fig. #1, page 8, which gives a cross-sectional view. The essential principle of this dynamometer is to generate energy and absorb it within itself, while the force is measured by means of a scale. The main difficulty encountered was that of determining the ampere turns in the field, and the amount of magnetic material required to give the rated capacity.

We had to make an approximate determination of the temperature rise when the machine was to be run for any length of time. To find the temperature rise of the surface of iron core with air at "V" feet per minute, the watts dissipated per square inch of radiating surface for 1 degree rise of surface temperature would be

\[ W = 0.0245 (1 + 0.00127 V) \]

Since most of the single phase motors of
one horse-power or less run at 1800 r.p.m., and as we wanted to design a machine to test a one-half horse-power motor we were able to determine "V" as follows:

\[ 1800 \text{ r.p.m.} \times \text{mean circumference of rotor} \left/ 12 \right. \]

We found that the temperature rise would be about 150 degrees centigrade. This is a little larger than we desired to have in such a machine, but since the test of a motor would not exceed a period of an hour or less, no serious damage would result.

The next step was to take a set of sizes for the rotor and field and check back and see if we had made the parts in the right proportion. We found that the sizes as indicated on the sections were approximately correct and that we could make up for any deficit by changing the rotor design.

The rotor is built up first of a disc of brass, then a ring of cast iron, one of brass, one of cast iron and lastly one of brass. Then after the rings are in place we calculated that
eighty pins of copper were necessary for successful operation. These pins are of copper wire and are placed in drilled holes in the rotor. Forty pins are long enough to connect the outer and inner rings of brass and the spider. The remaining forty are only long enough to interest the outer and central ring of brass. This is permissible due to the nature of the path of the currents which will flow in the inductors. The longer inductors will carry two distinct currents, while the short inductors will carry only one.

The area of the pole faces was obtained by the use of trigonometric formulae. The formulae used are the area of a segment of a circle, and the length of the third side of a triangle, having given two sides and the included angle. Then by adding and subtracting the proper areas, the required area is obtained. Reference to figure five will help make the following explanation clear.
Area of a segment = $\frac{1}{2} R^2 \cdot (a - \sin a)$

where $R =$ radius of circle

$a =$ angle between radii joining ends of cord of sector.

Angle $a_1$ between radii joining ends of cord to center: $a_1 = 2 \sin^{-1} \frac{L}{D}$

Where $L =$ length of cord in inches

$D =$ diameter of circle in inches $= 2R$

Side of triangle, having given two sides and the included angle:

$\text{Side} = \sqrt{\text{side } A^2 - \text{side } B^2 - 2AB \cos \text{Included angle.}}$

Area of pole face $= \text{area of rectangle, plus area of the upper segment, minus the area of the lower segment.}$

Solution: (Refer to figure 5)

$a_1 = 2 \sin^{-1} \frac{L}{D} = 2 \sin^{-1} \frac{1.5}{5} = 2 \sin^{-1} .3$

$a_1 = 35$ degrees

$a_2 = 2 \sin^{-1} \frac{L}{D_2} = 2 \sin^{-1} \frac{1.5}{44} = 2 \sin^{-1} .375$

$a_2 = 44$ degrees.
Area of upper segment:
\[ \frac{1}{2} R_1^2 (a_1 - \sin a_1) = .117 \text{ sq. in.} \]
Area of lower segment:
\[ \frac{1}{2} R_2^2 (a_2 - \sin a_2) = .1466 \text{ sq. in.} \]
Angle between radii:
\[ \frac{a_2}{2} - \frac{a_1}{2} = \sqrt{22 - 17.5} = 4.5 \text{ degrees.} \]
Side:
\[ \sqrt{(2.5)^2 - (2)^2} = 2 \times 2 \times 2.5 \times .9969 = .73 \text{ in.} \]
Area of rectangle:
\[ .73 \times 1.5 = 1.095 \text{ sq. in.} \]
\[ 1.095 - .117 = 1.212 \text{ sq. in.} \]
\[ 1.212 - .147 = 1.065 \text{ sq. in. = area of one outer pole face.} \]
\[ 4 \times 1.065 \text{ sq. in.} = 4.260 \text{ sq. in. = total area of outer pole faces.} \]
Area of inner pole faces:
\[ a_1 = 60 \text{ degrees} \]
\[ a_2 = 97.2 \text{ degrees.} \]
Area of upper segments:
\[ \frac{1}{2} R_1^2 (a_1 - \sin a_1) = .2045 \text{ sq. in.} \]
Area of lower segment:
\[ \frac{1}{2} R_2^2 (a_2 - \sin a_2) = .3514 \text{ sq. in.} \]
Angle between radii:

\[ 48.6 - 30 = 18.6 \text{ degrees} \]

Side:

\[
\sqrt{(1.5)^2 + (1)^2} - 2 \times 1.5 \times 1 \times .9478 = .64 \text{ in.}
\]

Area of rect. :=

\[ .64 \times 1.5 = .96 \text{ sq. in.} \]

\[ .96 - .2045 = 1.1645 \text{ sq. in.} \]

\[ 1.1645 - .3514 = .813 \text{ sq. in.} = \text{area of one inner pole face.} \]

\[ 4 \times .813 = 3.252 \text{ sq. in.} = \text{total area of all inner pole faces.} \]
DETERMINATION OF POLE-FACE AREA

PLATE #5
COIL COMPUTATIONS.

In the determination of the number of ampere turns required, the flux density was taken as 50,000 lines of force per square inch. As the two parts of the coil form a solenoid, the equations for a solenoid may be used in the computations of field strength and flux. The exact permeability of the cast iron used in the field structure was not determined. This was not necessary because the reluctance of the air gap is so great compared to that of the iron.

The air gap between the rotor and pole faces is taken as 0.01 of an inch. As the path of the flux crosses this gap four times, the total gap is .04 of an inch.

The field strength H, in a solenoid is given by the equation

\[ H = \frac{4\pi N I}{10 L} \]

The magnetic flux B, or flux per unit area is equal to \( uH \). In the case of air \( u = 1 \), and \( B = H \). The above formula is given in
centimeter units. To change it to inch measure,

\[ \frac{B}{\text{cms./sq.in}} = \frac{4 \pi NI}{10L \times 2.54(\text{cms./in.})} \]

\[ \frac{B}{6.45} = \frac{4 \pi NI}{10L \times 2.54} \]

\[ B = \frac{4 \pi NI \times 2.54}{10L} \]

\[ B = 50,000 / \text{sq. in.} \]

Then

\[ 50,000 = \frac{4 \pi NI \times 2.54}{10L} \]

or the ampere turns are

\[ NI = \frac{50,000 \times 10 \times 0.04}{4 \times \pi \times 2.54} = \frac{50,000}{2.54 \pi} = 630 \text{ ampere turns approx.} \]

and \( NI/\text{coil} = 315 \)

Knowing the ampere turns, the next problem was to determine the size of wire to be used. Assuming 50 volts per coil, use was made of Ohm's Law.

\[ E = RI \]

Let \( M = \) mean length of one turn

\( r'' = \) resistance per inch of conductor

\( N = \) total number of turns

\( I = \) current

\( 50 = \) volts per coil
Then \( M \times r'' \times N = \) total resistance per coil 
and \( I = \) current

Then \( E = RI \)

or \( 50 = (M \times r'' \times N) \times I \)

and \( r'' = \frac{50}{M \times N \times I} = \frac{50}{11 \times 315} = 0.0144 \) ohms.

From table of Belden Cat. #8

#32 wire has res. of 0.01365 ohms/ inch

#32 " gives 5960 turns/sq.in (enamedled cotton covered)

or 2980 turns / .5 sq. in.

or 1490 " / .25 sq. in.

Cubical space for coil = 5.4864 cu. in (total)

#32 wire has 81.35 ohms/ cu. in.

5.4864 x 81.35 = 445 ohms total resistance

\( I = \frac{E}{R} = \frac{100}{445} = 0.2245 \) amperes.

Check:

\( NI = 1490 \times 0.2245 = 335 \) (larger than req'd)

#32 wire has 699.8 ohms/ lb.

Wt. required = \( \frac{445}{669.8} = 0.638 \) lb.
DESIGN OF FRAME.

In the design of the frame to carry the dynamometer we had to take into consideration the variation in size of one-half horse-power motors.

The base is made of a plate of cast iron, 6 x 12 x 5/8". The pedestals are two upright pieces, specially cast. They are 3/4 in. in thickness, 3 1/2 inches wide at the base and 2 1/2 inches wide at the top. At the back, an extra rib was added to increase the stiffness. The bottom of the pedestals were milled so that when placed on the base they would stand perpendicular to it. They are fastened at the base by two machine screws fitting in holes drilled through the base, the holes being counter-sunk.

The upper part of the pedestal is slotted to accommodate the pillow blocks. These are held in place by set screws.
## BILL OF MATERIAL.

<table>
<thead>
<tr>
<th>Article</th>
<th>No.</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Structure</td>
<td>2</td>
<td>C. I.</td>
</tr>
<tr>
<td>Ball Bearings</td>
<td>4</td>
<td>Stock</td>
</tr>
<tr>
<td>Shaft</td>
<td>1</td>
<td>Steel</td>
</tr>
<tr>
<td>Rotor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 1/2 x 5 x 1/2&quot; ring</td>
<td>1</td>
<td>Brass</td>
</tr>
<tr>
<td>5 x 4 x 1/2&quot;</td>
<td>1</td>
<td>C. I.</td>
</tr>
<tr>
<td>4 x 3 x 1/2&quot;</td>
<td>1</td>
<td>Brass</td>
</tr>
<tr>
<td>3 x 2 x 1/2&quot;</td>
<td>1</td>
<td>C. I.</td>
</tr>
<tr>
<td>2&quot; x 1/2&quot; Disk</td>
<td>1</td>
<td>Brass</td>
</tr>
<tr>
<td>Inductor pins (#10 B. &amp; S. Gauge)</td>
<td>80</td>
<td>Copper</td>
</tr>
<tr>
<td>Couplings</td>
<td>1</td>
<td>Steel</td>
</tr>
<tr>
<td>Pillow Blocks</td>
<td>2</td>
<td>C. I.</td>
</tr>
<tr>
<td>Scale Arm</td>
<td>1</td>
<td>Brass</td>
</tr>
<tr>
<td>Base Plate</td>
<td>1</td>
<td>C. I.</td>
</tr>
<tr>
<td>Pedestal</td>
<td>2</td>
<td>C. I.</td>
</tr>
</tbody>
</table>
THEORY OF THE DYNAMOMETER.

The dynamometer is nothing more than an A.C. generator. The field is four pole, and much resembles a horse-shoe electro-magnet. The rotor is built up very similar to a squirrel cage rotor of an induction motor. Instead, however, of having the inductors or elements placed on the periphery of the rotor and parallel to the shaft, the inductors are placed radially or perpendicular to the shaft.

No leads are brought out from the rotor. All the inductors are short circuited so that any induced currents in the inductors flow in these short-circuit paths. These currents, according to Lenz' law oppose the action causing them, and tend to draw the movable field structure after the rotor as it revolves.

This tendency on the part of the field structure is checked and registered by a spring balance attached to the arm of the structure. Then, knowing the speed of the rotor, the length of arm, and the pull exerted, the power
output of the machine being tested, can be calculated from the ordinary horse-power formula, also applicable to the Prony brake, namely:

\[
\text{Horse-power} = \frac{2\pi L S W}{33000}
\]
SIDE AND END ELEVATION & SUPPORTING FRAME
SCALE: 1/4" = 1'-0"

PLATE #6

GRILL "A" SCHREIBER
1931.
CONCLUSION.

The dynamometer, as completed, may not be all that we would wish it to be, but it being a pioneer of machines of this type, it is understood that the first attempt would not yield results entirely satisfactory.

Owing to the lack of test data it would be useless to suggest changes and improvements here, as any statements we might make would be open to criticism, and we would have nothing by which we could prove what we say.