EFFICIENCIES AND ARMATURE REACTIONS
OF
500 Volt Shunt Motors

BY
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Efficiencies and Armature Reaction of 500 Volt Motors

Introduction

500 volt motors are now quite generally used principally because they can be run from a trolley circuit which is in most cases 500 volts. This eliminates the necessity of the installation of a generating plant. While 500 volts is not really dangerous to life and property, still from the standpoint of transmission it is very economical. Also from street railways 500 volt motors are mostly used where but little power is needed, such as small shops, laundries, printing offices, etc. Many have also been installed for elevator use. For such work motors are generally heavily overcompounded, in order to obtain...
a large starting torque. For ordinary shop work, a shunt motor is best suited, for the regulation is fairly good under quite a large range of load. Where regulation must be very good, a differential winding is often employed. In this case a few series turns are wound on the field in opposition to the shunt turns. Thus when the load becomes heavy and the motor tends to slow down, the current in these series turns becomes stronger, and, since the winding is differential, the field becomes weaker and causes the speed to remain constant, by tending to speed up.

As a general thing, shunt railway motors are series wound, since for this work no very large starting torque is required. A rush of current at starting is not so likely to cause trouble in the
series motor as in the shunt, because of the very fact that there is a large starting torque. The speed of a series motor is far from uniform, for a load naturally tends to bring down the speed while the increase of current strengthens the field, which also reduces the speed.

Starting Rheostat. - In the use of single motors there is always a starting box placed in the armature circuit. This is simply a rheostat which consumes part of the energy at starting and diminishes the voltage which is applied directly to the armature. This prevents a great rush of current at starting, for at that time the counter electromotive force
is too small to be of any use. As the speed increases, the resistance is gradually cut out. The connections with such a box are shown in the above figure. a b c and d are resistance coils, f g h i and j are brass blocks in which these coils terminate. H is a switch which slides over these blocks, cutting out or in the coils according as it is moved one way or the other. At E is a switch which when closed allows the current to pass into the field windings which are shown as a shunt, and through the resistance to the armature. The motor now starts and as the speed increases H is moved over g h and i, and stopped on j when all the resistance is out. The iron block K which is attached to H is now held by the magnet M which is excited by a few turns of the field.
wire. Now suppose this motor to be running from a trolley circuit, and for some reason or other the circuit breaker at the power station should open. This would shut off the power and M would release K, allowing H to go back to f under the pull of the spring S. The motor is now out of danger of burning out should the power again be applied. Some starting boxes do not have this protection, but every motor which is to run steadily and cannot be carefully watched should have it. Further than this, it should be carefully fused.
Reactions in Armatures.

In almost every dynamo is found an effect known as armature reaction. This is due to the magnetizing effect of the current in the armature conductors, which sets up a field at right angles to the main field. This may be explained by the following diagram:

Fig. 2 represents the magnetic flux through the armature at rest when the fields are separately excited. The sections of wire marked with a cross represent wire in which the current is flowing from the observer.
The dot in the section represents a wire in which the current is coming toward the observer. A blank section means no current. The field is seen to be symmetrical and fairly uniform, with the N pole on the right of the armature as shown.

Fig. 3 represents the condition when no current is on the field turns and a current is being passed through the armature conductors in the same direction in which it would flow were the dynamo running normally. The brushes are assumed midway between the pole tips. It is seen that a field is set up at right angles to that of the field magnets as shown by the dotted lines. Now suppose both conditions existed at the same time. We should then have a resultant of the two fields as shown in Fig. 4.

In a machine in operation we have almost
The resultant gives rise to a distortion of the field. The case just shown represents what takes place in a generator, the distortion taking place in the direction of rotation. In a motor this is reversed, the magnetic lines being crowded in the opposite direction.

The brushes of a machine should always be placed at the neutral points, or rather just a trifle ahead of the neutral point. They should be nearly at the neutral, because while the brush short-circuits a coil it must not be generating much electro-motive force; and it should be just a trifle ahead be-
cause it will then be generating an electro-
motive force which tends to send a current in
it in the same direction as the current which
is just about to enter will flow. Thus there
will be no self-inductive impedance and the
current will pass through the new coil more rudi-
ly than it will arc across to the brush. This
increases the lead of the brushes in a generator
and diminishes the lag in a motor, and in
general it will be noticed that generator brushes
lead by a larger angle than motor brushes lag.
It is obvious that if a machine has a very heavy
field the distortion will not be so great as when
the field is light, for the reason that the cross
magnetic field has a larger force to deal with. This
fact is sometimes made use of in motors which
must be often reversed and cannot be carefully
watched, such as street railway motors. These motors are reversed and run heavy loads in either direction without excessive sparking.

There are several methods of compensating for armature reactions, such as Sugesu, Ryan, Fischer, Himrie, etc., but these cannot be taken up in detail. One method employs small auxiliary poles which are excited by a series winding and set up a field directly opposite to the armature field. Both are proportional to the armature current, hence may be made compensating.

Another method is to pass series conductors through the pole pieces, parallel to the axis of the armature. These carry current in an opposite direction to that in the armature conductors and neutralize their magnetic effect. The methods have proved successful, although
Tests of Efficiency

There are various methods of testing dynamos and motors for efficiency. Some of these employ only electrical measurements, and some both electrical and mechanical. Some common methods of testing are: The Brønn Brake Method, the Dynamometer Method, and the Stray Power Method.

The Brønn Brake Method. — The Brønn Brake method is one in which an actual load is applied at the pulley of the motor, and the power necessary to drive the motor measured electrically. In this way we get directly the output and the input at different loads. The mechanical...
output is measured with a "brake". The brake is a clamp of two parts as shown in the figure. These are held together by a metal strap on one end and a bolt on the other end. As the pulley turns it tends to turn the brake but is prevented by a force acting at the end of an arm of length \( L \). This force must act tangential to the circumference of the circle whose radius is \( L \). The torque there is \( P\theta \). Water must be kept flowing through a hole in the upper block of the clamp to keep the apparatus cool lest it burn. The pulley now is turning against a frictional resistance which acts at the circumference of the pulley. Let this force be called \( f \) and the
radius of the pulley \( r \). The velocity at the circumference of the pulley then is \( 2\pi r \) where \( n \) is the number of revolutions per second, and the work done is \( 2\pi n r \) foot pounds if \( r \) is measured in feet. This is \( \frac{2\pi n r}{550} \) horse power. The torque was seen to be \( PL \) also \( fr \). Hence \( PL \) = \( fr \) if \( L \) is in feet. The horse power output then is \( \frac{2\pi n PL}{550} \).

The input is the product of the volts and amperes and is watts. This is reduced to horse power by dividing by 746. The frictional resistance may be varied by varying the tension in the belt which controls the pressure of the clamp upon the pulley. This method is not easy to perform, and is very disagreeable since water is scattered about by the pulley. There are many mechanical difficulties which prevent very accurate results.
The Dynamometer Method. - The dynamometer method depends on the measurement of the power transmitted by the belt and the electrical input. The motor is mounted on a dynamometer so that the axis of rotation is exactly in line with the fulcrum of the dynamometer, and the entire apparatus is balanced with the belts off. Then when the belts are put on, the torque rotates the armature in one direction and tends to rotate the remaining part of the machine and the swinging part of the dynamometer in the opposite direction. A weight slid out on the beam of the dynamometer then measures the torque which tends to rotate the machine. This is \( G l \) where \( G \) is the weight and \( l \) the distance it had to be moved out to balance. This torque is the same as that which rotates the
pulley. This torque is the driving force of the belt, multiplied by the radius of the pulley. The driving force of the belt is the difference between the tension in the taught and slack parts of the belt. Call this \( F \) and the radius of the pulley \( r \). Then the torque is \( F r \).

The work done by the belt is the driving force times the velocity of the belt. If the pulley makes \( n \) revolutions per second, the velocity is \( 2\pi n r \), and the work is \( 2\pi n r F \), or \( 2\pi n T \) where \( T \) is the torque. Substituting \( n G \) for \( T \), the work is \( 2\pi n G \) foot pounds per second if \( G \) is feet. The horse powers of transmission are

\[
\frac{2\pi n G}{330}
\]

This method is comparatively easy of performance and gives fairly good results. By this method the hysteresis and eddy currents, the brush friction, and the bearing and air friction may be separated.
The Stray Power Method.

The Stray Power method is probably the most convenient method. It is purely electrical in its measurements. It depends upon the fact that certain losses, called stray power losses, remain constant for all loads provided the voltage, speed, and effective field remain constant. These losses are: eddy currents, hysteresis, and friction. If the motor is separately excited and run at normal speed and voltage, the power taken in the armature circuit is stray power, for besides stray power, the only losses there are in the machine are $C^2R$ losses and when running light the $C^2R$ loss in the armature is so small that it may be neglected. The $C^2R$ losses in field and armature can be computed for all loads. Then all the losses are known and the efficiencies at the various loads can be computed. This is the method
used in the tests and will be more fully dis-
cussed later. The method is easy to perform,
requires no special apparatus and gives very
good results.
Armature Reactions.

If the field of the motor were evenly distributed, that is if there were no distortion of the field, the neutral point would be midway between the pole tips. The rate of cutting of magnetic lines by the armature coils at the various positions would be represented very nearly by fig. 6. This shows that after a certain point on the path of the coil, the cutting remains uniform for a way till another critical point is passed, when it gradually falls off and repeats in a negative direction. This is not the case when there are reactions. The magnetic lines are crowded into one pole-tip and the rate of cutting
varies as in Fig. 7. The distribution of magnetic lines as shown by the preceding diagrams may be obtained by several methods, of which perhaps the best known and most frequently used are Thompson's and Morley's Methods. The former gives us directly a curve representing the rates of cutting of magnetic lines and resembling Fig. 6 and 7. The second method gives a curve representing the total cutting between one of the motor brushes and any other point of the commutator.

Thompson's Method. — Thompson's method consists in traversing the circumference of the commutator with two small exploring brushes which are connected through a voltmeter. The points of contact of these small brushes with the commutator must be kept at a constant
distance from each other. This distance is preferably the width of one commutator segment. If this distance is not kept constant the readings of the voltmeter will be too large or too small according as the distance is too large or too small. This is true because if the distance is greater than one segment the brushes will part of the time be spanning over two coils instead of one which is the case when the distance is equal to the width of one segment. Great care must be taken to keep the distance constant. The brushes should be so thin that they will not short-circuit a coil by spanning across the insulation between two segments, or there will be intense sparking when it measures the induction in a heavy field. It was found that this springy feel
copper was satisfactory. It is usual to mount the brushes on a wooden or metal ring concentric with the shaft and commutator and made to fit in a slot in which it can be rotated about the commutator. It is often difficult to design such apparatus as some machines do not offer enough space. The apparatus used for the Edison motor is shown in blue print plate [1].

Moolky's Method - Moolky's is somewhat like Thompson's but only one exploring brush is used. This brush is connected to one of the motor brushes through a voltmeter. The apparatus used may be the same that was used in Thompson's method except that one brush is removed. The remain
ing brush is then moved about the commuta-
tor as the two were. The voltmeter reading then
will give the total voltage from the motor
brush to the exploring brush, which corre-
sponds to the lines cut by the coils between
these brushes. The curve obtained thus will
be as shown by plates 13a, 14a and 15a.

In general it may be said that as
far as direct results are concerned Thompson’s
method gives the best curve, but from the stand-
point of accuracy Mordy’s method is to be pre-
ferred. Mordy’s method is more accurate because
greater voltages are read and an error of one
volt is a smaller percentage than in Thompson’s
method. Furthermore, Thompson’s curve may
be derived from Mordy’s and the probability is
that it is more accurate than if obtained directly.
The armature reaction test on the Edison motor was made by Thompson's method. The apparatus used is shown by the print plate. An iron ring with a groove cut in its circumference contained another ring of brass, which carried the brushes. The brass ring was halved and held together by bolts so that it could readily be taken off and put on, and could also be tightened and loosened. The iron ring was graduated. The brushes were thin copper which had been worked and had a slight temper. They were set against the commutator, one segment apart and rotated about it, reading being taken every ten degrees on the voltmeter connecting them.

Curves were taken with the machine.
running as a motor at half load, full load, and no load, and as a generator at the same load. When run as a generator the machine failed to give 500 volts, even at no load, and the curve was taken at 450 volts. At half load it dropped off still more and a storage battery was placed in series with the field to obtain 500 volts. The same was done for full load but still the voltage dropped off below 500 and during the test varied from 400 to 490 volts. This variation was not serious. As a motor the machine gave no trouble.

The curves are almost all smooth curves. At no load there appears to be no distortion whatever, and from 40 degrees to 170 degrees the voltage is approximately constant.
for both motor and generator. At one half
load there is a marked distortion. The
motor curve has its maximum at about 50
degrees ahead of the neutral point, being forced
backward by the cross-magnetization. The gen-
erator has its maximum at about 40 degrees behind
the neutral point, being forced ahead by the
cross-magnetization. At full load the dis-
tortion is similar but much more pronounced.
The exact shape of the curves may be seen
in plates 8, 9 and 10.
For all the sparking it is strange to say
that while the machine was running as
a motor the brushes kept the same position
for all loads, and to all appearances worked
properly. This may be due to the fact that
thick brushes were used on the motor, and
hence could not be adjusted very accurately. The brushes had to be pretty thick to obtain enough cross-section since they were cut pretty narrow to allow the adjustment of the apparatus. It is still stranger still that at no load for the generator the brushes had to be set back five degrees behind the neutral point of the motor. At half load they led by five degrees and at full load ten degrees. This shows a very small amount of necessary shifting. There was some sparking all the time but this was due to a bad commutator.

The armature reactions of the Westinghouse four pole motor tried by Thompson's method as in the case of the Edison motor. Owing to the construction of the machine an iron ring as was used in the Edison motor test could
PLATE 4

APPARATUS FOR EXPLORING COMMUTATOR OF EDISON 4 HP. 600 VOLT MOTOR.

RING "A" IS MADE OF CAST IRON.

B " " BRASS.
ARMATURE REACTIONS.

MACHINE, EDISON 500 VOLT 4H.P. MOTOR.

METHOD OF EXPLORATION, Thompson's.

MACHINE RUN AS, Motor

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LOAD = 0
VOLTAGE = 500
LEAD OF BRUSHES = 15°
ARMATURE REACTIONS.

MACHINE, Edison 500 Volt 4 H.P. Motor.

METHOD OF EXPLORATION, Thompsons

MACHINE RUN AS GENERATOR.

LOAD = ZERO
VOLTAGE = 450
LEAD OF BRUSHES = 10°

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PLATE 8.
EXPLORATION CURVES OF EDISON MOTOR.
NO LOAD.

Pole Piece.

Generator run at 450 Volts.
Motor run at 500 Volts
ARMATURE REACTIONS.

MACHINE, Edison 500 volt 4 H.P. Motor.

LOAD = One Half or 3 amp.

VOLTAGE = 500

METHOD OF EXPLORATION, Thompson's.

MACHINE RUN AS - Motor

LEAD OF BRUSHES = 5°

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ARMATURE REACTIONS.

MACHINE, Edison 500 Volt 4 H.P. Motor.

LOAD = ONE-HALF or 3 amp.

VOLTAGE = 500 Volt.
LEAD OF BRUSHES = 10°

METHOD OF EXPLORATION, Thompsons.
MACHINE RUN AS, Generator

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ARMATURE REACTIONS.

MACHINE, Edison 500 Volt 4 H.P. Motor.
METHOD OF EXPLORATION, Thompson's
MACHINE RUN AS, Motor

LOAD = Full or 6 amp.
VOLTAGE = 500
LEAD OF BUSHES = 0°

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ARMATURE REACTIONS.

MACHINE, Edison 500 Volt 4 H.P. Motor

METHOD OF EXPLORATION, Thompsons.

MACHINE RUN AS Generator.

LOAD = Full or half.

LEAD OF BRUSHES = 10°

VOLTAGE, Varied between 490-500.

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PLATE 10
EXPLORATION CURVES OF EDISON MOTOR.
FULL LOAD.

Volts

0 40 80 120 Degrees 160 240 280 360

Pole Piece.

Generator
Motor

Gen. run at 450 to 500 Volts
Motor " = 500 Volts
not be need. Therefore a wooden frame such as it is shown in blue print plate 5 was made and fastened against the frame of the field by brass straps. A wooden ring was made to fit into the frame in such a way that it could be revolved concentrically about the commutator. On this ring were two brass posts which held two small sheet-copper brushes. These brushes were set against the commutator one segment apart. However the ring warped slightly, did not fit snugly and could not be made perfectly concentric. Therefore the brass posts were not always the same distance from the commutator, and the distance between the bearing points of the brushes on the commutator varied and the readings were not correct. For this reason Mordy's method was
adopted. One brush was removed and the remain-
ing brush was connected to one of the motor brushes
through a high reading voltmeter.

The curves for no load show no distortion
to amount to anything, and the first half
of the circuit shows a remarkable regularity
for both generator and motor, although it is
not clear why the generator curve should
attain a greater maximum than the motor
in the first half and a lesser one in the
second. This is also noticeable at one half
load and full load. At half load and full
load the distortion is very evident.

The motor test was run with the brushes
in the same position for the three loads and
no sparking was noticeable. However for the
generator test at no load the brushes retained
the same position as in the motor tests, probably the point midway between the pole tips, but had to be advanced 5 degrees for half load and 10 degrees for full load. The commutator was in excellent condition and unless the brushes were shifted out of the neutral position there was no sparking.
PLATE 5.

PARATUS FOR EXPLORING COMMUTATOR OF 500 VOLT, 4 H.P., WESTINGHOUSE MOTOR.

scale, 1/4" = 1"

Back view.
(Wood)
ARMATURE REACTIONS.

MACHINE, WESTINGHOUSE 500 VOLT 3 1/2 H.P. MOTOR. LOAD = O

METHOD OF EXPLORATION, MORDEY'S LEAD OF BRUSHES = 0°

MACHINE RUN AS MOTOR. MACHINE RUN AT 500 VOLTS.

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# Armature Reactions

**Machine, Westinghouse 500 Volt 3 1/2 H.P. Motor.**

**Method of Exploration, Mordeys.**

**Machine Run As, Generator**

**Load = 0**

**Lead of Brushes = 0°**

**Machine Run At 500V.**

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PLATE 13
EXPLORATION CURVES OF WESTINGHOUSE MOTOR.
NO LOAD.

ARMATURE REACTIONS:

Pole Piece Pole Piece Pole Piece Pole Piece

Motor
Generator

Volts

40 80 120 220 300 Degrees

40 80 120 220 300 Degrees

40 80 120 220 300 Degrees

40 80 120 220 300 Degrees
ARMATURE REACTIONS.

MACHINE, WESTINGHOUSE 500 VOLT 3½ H.P. MOTOR.

LOAD = 3 AMPERES.

METHOD OF EXPLORATION = MORDEY'S.

LEAD OF BRUSHES = 0°

MACHINE RUN AS MOTOR

MACHINE RUN AT 500 VOLTS.

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ARMATURE REACTIONS.

MACHINE, WESTINGHOUSE 500 VOLT 3 1/2 H.P. MOTOR.
LOAD = 2.5 AMP.
METHOD OF EXPLORATION, Mordey's.
LEAD OF BRUSHES = 5°
MACHINE RUN AS, GENERATOR.
MACHINE RUN AT 500 Volts.

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PLATE 14

EXPLORATION CURVES OF WESTINGHOUSE MOTOR.

ONE-HALF LOAD.
ARMATURE REACTIONS.

MACHINE, WESTINGHOUSE 500 VOLT 3 1/2 H.P. MOTOR.  LOAD = 5 AMPERES
METHOD OF EXPLORATION = MORDEY'S.  LEAD OF BRUSHES = 0°
MACHINE RUN AS MOTOR  MACHINE RUN AT 500 VOLTS

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ARMATURE REACTIONS

MACHINE, WESTINGHOUSE 500 VOLT 3½ H.P. MOTOR. LOAD = 5 amp.

METHOD OF EXPLORATION, Mordey's.

LEAD OF BRUSHES = 10°

MACHINE RUN AS, Generator.

MACHINE RUN AT 460 Volts.

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PLATE 15 A
EXPLORATION CURVES OF WESTINGHOUSE MOTOR.
FULL LOAD

Pole Piece

480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0

Volts

Degrees

Generator run at 460 Volts.

Motor run at 500 Volts.
The Stray-Power Test.

The Stray Power test is one which is easy and convenient to make and is comparatively simple. It depends on the fact that certain losses, known as stray power, are constant on a machine for all loads, provided the voltage, speed, and field remain constant. All other losses in the machine can be calculated for the various loads; hence if the stray power is determined, all losses are known and the efficiency of the machine may be calculated for all loads.

To obtain the $C^2/R$ losses the resistance of the various windings must be known. This is obtained by Ohm's law:

$$C = \frac{E}{R} \quad \text{or} \quad R = \frac{E}{C}$$

A current is passed through the coils and
the voltage across the terminals measured.
Since the voltage and current are known, the
resistance may be computed by the formula
given.

In the test the machine should be run
as nearly as possible under normal con-
ditions. This would imply that it should be
excited by shunting the field across the brushes
as would normally be done, but for reasons
which will be explained later they had better
be separately excited. A voltmeter is placed
across the brushes and an ammeter is placed
in the armature circuit. The machine is then
run at normal speed and voltage as a motor.
The field may be adjusted by varying the field
current. After this the field should remain
uniform, for if it does not the speed
will not be proportional to the voltage. The 
$C^2R$ losses will vary for different loads, but 
all other losses will remain constant. The 
stray power losses are composed of eddy currents, 
hysteresis, brush friction, and bearing and air 
friction. All these have been experimentally proven 
to be constant for all loads, if voltage, speed, and 
field remain constant. Now if the machine 
is run light, the voltage at the brushes times 
the current in the armature minus the $C^2R$ in 
the armature is equal to the stray power, since 
the field is separately excited to remain constant. 
The $C^2R$ in the armature when the motor 
is running light is negligible, since both 
current and resistance are small. Hence it 
may be said that the input in the armature with 
fields separately excited and with no load is the
Stray power.

Separation of Eddy Currents. - The stray power is known as a whole, but as yet we do not know how it is divided. We know there are eddy currents, hysteresis, and friction, but to know in what point of construction the machine is weak, we must know what each of these is.

It has been shown that eddy current losses vary as the square of the speed, if the field is kept constant. The field remaining constant, it is also true that the speed varies as the voltage. This being known, the eddy currents are determined as follows:

The machine is run as before, as a motor at no load, and a constant field. The voltage across the brushes is then varied, and the current in the armature obtained. By
plotting volts across the brushes as abscissa and armature current as ordinate a curve like OC in Fig. 8 is obtained. The point C is the average current reading in the preceding test, where the total stray power was obtained. It will now be noticed in regard to the curve OC that the area represented by the product of the volts and amperees gives us the stray watts at any voltage and speed. It is known that all stray power losses except eddy currents vary as the speed and the locus of the amperees which go to overcome these losses would be a straight, horizontal line. The only loss which can cause the line OC to slope is eddy currents, for it is known that eddy current losses vary as the square of the
speed. As the voltage approaches zero it is seen that the ordinate of \( OC \) approaches \( OD \). At no voltage there would be no speed and no losses but \( OD \) represents the ordinate of the curve which shows the amount of current necessary to overcome hysteresis and friction. This line has been shown to be horizontal and is represented by \( OB \). It will be seen that the lost watts computed from above this line vary as the square of the volts and speed. They are eddy current losses. Therefore at full load voltage the eddy current losses are \( OBXBC \) and hysteresis and friction losses are \( OBXAB \). \( OBXAC \) is the total stray power.

In Fig. 8 per cent of load are plotted as abscissae and watts lost as ordinates. At constant speed and voltage all of the stray power losses are constant and are here represented by straight horizontal lines. From Fig 8 we
know the total stray power and the eddy current losses. Hence we know the points Y and Z, because XZ is to XY in Fig. 9 as AB is to AC in Fig. 8. The losses below the eddy currents in Fig. 9 are hysteresis and friction.

Separation of friction losses. — If we can now find what the friction losses are we will also know the hysteresis losses. This may be done as follows:

The machine under test is driven by a small motor by means of a belt. The machine should have no field excitation; hence the power supplied by the motor is used in overcoming
brush, bearing, and air friction. This power
may be determined by:

1) Measuring the total power supplied to the
armature of the small motor when it is
running the machine under test at its nor-
mal speed.

2) Measuring the power supplied to the armature
of the small motor when it is running light
under the same conditions of speed and
voltage as when it was running the machine
under test.

3) Computing the extra &r; loss in the
armature when driving the machine under
test as compared with those when running light.
The power lost in friction in the machine under
test will be the difference of the first and the
sum of the other two. The brush friction
may be determined similarly by running the
machine with brushes up, and determining
the extra C2R losses in this case.

These tests hold if the field magnetization of
the small motor is kept constant, and to
attain this the field should be separately
excited. If this is done the C2R losses in
the field of the small motor will not have
to be considered. The speed and voltage
of the small motor should be carefully
matched and kept constant. All stray
power losses have now been obtained.

C2R Losses. - The C2R losses in the field
are practically constant and need be computed
but once. Those in the armature vary for
all different loads and must be computed for each
load to obtain the efficiency at that load. Of
course, the \( C^2R \) in the armature cannot be computed till it is known how much power is put into it, and this is not definitely known till the \( C^2R \) in the armature is known. Therefore we must first make an approximation. This is done by neglecting \( C^2R \) in finding the power that goes into the armature. Then we compute the approximate \( C^2R \) in the armature. Knowing this we compute a second time an approximate current for the armature. This may be accepted as the true current for it will probably be correct within a fraction of a percent.

**Efficiencies:** Knowing all the losses for the different loads the efficiencies may be computed. Besides the commercial efficiency there are two more efficiencies to be computed: Electrical efficiency,
and efficiency of conversion. The electrical efficiency is a relation between the total electrical energy supplied and the total electrical energy minus the purely electrical losses which are $E^2R$ losses. All other losses may be classed as mechanical losses since they offer resistance to motion, and mechanical power must overcome them. Efficiency of conversion then is a relation between the total mechanical energy generated and the total mechanical energy minus the mechanical losses.

Commercial efficiency is the product of the two preceding efficiencies or the ratio of the total power available at the pulley to the total electrical energy supplied to the machine.

If we represent the output of the machine
by \( W \), the stray power by S. P., the C\(2R \) in the
armature by \( C^2R_a \), and that in the shunt field
by \( C^2R_f \), we may express the efficiencies as follows:

\[
\text{Commercial Efficiency} = \frac{W}{W + S. P. + C^2R_a + C^2R_f}
\]
\[
\text{Electrical Efficiency} = \frac{W}{W + S. P.}
\]
\[
\text{Efficiency of Conversion} = \frac{W}{W + S. P.}
\]

It is obvious that in the method here described
for determining eddy-current losses some
difficulty would be encountered if applied to
a series or compound motor, for the field
would not remain constant and separately
excited the normal conditions would be
altered.
All of the experimental work of this thesis was conducted under disadvantages, but especially was this true in the case of the efficiency tests since for the two sources of 500 volts were necessary, one for the field and one for the armature. The laboratory contained no 500 volt generator, so the Westinghouse 1 pole motor was run as a generator. This motor is heavily overcompounded for elevator purposes and the series field gave trouble, for it was placed on the armature circuit and as the motor was started and the resistance gradually cut out, the machine suddenly became overloaded owing to a rush of current, and threw off the belt.

An attempt was made to remedy the fault by placing a shunt in parallel with the series turns of the generator. This reduced the series amper-
time and really remedied the fault above mentioned but caused a new one. The machine becoming hot no longer gave 500 volts and had to be abandoned. The Jenney motor was then set up and run at 1000 revolutions, 300 above the usual. This proved satisfactory.

The motor under test had to be separately excited since the voltage at the armature was to be varied and the field kept constant. The second 500 volt circuit was made up of 110 volt machine and two storage batteries. The 500 volt machine was placed on the field and the machines in series were placed on the armature. This was done so that as the voltage was diminished one machine after another could be cut out and the remaining ones still run near their maximum voltage where they are the steadiest. A half horse power
Jenney motor was used in the second part of the test to drive the machine under test without field excitation.

Blueprint plate 1 shows the connections for making a stray power test only a Westinghouse motor is shown under test instead of an Edison.

Blueprint plate 2 shows how the friction losses were separated.

The Edison motor shows an efficiency of 80.4% at full load, 32,400 or 411.7. The efficiency falls off pretty rapidly and at about one fifth load is 50%. This is commercial efficiency. It is slightly better than the Westinghouse motor run as a shunt machine, but considerably poorer than the Jenney motor. The curve obtained by varying the voltage showed that the stray power losses varied
PLATE I

CONNECTIONS OF MACHINES AND APPARATUS FOR MAKING STRAY POWER EFFICIENCY TEST ON 4 POLE, 3 1/2 H.P. WESTINGHOUSE MOTOR.

WESTINGHOUSE 500V.

WESTON

JENNY 500V.

STORAGE BATTERY

EDISON

STORAGE BATTERY

STONE-BEGOLE
PLATE 2
Machines, Instruments and Connections
for
Obtaining and Separating Friction Losses

Motor under Test

Auxiliary Motor

Storage Battery

Starting Box

Armature Circuit

Field Circuit

Storage Battery

Motor under Test
Data on Edison 4 H.P. Motor.

Type 185 3 K.W.
Field Winding, Shunt.
Normal Speed = 1500.
Type of Armature, drum.
Bipolar.
Voltage 500.
Amperes at full load = 6.
Polar Embrace = 75%.
Number of Commutator segments = 44.
Number of turns per division = 1.
Diam. bare wire in inches = .035".
Thickenss of insulation = .005

Weight of wire in arm. = 11 lbs.
Armature resistance = 4.82 N.
Length of arm. (over all) = 32 3/8".
Diam. = 5 5/16".
Length of Core = 8".
Diam. Shaft at bearings = 7 1/8".
Diam. Commutator = 3 3/8".
Length of " = 2 1/4".
Diam. Magnet wire = .018".
Thickness insulation = .005.
Wire wire on both cores = 37.5".
Resistance of field = 1200 ohms.
## S.P. Test on Edison 4 H.P. Motor

**Data:**

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<td>.39</td>
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<td>300</td>
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</table>

500 Volts on Field.

## Friction Losses

<table>
<thead>
<tr>
<th>ARM. Volts</th>
<th>ARM. Cur.</th>
<th>SPEED Jenny</th>
<th>SPEED Edison</th>
<th>ARM. V. JEN. 1/2</th>
<th>ARM. C. JEN. 1/2</th>
<th>SPEED Jenny</th>
<th>SPEED Edison</th>
</tr>
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<tbody>
<tr>
<td>BRUSHES DOWN</td>
<td>97.5</td>
<td>2.05</td>
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<td>1900</td>
<td>99</td>
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<td>98</td>
<td>&quot;</td>
<td>2580</td>
<td>1910</td>
<td>98.5</td>
<td>1.25</td>
<td>2500</td>
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<tr>
<td>BRUSHES UP</td>
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<td>&quot;</td>
<td>2570</td>
<td>1900</td>
<td>&quot;</td>
<td>&quot;</td>
<td>JENNY 1/2 H.P. ALONE.</td>
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<td>&quot;</td>
<td>98.5</td>
<td>1.3</td>
<td>2600</td>
<td>1910</td>
<td>98.5</td>
<td>.90</td>
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<td>&quot;</td>
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<td>.89</td>
<td>2620</td>
</tr>
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</table>
COMPUTATIONS FOR S.P. TEST ON EDISON 4 H.P. MOTOR.

Stray Power = 500 \times 6.6 = 3300 watts.
Eddy Currents = 195 watts.

\[ C^2R \text{ in motor field} = 4^2 \times 1200 = 192 \]  
\[ \text{Fritton and Hysteresis} = 135 \text{ watts} \]

**Separation of Hysteresis from Friction Losses.**

- Power to run Jenney 1/2 H.P. Motor, Brushes down on Edison = 201 Watts.
- \( C^2R \text{ in Jenney armature} = 2.05^2 \times 2.9 = 9.6 \) "
- Power to run Jenney Motor light
- \( C^2R \text{ in Jenney armature (when run light)} = 1.9 \) "
- Total Friction loss = 201 - (89.1 + (9.6 - 1.9)) = 104.2 "

**Separation of Brush from Air and Bearing Friction.**

- Power to run Jenney Motor, Brushes up on Edison = 98.5 \times 128 = 126 "
- \( C^2R \text{ in armature} = 1.28^2 \times 2.9 = 3.7 \) "
- Bearing and Air Friction = 126 - (89.1 + (3.7 - 1.9)) = 35.1 "
- Brush Friction = Total Friction loss - Air and Bearing Friction = 69.1 "

**EFFICIENCIES.**

<table>
<thead>
<tr>
<th>Per-Cent of Load</th>
<th>100</th>
<th>83.3</th>
<th>66.6</th>
<th>50.0</th>
<th>33.3</th>
<th>16.6</th>
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</thead>
<tbody>
<tr>
<td>( C^2R \text{ in armature} )</td>
<td>212</td>
<td>155</td>
<td>105</td>
<td>65.0</td>
<td>35.0</td>
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<td>Commercial Efficiency</td>
<td>80.4</td>
<td>79.3</td>
<td>76.2</td>
<td>71.9</td>
<td>69.2</td>
<td>48.3</td>
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<tr>
<td>Electrical</td>
<td>89.2</td>
<td>89.0</td>
<td>88.7</td>
<td>87.7</td>
<td>85.9</td>
<td>80.3</td>
</tr>
<tr>
<td>Efficiency of Conversion</td>
<td>91.0</td>
<td>88.3</td>
<td>85.8</td>
<td>82.6</td>
<td>75.2</td>
<td>60.2</td>
</tr>
</tbody>
</table>
PLATE 6
SEPARATION OF LOSSES IN EDISON MOTOR,

EDDY CURRENTS

FRICITION AND HYSTERESIS

$\text{C}^2 \text{R in Armature}$

$\text{C}^2 \text{R in Shunt Field}$

EDDY CURRENTS

HYSTERESIS

BRUSH FRICTION

BEARING AND AIR FRICTION.
PLATE 7

CURVES OF EFFICIENCY FOR 4 H.P. 500 VOLT EDISON MOTOR.

(EI) EFFICIENCY OF CONVERSION
(II) ELECTRICAL EFFICIENCY
(III) COMMERCIAL " "

100%
90%
80%
70%
60%
50%
40%

EFFICIENCY

Per-Cent of Load: 00 33.3 66.6 83.3 100
as they should. The losses separated may be seen from plate 6.

In the test on the Vethughouse this machine was run as a shunt motor. The connections are shown in plate 1. The test indicates that as a shunt motor it is slightly less efficient than the Edison and very much less than the Jenney. The curve obtained by varying the voltage and speed, although not quite as near straight as in the case of the Edison, shows that the losses varied very nearly as they should. The commercial efficiency at full load is 79.8%, .6% lower than the Edison, while at one sixth load it falls off to 74.4%.

The separation of the losses was conducted as in the Edison and the results are shown in plate 11.
Data on Westinghouse 500 volt motor.

Number of Motor, 45889.
Output = 3½ H.P.
Voltage = 500.
Number of Poles = 4
Speed (normal) = 1050 R.P.M.
Field winding, over compound
Type of armature, drum.
Resistance of armature = 3.45 Ω

Resistance Shunt Field = 1136
" Series " = 1.38
Kind of Brushes = Carbon
Number " " = 2.
" Commutator Segments = 93.
Diameter Commutator = 5.41"
Polar embrace = 57 °
**Stray Power Test on Westinghouse 3 1/2 HP Motor.**

**Data:**

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<td>500</td>
<td>.73</td>
<td>41</td>
<td>1280</td>
<td>300</td>
<td>.57</td>
<td>.39</td>
<td>780</td>
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<td></td>
<td>.71</td>
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<td>1290</td>
<td>250</td>
<td>.56</td>
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<td>690</td>
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<td></td>
<td>.72</td>
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<td></td>
<td>Sep. Losses</td>
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<td>.67</td>
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<td>1020</td>
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<td>1050</td>
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<td>350</td>
<td>.61</td>
<td>&quot;</td>
<td>920</td>
<td>100</td>
<td>.51</td>
<td>&quot;</td>
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<td>900</td>
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<tr>
<td>300</td>
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<td>.39</td>
<td>780</td>
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</table>

500 Volts on Field.

**Friction Losses.**

<table>
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<td>Brushes down on West. 87</td>
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<td>2020</td>
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<td>87</td>
<td>.85</td>
<td>2070</td>
<td>1300</td>
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<td>87.5</td>
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<td>1280</td>
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<td>2050</td>
<td>1290</td>
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<tr>
<td>88.</td>
<td>&quot;</td>
<td>2070</td>
<td>1290</td>
<td>88.</td>
<td>.82</td>
<td>2070</td>
<td></td>
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<tr>
<td>Brushes up. 87</td>
<td>1.85</td>
<td>2070</td>
<td>1290</td>
<td>87</td>
<td>&quot;</td>
<td>2070</td>
<td></td>
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</table>
## Computations for S.P. Test on Westinghouse Motor

Stray Power = 500 \times 0.72 = 360 \text{ watts.}\n\text{Eddy current loss } = 142.5''\nC^2R \text{ in motor field } = 181.8 \text{ watts.}\n\text{Hysteresis and Friction } = 217.5''\n
### Separation of Hysteresis from Friction losses.

- Power to run Jenney 1/2 H.P. motor, Brushes down on Westing... = 267 watts
- \( C^2R \text{ in Jenney armature } = 9.3 \times 2.29 = 21.3''\)
- \( C^2R \text{ in Jenney motor light } = 70.8''\)
- \( \text{Total friction loss } = 267 - (70.8 + (21.3 - 1.5)) = 176.4''\)

### Separation of Brush from Air and Bearing Friction.

- Power to run Jenney motor, Brushes up on Westinghouse = 161."
- \( C^2R \text{ in armature } = 3.4 \times 2.29 = 7.8''\)
- \( \text{Bearing and Air friction } = 161 - (70.8 + (7.8 - 1.5)) = 83.9''\)
- \( \text{Brush friction } = \text{Total friction loss } - \text{Bearing and Air} = 132.1''\)

## Efficiencies

<table>
<thead>
<tr>
<th>Percent of Load</th>
<th>100</th>
<th>83.3</th>
<th>66.6</th>
<th>50</th>
<th>33.3</th>
<th>16.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C^2R \text{ in armature} )</td>
<td>123</td>
<td>90.6</td>
<td>62.0</td>
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<td>21.6</td>
<td>8.7</td>
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<tr>
<td>Commercial Efficiency</td>
<td>79.7</td>
<td>77.5</td>
<td>74.3</td>
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<td>44.2</td>
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<td>Electrical &quot;</td>
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<td>88.3</td>
<td>85.9</td>
<td>80.6</td>
</tr>
<tr>
<td>Efficiency of Conversion</td>
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<td>82.7</td>
<td>79.9</td>
<td>70.3</td>
<td>56.9</td>
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</table>
PLATE 12.

CURVES OF EFFICIENCY FOR 3½ H.P. 500 VOLT WESTINGHOUSE MOTOR.

I = ELECTRICAL EFFICIENCY.
II = Effy. of CONVERSION
III = COMMERCIAL EFFICIENCY.
The Jenney motor was tested by the stray power method, much as the Edison and Westinghouse were tested. The Westinghouse motor with a storage battery in the field windings and with no series windings was connected in series with a storage battery to excite the field of the Jenney motor. The same connections that were used in the former tests could not be used in the armature circuit because two of the machines were so badly grounded that they could not be connected in series. Another scheme had to be employed. A brush arc light dynamo, with a capacity of 10 lamps was available, but since it gave a constant current of 9.6 amperes it could not be used directly. This current of 9.6 amperes was run through a 40 ohm water rheostat causing a difference of potential of about 375 volts at the terminals of the rheostat.
PLATE 3

CONNECTIONS OF MACHINES AND APPARATUS FOR OBTAINING STRAY POWER OF 5 H.P.

JENNY MOTOR.

EDISON

JENNY 5 HP.

STONE-BEGOLE.

STOR. BATTERY

STORE. BATTERY

RHEOSTAT

BRUSH ARC DYNAMO

WESTINGHOUSE
DATA ON 5 H.P. 500 VOLT MOTOR, #1130.

made by Jenney Electric Construction Co. Indianapolis, Ind.

Normal Speed = 1500 R.P.M.

Weight = 612 lb.

Resistance of armature = 3.59 ohm.

Resistance of field = 1567 ohm.

Diam. arm. core = 8 1/4" (bare).

Length " = 9 3/8".

Arm. winding has 68 conductors.

Number of turns per cond. = 9

No. of wire = 18 B+5.

Length of wire = 1836 feet.

Floor space = 13 1/2" x 22".

Height = 20".

Diam. pulley = 8"

Mag. Core = 19 1/4" long

= 5" in diameter.

75 layers of windings.

Turns per layer = 320.

Length of field wire = 479 1/16".

Diam. commutator = 3 3/16".

Length commutator = 4 1/2".
STRAY POWER TEST ON JENNY 5 H.P. MOTOR.

Data:

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<td>&quot;</td>
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<td>1390</td>
<td>200</td>
<td>.55</td>
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<td>450</td>
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</table>

500 VOLTS ON FIELD.

FRICTION LOSSES

<table>
<thead>
<tr>
<th>ARM. Volts</th>
<th>ARM. Cur(T-H)</th>
<th>Speed T-H</th>
<th>Speed Jenny</th>
<th>Speed T-H</th>
<th>ARM. Volts</th>
<th>ARM. Cur.</th>
<th>Speed Jenny</th>
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<tr>
<td>Brushes down on Jenny 63</td>
<td>3.4 1200 1500 1230 T-H Light</td>
<td>630 1.85</td>
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<td>Brushes up 63</td>
<td>3.05 1200 1500</td>
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</tr>
</tbody>
</table>

SEPARATE T-H FIELD CONSTANT AT 945 AMPERES.
Computations for S.P. Test on Jenney Motor.

Stray Power = 500 x 5 = 250 Watts  
C²R in motor field (Phunt) = 150.5 Watts

Eddy Currents = 140  
Friction and Hysteresis = 110

Separation of Hysteresis from Friction losses.

Power to run T-H exciter (as motor), Brushes down on Jenney = 214 watts
C²R in T-H armature = 11.5 x 96

Power to run T-H light -
C²R in T-H armature (When run light) = 3.92 x 96
Total Friction loss = 214 - (1165 + (5.3 - 1.6))

Separation of Brush from Air and Bearing Friction

Power to run T-H, Brushes up on Jenney
C²R in armature = 3.02² x 96

Bearing and Air Friction = 192.2 - (1165 + (428 - 1.6))
Brush Friction = Total friction loss - Air and Bearing

Efficiencies.

<table>
<thead>
<tr>
<th>Per-Cent of Load</th>
<th>100</th>
<th>83.3</th>
<th>66.6</th>
<th>50</th>
<th>33.3</th>
<th>16.6</th>
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<tbody>
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<td>C²R in armature</td>
<td>230.0</td>
<td>163.0</td>
<td>108.0</td>
<td>65.0</td>
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<td>Commercial Effy</td>
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<td>Electrician</td>
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<td>93.6</td>
<td>92.5</td>
<td>90.9</td>
<td>88.2</td>
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FRICTION LOSSES IN JENNEY 5 H.P. MOTOR AT DIFFERENT SPEEDS.

<table>
<thead>
<tr>
<th>Armature Volts</th>
<th>Armature Current</th>
<th>Field Current</th>
<th>Jenney Speed</th>
<th>T-H Speed</th>
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<td>63</td>
<td>3.4</td>
<td>.945</td>
<td>1500</td>
<td>1200</td>
</tr>
<tr>
<td>8&quot; Pulley on Jenney</td>
<td>3.0</td>
<td>.945</td>
<td>190</td>
<td>1200</td>
</tr>
<tr>
<td>12&quot; Pulley on Jenney</td>
<td>3.35</td>
<td>.945</td>
<td>540</td>
<td>1200</td>
</tr>
</tbody>
</table>

Jenney

Edison 6 K.W.

Stone-Begole.
PLATE 16
Separation of Losses in Jenney Motor.

Eddy Currents
Friction
Hysteresis

Watts lost

C²R in Armature.

C²R in Shunt Field.

Eddy Currents.

Hysteresis
Brush Friction

Bearing and Air Friction.
PLATE 17

CURVES OF EFFICIENCY FOR 5 H.P. 500 VOLT JENNEY MOTOR.

I = Electrical Efficiency = \[ \frac{W - (C^2R_a + C^2R_i)}{W} \]
II = Efficiency of Conversion = \[ \frac{W}{W + S.P.} \]
III = Commercial Efficiency = \[ \frac{W}{W + S.P. + C^2R_a + C^2R_i} \]

Per-cent of Load

16.6  33.  50  66.6  83.3  100
Since only a small current was wanted it could be taken in shunt with this rheostat and not alter the voltage much. The remaining voltage was obtained from an Edison dynamo. The connections for this are shown in blueprint plate 3. The water in the rheostat became heated and its resistance decreased, causing some difficulty in keeping up 500 volts across the brushes of the motor. The test was however completed satisfactorily. The efficiency shows up well, being 85.6% at full load, which is over 5% better than the Edison motor. At one eighth load it had an efficiency of 60.5%.

When the losses were separated it was found that some of them did not vary as they should, for the line obtained by varying the voltage and plotting volts and amperes was far from straight.
The curve may be seen by referring to plate 16.

This could not be caused by eddy currents or hysteresis and all that remained to cause the trouble was friction. Under this assumption another test was made to verify it. A 3 KV, T-H generator was used as a motor. The Jenney motor was belted to this and run without field excitation at different speeds, the losses in the T-H motor being kept constant by keeping its speed constant. The speed of the Jenney motor was varied by varying the size of the pulleys. By this means the true friction losses at the different speeds were obtained. Then plotted these losses were represented by an irregular line. When the ordinates were deducted from the first line obtained by varying the voltage a straight line resulted showing that the eddy current and hysteresis losses varied according to the laws. The friction line should have
been straight and horizontal showing that they varied as the speed. These tests show that the trouble was caused by friction. The probability is that it was the friction of the brushes. The remaining part of separating the losses was carried out in the usual manner and plotted in plate 16.

The eddy currents and C2R losses appear to be the greatest part of the losses in this case. This is accounted for probably by the large amount of iron in the armature and field of this motor as compared with its size, so this would tend to increase eddy currents and to reduce hysteresis by reducing the density of magnetic lines. Hysteresis however appears in this case abnor-

mally small.
Instruments Used. — The instruments used were
Dekovor meters. Two milliammeters were used at
different times. These were calibrated before the
tests began and were found to be so accurate
that the errors could not be plotted. The same
was found to be true of the 600 volt meter and
the 0-15 ammeter. The Whitney ammeter which was
used was not used for any accurate measurements,
but only to determine roughly what current was
flowing in some circuit.
The calibrations were made by means of
Kelvin balances.