Scholars' Mine

Masters Theses

Student Theses and Dissertations

1965

Measurement of stray load loss of d.c. machines

Kanaiyalal Ramanlal Shah

Follow this and additional works at: https://scholarsmine.mst.edu/masters_theses

Part of the Electrical and Computer Engineering Commons

Department:

Recommended Citation

Shah, Kanaiyalal Ramanlal, "Measurement of stray load loss of d.c. machines" (1965). *Masters Theses*. 6693.
https://scholarsmine.mst.edu/masters_theses/6693

This thesis is brought to you by Scholars' Mine, a service of the Missouri S&T Library and Learning Resources. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

T1733

MEASUREMENT OF STRAY LOAD LOSS OF D.C. MACHINES

BY

K. R. SHAH, 1939-

58p

A

THESIS

113672

submitted to the faculty of the

UNIVERSITY OF MISSOURI AT ROLLA

in partial fulfillment of the requirements for the

Degree

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

Rolla, Missouri

1965

Approved by

George McAlhaney Jr. (advisor) Richard C. Harden

William J. Jensen Lee J. Bain

ACKNOWLEDGEMENTS

The author gratefully acknowledges the guidance and help which he has received throughout the thesis work from Professor George McPherson, Jr., Electrical Engineering Department, University of Missouri at Rolla. Without his continued, lively interest and help in every aspect of this paper, it would not have been possible for the author to present the given material in such a short time.

He would like to tender his sincere thanks to Professor Rhea of Mechanical Engineering Department for his guidance and help in the preparation of the current collecting ring assembly. The author is indebted to Mr. Frank Huskey for his help and co-operation, and to Mr. M. E. Brubaker for helping the author in taking experimental results and finally to Mrs. K. W. Davidson for typing the thesis.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENT ii

TABLE OF CONTENTS iii

LIST OF ILLUSTRATIONS v

LIST OF TABLES vi

I. INTRODUCTION 1

II. THEORY OF STRAY LOAD LOSS 3

2.1 Definition of American Standard. 3
2.2 Increase of core losses Caused By Load Currents 3
2.3 Eddy-current Losses In Armature Conductors . 7
2.4 Skin Effect In The Armature Conductors . . . 9
2.5 Short Circuit Losses of Commutation 9

III. EXISTING METHODS FOR MEASURING STRAY-LOAD LOSS 11

3.1 Input-Output Method. 11
3.2 Suggestions of A.I.E.E.E. Committee (1949) . 11
3.3 Blondel's Opposition Principle 12

IV. DIFFERENCE BETWEEN THE EXISTING METHODS AND PROPOSED METHODS 15

4.1 Difference Between the Existing Methods and Proposed Method 15
4.2 Short Circuit Test 17
4.3 Separation of Losses Under Short Circuit 18

V. TEST PROCEDURE 19

5.1 Short Circuit Test 19
5.2 Pump-Back Load Test. 20
5.3 Blondel's Opposition Test 22
5.4 Measurement Techniques for Above Tests . . . 23

VI. EXPERIMENTAL RESULTS AND COMMENTS 27

6.1 Preliminary Tests 28
6.2 Experimental Results and Comments 29
6.3 Correction Factor For Short Circuit Test . . 51

Page

VII. CONCLUSION 52

7.1 General 52
7.2 Future Tests 53

APPENDIX 55

BIBLIOGRAPHY 57

VITA 58

LIST OF ILLUSTRATIONS

Figure		Page
2.3	Trapezoidal Flux Density Distribution Under The Poles.	6
2.3.1		7
3.1.1	Pump Back Connection For Measuring Total Loss Of Two Machines	12
4.2.1	Schematic Diagram For Short Circuit Test	17
5.1.1	Measurement of Armature Resistance	21
5.3.1	Blondel's Opposition Test.	22
5.5.1	Current Collecting Ring Assembly	25
6.a	Photographic View of the Experimental Set Up . .	27
6.b	Oscillogram of Flux Density Waveform at No Load.	35
6.c	Oscillogram Showing Analysis for Case.	35
6.1	Curves of Stray Load Loss Vs Load Current	44
6.2	Stray Load Loss Vs I_f	45
6.3	Separation of Stray Load Loss Into Its Component	46
6.4	Comparison of Stray Load Loss by Different Methods.	47
6.5	Stray Load Loss Vs. Load Current	48

LIST OF TABLES

Page

6.1 Short Circuit Test Results. 30

6.2 Pump-Back Load Test Results 32

6.3 Blondel's Opposition Test 33

6.4 Modification of Blondel's Opposition Test By Reversing the Rotation 38

6.5 Determination of Iron Losses In Teeth Under Load Condition 40

6.6 Separation of Two Components of Stray Load Loss 40

I. INTRODUCTION

For many years the standard practice, in calculation of conventional efficiency of d.c. machines, has been to include stray load losses as equal to 1% of the output. This assumption may be true for large, compensated d.c. machines but it is known to be small for smaller, uncompensated, general-purpose, industrial-type machines of open design. An A.I.E.E. Committee on Rotating Machines was formed to investigate whether the present practice of assigning 1% for the stray load loss is justified or not. They reached a conclusion, reported in 1949 (Ref. 1), after investigating 243 stray loss tests on different motors ranging from 1/2 hp to 50 hp, that the present practice should be continued until a new method is available which gives a direct measure of these losses.

Stray load losses is one of those perennial subjects which one may want to elude but cannot. It affects, as do the other losses, the heating of the machine and must be accounted for by a manufacturer in working out the utilization of material, machine dimensions and the ventilation of machines. It may affect the power input or output by several per cent, especially under light-load conditions.

Publications and theories of stray load losses in d.c. machines show that no adequate theory has been developed. Nor has an adequate test method for determining these losses

been found which gives consistent results. This is because of the great complexity of the problem.

Everyone associated with this field wants reliable equations for each of the components of stray load losses, or a test method that will help the designer to predict the amount of stray load loss in his design more accurately than at present.

Since d.c. machines are used under varying speeds and load cycles, the commercial importance of these losses is not great, practically speaking. However, their increased use in controlled industrial drives and in automation has created a renewed interest in the finer points of their design.

In this article, an attempt is made to measure stray load losses directly by a short circuit test. This method has been suggested by many (Ref. 2) in one form or the other, but no one has come to a <u>definite</u> and precise conclusion, or has explained these losses, as they occur, under short circuit test.

II. THEORY OF STRAY LOAD LOSSES

2.1 Definition by American Standard

American Standard (50.4 - 1955) for d.c. machines, specifies 11 different types of losses to be considered in determining the efficiency. Out of these, only the 11th loss is not precisely calculable or can be obtained by simple tests. This is the stray-load loss.

According to this standard, the stray load losses in d.c. machinery are defined as the sum of the following partial losses:

(1) Additional core loss due to the flux from armature windings excited by load current

(2) Eddy currents in the armature windings

(3) Short circuit loss of commutation.

In the following, each of the above losses will be discussed separately.

2.2 Increase of Core Losses Caused by Load Currents

When load is applied to a direct-current machine, an exciting m.m.f. is produced in the armature. If this armature reaction is not well compensated, it produces demagnetizing effect in the direct axis and the flux density distribution in the air gap under the poles no longer remains flat topped and has a marked peak at one of the pole tips (see oscillograms presented on page 48 in this paper.) This increases the peak flux density in the armature teeth, core

and pole tips at one end and reduces it on the other end. The hysteresies losses, which are proportional to the square of the peak flux density,assuming Steinmetz exponent to be 2.0 will increase; while eddy-current losses, which depend upon the flux density waveform, will increase at one pole tip and decrease on the other. The net effect is usually an increase in iron losses.

In addition to these losses, the appearance of current in the commutating-pole winding creates losses in armature teeth.

Iron losses contributed by stray fluxes in ventilating spacers, and due to leakage flux between pole face and armature face will increase under load.

Previous Work on Incremental Core Losses

Carr suggested an empirical formula for the ratio of total full load core loss to total no load core loss, as follows: 1 + 0.25 (Armature ampere-turns/field ampere turns)^2, regardless of saturation. He stated that the coefficient 0.25 may vary.

Hughes[2] derived the formula for incremental iron loss in the teeth, neglecting iron losses in teeth under commutating pole, for the cases: (1) when the flux density in the air gap is not reversed and (2) when it is reversed at one pole tip in the presence of weak main field and strong cross field.

The iron losses in the teeth for case (1):

$$W_t = kf^{1.5} V_t \, B_1^{\,2} \tag{1}$$

where k = constant, V_t = volume of teeth, f = frequency, B_1 = flux density in tooth when under saturated pole tip.

Iron losses in teeth for case (2):

$$W_t = kf^{1.5} \, (B_1 + B_2)^2 \, V_t \tag{2}$$

where B_2 = flux density in tooth at the pole tip having reversal of air-gap flux-density.

He also showed the increase in armature core loss in the case of flux reversal under a pole. This must be considered, because the flux which reenters the pole shoes has to be carried by the armature core and comparatively high induction prevails there. He gave the following formula showing the variation of losses in the armature core under load.

$$Ba = \frac{\phi + 2\phi_c}{A} \tag{3}$$

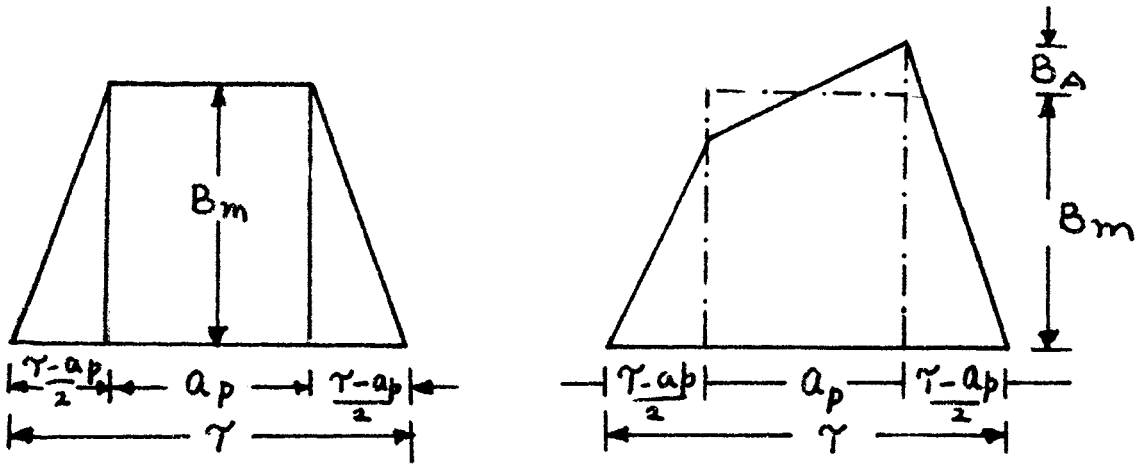
where ϕ = resultant flux per pole

ϕ_c = cross-flux reentering pole shoe

A = sectional area of armature core per pole.

There is a controversy in the literature as to the existence of this change in loss under load but in the absence of any experimental proof, one can not prove or disprove this. The problem is complicated since in the core both the magnitude and direction of flux density changes continuously.

In 1925, Von Blittersdorf[2] developed a simple method for the calculation of the additional hyster sis and eddy current losses under load. It is based on the assumption



(A) (B)

Fig. 2.2

of a trapezoidal flux density distribution under the poles, as shown in Fig. (2.2A). He assumed that at load this dis tribution is changed to that of Fig. (2.2B). He assumed that the hysteresis losses vary with the square of the peak flux density. This led to the following equations for the incremental core losses in the teeth:

$$W_{\text{add hysteresis}} = C_1 \ (2 \ B_m B_A + B_A^2) \tag{4}$$

$$W_{\text{add eddy loss in the iron of teeth}} = C_2 \ \left(\frac{\tau}{ap}\right)\left(\frac{1}{\tau - ap}\right) \ BA^2 \tag{5}$$

Most of the work is done on tooth iron loss by considering the flux in teeth as an alternating flux similar to that of a transformer. The main reason for the lack of literature for core loss in armature is, again, complexity of the problem.

Pole face losses will be affected by the local change in flux density which will increase loss at one pole tip and decrease at the other. There is a feeling among students of problem that the increase in the pole face losses is far less than other increments. (Ref. 2)

The iron losses caused by the axial fringing flux will increase under load but for a well designed machine they are assumed to be negligible. Also, eddy currents set up in binding wires and metallic rings will increase under load. The increased use of nylon strings in place of binding wires will decrease the amount of this loss.

2.3 Eddy Current Losses in Armature Conductors

Additional copper losses in the armature winding are the result of the cross-flux in the slots. The current which flows in the conductors of a d.c. machine is an alternating current of approximately trapezoidal waveshape of frequency $f = \frac{NxP}{120}$. The change in sign of current causes changes of the slot-cross-flux which produces eddy currents in the conductors. The polar flux also causes eddy currents in the armature conductors. Though the bulk of the flux enters the top of the tooth, a certain amount may enter the tooth from the

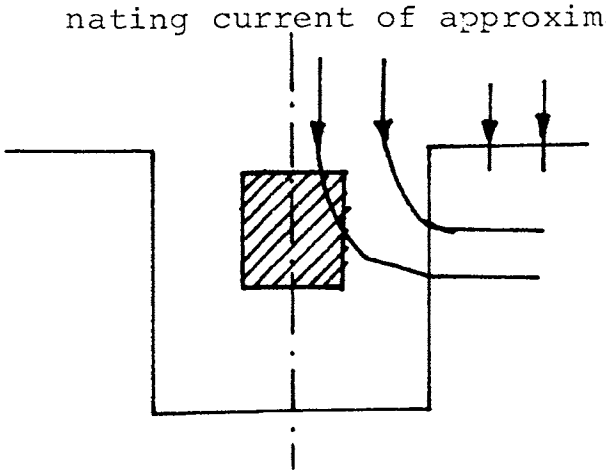


Fig. 2.3.1

sides of the slot due to high saturation of armature teeth and this will pass through the conductors as shown in Fig. 2.3.1. Such flux will produce eddy currents which flow mainly when the slot is traversing the interpolar arc. And, as the field distortion of the armature m.m.f. saturates greatly the teeth opposite one of the pole tips, the shunting effect of the flux in the slot becomes more marked. Thus, this effect will increase under load conditions. Obviously, the eddy currents due to this effect will be larger in a conductor which is at the top of the slot than one at the bottom of a slot.

Another source of increased copper loss is the main flux distortion due to the armature m.m.f., which increases flux density at one side of pole and lowers it on the other side. This causes increased eddy current losses in armature conductors of the same kind as those pronounced by the main flux at no-load.

The reversal of the end-connection leakage flux under load induces eddy currents in the end connections of the armature winding. The resulting loss is very small in comparison with the other stray-load-losses. It is usually neglected.

Because the current in the armature of a d.c. machine is an alternating current, the sinusoidal current equations can and have been often applied to the calculation of the

eddy current loss in d.c. armature conductors. The classic papers of A. B. Field (Trans. A.I.E.E.E. 1905) Emde (Ekctrotechnik und Machinebau, 1904) and Drefus (EUM, 1914) give practical calculations of eddy currents in the copper of armature slots of d.c. machines. While Lyon's (Ibid 1921) and Carter's (Journal I.E.E., 1927) papers give calculations for armature copper eddy current loss when there are several coils per layer.

As seen from a review of literature, the slot copper losses caused by a.c. nature of the armature current can be calculated with sufficient accuracy but there is no simple experimental method to determine the effective resistance due to the a.c. current.

2.4 Skin Effect in the Armature Conductors

The slot-cross-flux also forces most of the current to flow in the top part of the conductor, thus decreasing the effective area of the conductor and increasing its resistance. This is known as "skin effect" and is more pronounced when the height of the conductor increases. This loss is considered to be the major portion of stray load loss for a well compensated machine having conductors of large cross-section.

2.5 Short Circuit Losses of Commutation

Commutation condition changes with the change in load and its influence on brush drop is known. Wilson gave a

formula based on constant brush resistance to estimate the losses at the brush contact. (Ref. 2)

The increased loss is due to (1) high frequency currents circulating in the coils passing through the brush and (2) reactance voltage may not be fully compensated under overload and as a consequence losses occur in the coil and under the brush. Festisov's (Elektrichestvo, 1953) theory considers the energy liberated during commutation and gives relations for the brush drop and increased commutation loss of any type of armature winding.

III. EXISTING METHODS FOR MEASURING STRAY-LOAD LOSS

3.1 Input-Output Method:

Stray load loss, as was pointed out in earlier chapters, is difficult to measure because the core-loss component appears in part as an armature-circuit loss component. Hence these components are interrelated. Therefore, the present practice is to measure these losses--not directly--but indirectly by the well known input-output method. The input-output method consists in measuring the output power and input power. The difference between the two gives the total losses. From these losses are subtracted the sum of running light loss, brush contact loss and copper loss (after converting it to the temperature rise depending upon each load condition) to yield stray load losses.

This method gives results which are neither consistent nor accurate, since it involves taking the difference between two large quantities. An error in either of the two measurements will produce an error of considerable magnitude in their difference. The results obtained by this method vary over a wide range depending upon human error, instrument accuracy, brush setting, etc.

3.2 Suggestions of A.I.E.E.E. Committee (1949)

In order to get more consistent results, it is necessary to measure losses by direct means. Sand (Ref. 1) suggested that the Blondel's opposition principle should be

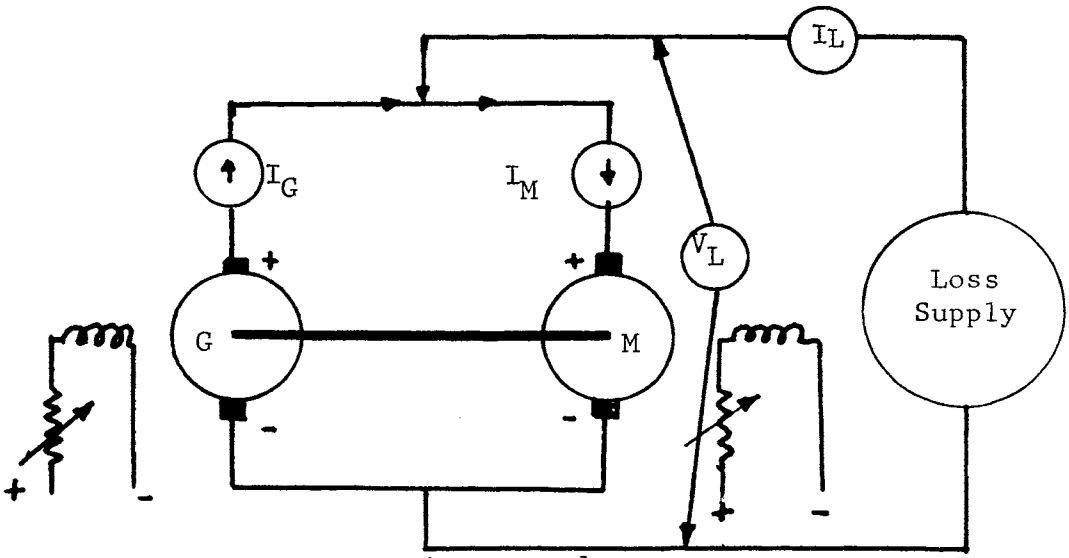


Fig. 3.1.1 Pump-Back Connection
For Measuring Total Loss of Two Machines

given consideration. Lynn (Ref. 1) proposed the pump-back method of testing, particularly for large machines. This method, in principle, is the same as the above method. Caldwell (Ref.1) gave a simple pump-back load test as shown in Fig. (3.1). This requires two identical machines. This method requires measurement of input current and line voltage to compute total losses. Stray load loss is obtained by subtracting recognized losses from total losses, and dividing by two.

3.3 Blondel's Opposition Principle

A test method based on Blondel's opposition principle of loss measurement was carried out by Sieron and Grant (Ref. 3) in 1956. This method requires another identical machine. Their measured stray load loss was made up of two components, namely: (1) an armature-circuit component and (2) a core-loss component, assumed to be supplied by the driving motor.

No attempt was made to explain each of the above components and the assumptions made in treating stray load loss as two separate components. They concluded that the armature circuit component of stray load loss is nearly proportional to the square of current and the core loss component increases with the load current, and, after reaching peak, decreases to a value less than that at no load. The rise in core loss at low values of armature current was explained to be due to the increased flux caused by the interpoles. At larger values of armature current the saturation effect of cross-magnetisation on the main poles overshadows the effect at the interpole and the core loss component decreases. They tried to strengthen this argument by giving the core loss component vs armature current with half-rated excitation applied to the shunt field. In this case the core losses are greater since it takes higher values of armature current to establish saturation effect.

It seems to the author that this argument of interpole effect in explaining the particular behavior of core loss is in controversy with the work done by other investigators. In particular, Hughes pointed out with his experimental proof, that the iron loss in the teeth under interpole is not responsible for the increase in iron loss with armature current. The eddy current loss due to transformer action occurs when teeth move into and out of interpole field. Hughes also showed that the increase in iron loss caused by a given

current in the interpole is practically independent of the main pole flux (Ref. 2). And the increase in core loss at half-rated excitation but with the same armature current is, probably, better explained by the reversal of flux in the presence of strong cross-field and weak main field flux Ref. 2).

IV. PROPOSED METHOD

4.1 Difference Between The Existing Methods and Proposed Method:

As already been pointed out that the input-output method does not yield consistent results, while Blondel's opposition test is complicated because it requires (1) Correct setting of brushes in the neutral position so as to generate equal voltage for the same excitation, (2) another identical machine (which may put restrictions on the use of this method for large size machines since the manufacturer has to build another unit for stray load loss measurements!) and (3) another driving motor to supply the mechanical power, plus a booster generator having unusual ratings.

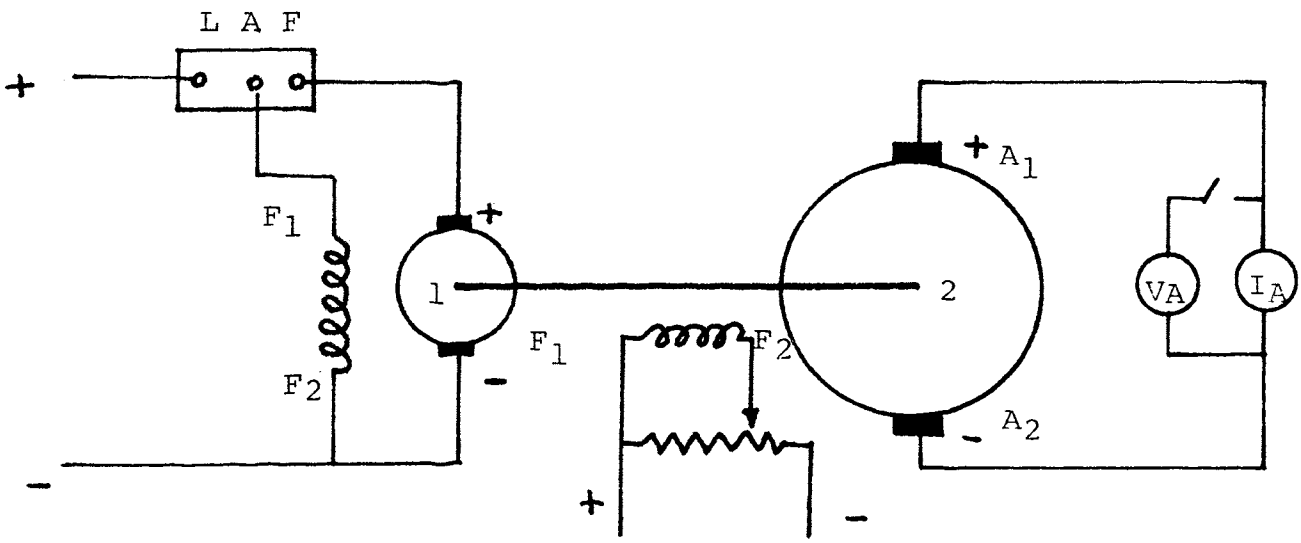
The stray load loss can also be disclosed by short circuiting the armature terminals, and adjusting the field for rated armature current, with the machine driven at rated speed. The mechanical input to the machine is measured. In this, the stray load losses are considered as made up of a number of separate components: (1) a core loss component, which consists of additional increase in hysteresis and eddy current losses in armature teeth and armature core resulting from the distortion of the air-gap flux by the armature mmf. This loss appears as a counter torque; (2) Increased armature-circuit loss arising from skin effect and eddy currents in armature conductors, due to the alternating current flowing in the armature; (3) eddy current loss in the iron sur-

rounding the armature conductors which results from the a-c armature-current field. This appears as increased winding resistance. (4) Hysteresis loss resulting from a.c. field around armature conductors which appears as increased winding resistance, as in transformers; (5) additional brush contact loss due to imperfect commutation (when full load current is flowing in the armature) is reflected in increased brush drop and hence increased resistance; and (6) losses in metal fringes and binding wires supporting the armature and coils.

The first component of stray load loss is termed as "core loss" component while all the remaining components are put under the term "increased resistance loss" since they result in increased winding resistance irrespective of their cause of existence.

During the short-circuit test, the core loss component in a small uncompensated machine will be greater than that occurring under load. In the presence of a weak main field (since under short-circuit conditions the exciting ampere turns required to circulate full load current will be small) and strong cross-field due to armature mmf, the flux density will reverse under the pole. But, for the machine with compensating windings this component is not of any significant importance. The other component, due to armature alternating current, is little affected by the magnitude of main field. Therefore, this test should measure stray load losses

accurately for the compensated machine while for small uncompensated machines, the results obtained will be corrected by a factor which will be described later.



1. Calibrated d.c. motor
2 D.C. Machine under test

Fig. 4.2.1 Schematic Connection Diagram For Short Circuit Test

4.2 Short Circuit Test:

In this test the machine is driven at rated speed by a calibrated motor which is coupled to the machine by a common shaft. Its excitation is increased from zero until full-load current flows in the short circuited armature. Under this condition, the current flowing in the armature winding is alternating with a frequency determined by rated speed and the number of poles of the machine. Since the armature is short circuited, the output is zero and the extra mechanical power supplied by the driving motor, after subtracting losses due to (1) windage and friction (2) brush contact loss and (3) ohmic losses, gives the total stray load loss.

The summation of all the above losses will be defined as short circuit power loss.

4.3 Separation of Core Loss and Increased Resistance Loss From Stray Load Losses Obtained Under Short Circuit Condition:

The separation of the stray load losses into its two components is achieved by using Blondel's opposition test, using the definition of Sieron and Grant. The increased resistance loss obtained by the latter test is the same (practically) as that of the short circuit test. Therefore this loss, if subtracted, from the stray load loss obtained under short circuit test, gives the core loss component. As explained earlier, this core loss component will be more than that of the full load condition.

Stray load loss will be determined by three different tests (1) short circuit test (2) pump-back test and (3) Blondel's opposition test. Results obtained will be compared and correction factors will be derived. Additional core losses will be determined (approximately) from the oscillograms of flux-ensity waveforms obtained for each load condition and also under short circuit, by using Von Blittersdorf's method and Hughes' equations.

V. TEST PROCEDURE

5.1 Short Circuit Test

(1) After operating under load to attain the temperature rise corresponding to the load in question, the machine was driven at rated speed by a calibrated motor with the armature short circuited through an ammeter. With the residual magnetism reduced to zero, the field excitation is increased from zero till the required load current is obtained. The driving power and the voltage drop across the ammeter are measured. The power lost into ammeter is subtracted from the driving power to get the net short circuit power (P_{SC}).

(2) With the same field excitation and speed, but with the armature open circuited, the open circuit power required to drive the machine is measured.

(3) Armature resistance measurement was made with a special method proposed by Professor John Usry, Electrical Engineering Department, University of Missouri at Rolla. This test was taken when machine was running very slowly. The armature was supplied from a variable d-c source. Measurements of d-c current flowing through the armature (I_A) and voltage applied across armature terminals (V_A), were plotted for different values of load current. V_A was taken as the ordinate and I_A as abscissa (Fig. 5.1). A tangent to the curve is drawn, which, when extended to y-axis (for zero armature currents), gives the brush drop = 2.0 (I.E.E.E. conventionally assumes brush drop = 2.0 volts) and slope of

the tangent gives the required value of resistance. Measurements should be made as quickly as possible so as to avoid heating of armature. The armature resistance, after correcting for the corresponding temperature rise, is multiplied by the square of load current to obtain the ohmic armature copper loss.

(4) Brush contact loss was calculated by multiplying the corresponding current by 2 volts.

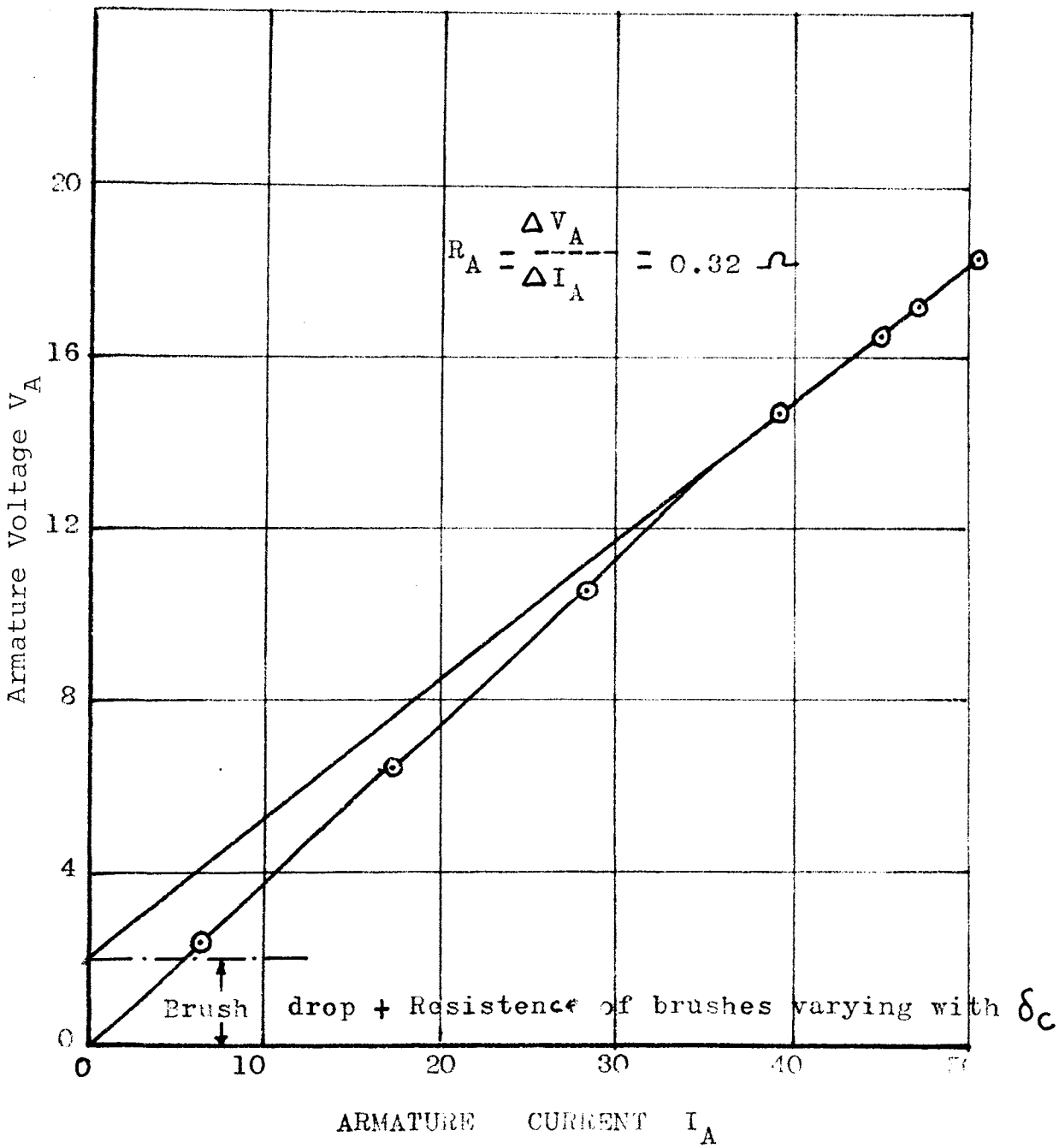
Stray load loss is obtained after subtracting losses due to (2) (3) and (4) from (1).

The same set of readings were taken for different speeds and stray load loss was determined for each speed with the same armature current.

5.2 Pump-Back Load Test (Fig. 3.1)

1. Two identical machines are mechanically coupled together. One machine is connected to a power supply through a starting box, and is started as a motor. After adjusting the separately excited fields of the two machines to generate equal voltages, the machines are connected in parallel. The two fields and loss supply voltage are adjusted for rated speed and rated armature current in the test machines. One machine is now operating as a motor and the other as a generator.

   Measure line voltage and line current for the above case (i) and again after reversing their modes of opera-



δ_c - current density.

Fig.5.1.-- Measurement of Armature Resistance.

tion (ii). Average these two sets of readings.

2. Determine the running light losses with the speed and

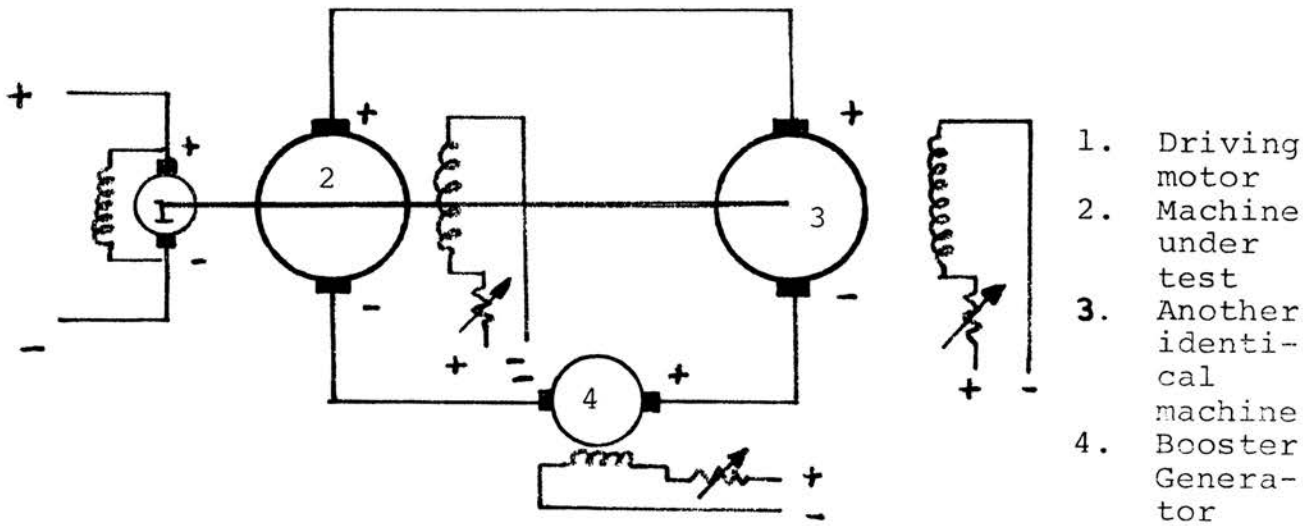


Fig. 5.3.1

excitations as (i) but with zero current.

3. Copper losses and brush contact losses for both machines are determined according to 5.1.3 and 5.1.4.
4. Stray load loss for one machine is obtained by subtracting the total losses (2) + (3) from loss supply and dividing by two.

5.3 <u>Blondel's Opposition test</u>.

1. Arrange the brushes of two identical machines into neutral position so that the effect of armature reaction will be the same in both machines.
2. Mechanically couple machines and drive them at rated speed by means of a calibrated motor. Adjust the excitations so as to generate rated voltages of opposite polarity. Insert a booster generator into the armature circuit so as to produce the required load current.

Measure the driving power and the inserted power.

3. Run the machines at a very low speed with the same armature current but with residual magnetism reduced to zero. Measure the inserted power in the armature circuit.

4. With the excitations as that of case 2, but armature open circuited, measure the driving power required to rotate both machines at rated speed.

Stray load loss, in this test, is given

$$= \left(\frac{Wd_1 - Wd_2}{2}\right) + \left(\frac{W_1 - W_a}{2}\right)$$

where Wd_1 - drive motor output to both machines under load (case 2)

Wd_2 - drive motor output to both machines under no-load (case 4)

W_i - inserted armature power (case 2)

W_a - armature circuit loss (case 3)

The first component is known to be approximately equal to core loss component of the stray-load loss while the second component is approximately equal to additional armature circuit load loss of the machine under load.

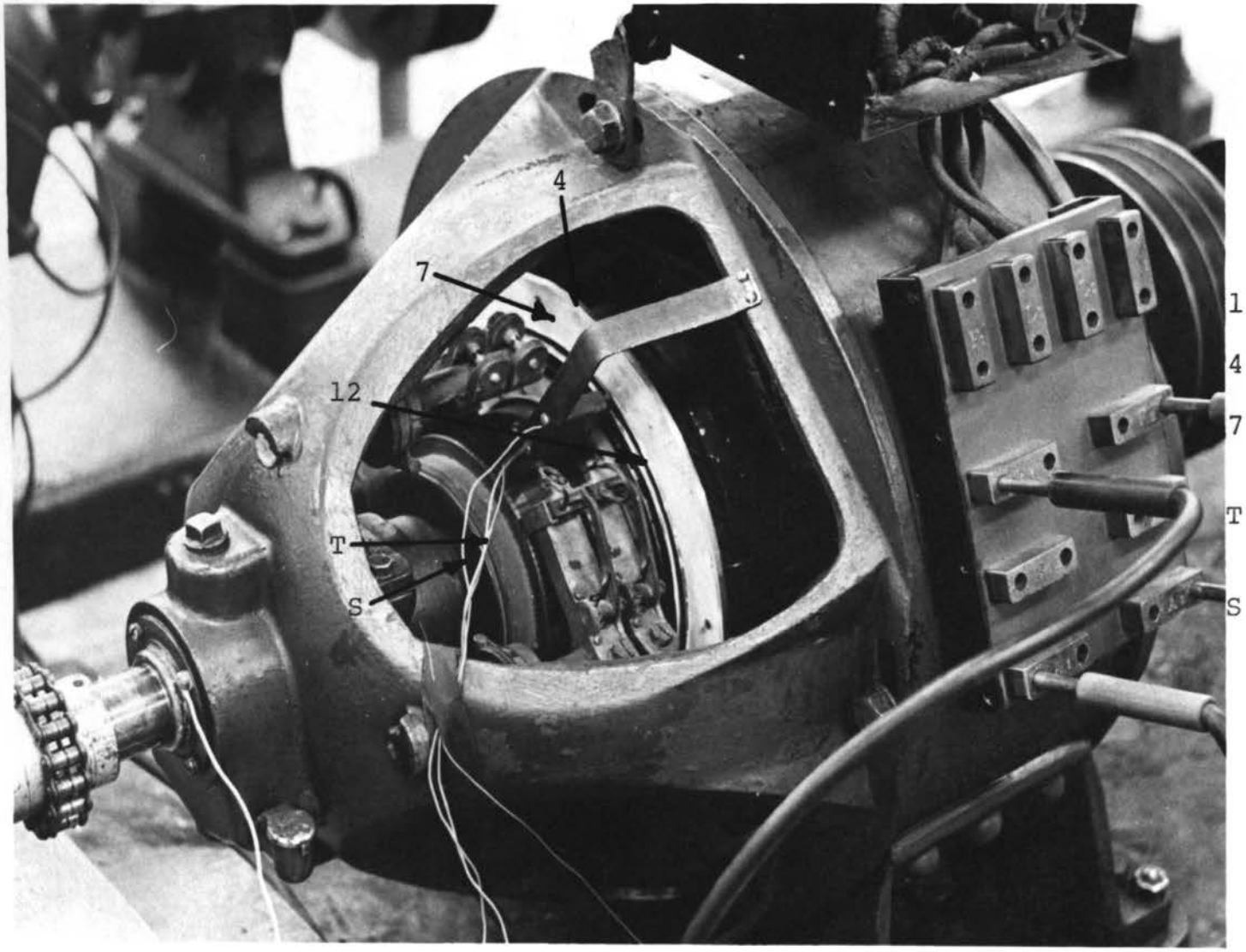
5. 4 <u>Measurement Techniques for above tests</u>:

1. A search coil of one turn was introduced into one armature slot to obtain oscillographs of the voltages generated in the armature at different loads and also

during the short circuit test. This search coil is isolated from the armature circuit electrically but is subject to the same flux as the armature winding. In this test, only one side of the search coil is in the armature slot. The other side is grounded to the motor shaft and hence this side is not included in the flux path. In effect, this search coil gives us a true indication of a single conductor cutting the flux of the machine. The ungrounded lead of the search coil is taken via a brass collector ring to a carbon brush and finally to the cathode-ray oscillograph.

2. To measure the temperature of the armature winding, a thermocouple junction made up of copper and Constantin is introduced in the armature slot just opposite to the slot in which the search coil was placed, so as to maintain dynamic balance. The two ends of the thermocouple were connected to collector rings and the brushes contacting these rings were connected to a potentiometer.

3. Mechanical details of the current collector rings: The brass rings (1,2,3) are separated, electrically, from the aluminium disc (4) by plastic insulator (7) and held together with nylon screws. The whole assembly rests on the commutator riser and is electrically isolated by a phenolic insulator. The boss (6) of the disc is slotted so as to insure better bracing of the disc when fixed against the commutator. A clamping



1,2,3, Brass rings

4 Aluminium disc

7 Plastic Insulator

T From Thermocouple

S From Search coil

Fig. 5.5.1 Current Collecting Ring Assembly

ring which is placed on the boss holds the disc tightly onto the commutator.

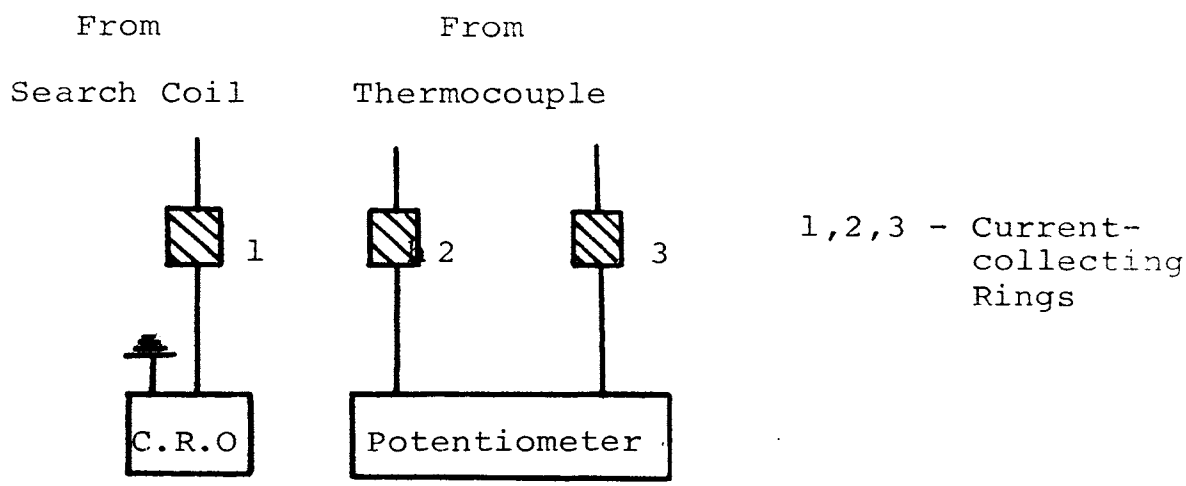


Fig. 5. 5. 1

For collecting current from the rings, round brushes whose diameters are same as the width of a collector ring, are housed in holes drilled of the phenolic brush socket. The brush arm is prepared from the spring steel.

4. Since accurate speed measurement is a must in this test, the speed is measured with a tachometer which was calibrated from time to time with the speed of a synchronons motor.

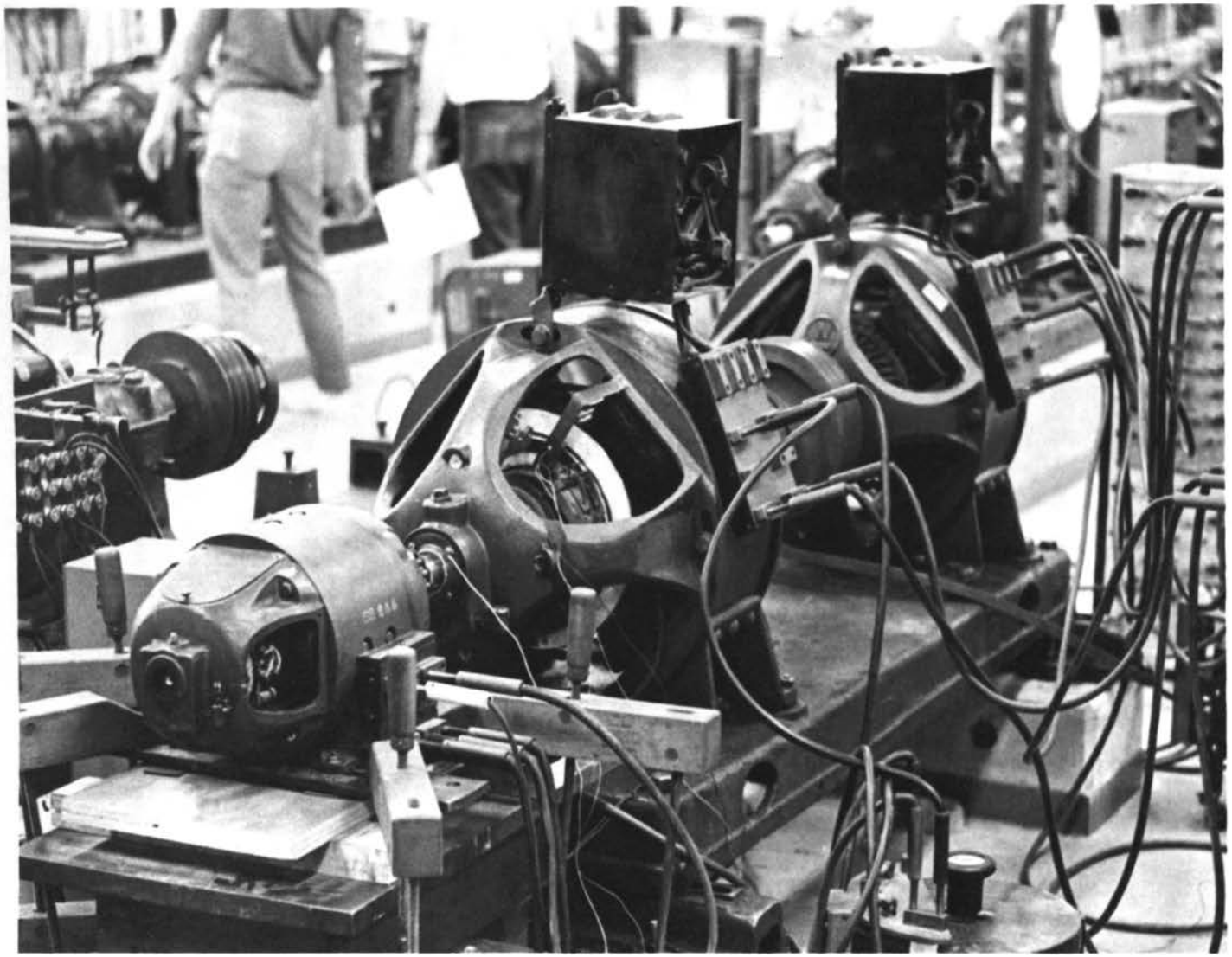


Fig. 6.a Photographic View of the Experimental Set Up for S.L.L. Measurement

VI. EXPERIMENTAL RESULTS AND COMMENTS

6.1 Preliminary Tests:

The measurement of stray load loss was made on the two largest size, identical d.c. machines available in the laboratory. The machine ratings are as follows:

D.C. Motor	D.C. Generator
15/18.5 H.P.	12 kw, 250V
230V	48 amps
58/70A, 900/1200 R.P.M.	1200 R.P.M.

Throughout the experiment, the machine under test was run as a generator and was driven either by a calibrated small d.c. motor or connected in opposition with the other identical machine and mechanically coupled to it. The ratings of a small driving d.c. motor were: 2 H.P.

7.9A, 230V, 1150 R.P.M.

(1) Calibration of a Small d.c. Motor

Calibration of this machine was made by means of a d-c dynamometer, which is driven as a generator by the d.c. motor. The input to the d.c. motor was read accurately on the calibrated instruments, while motor output was measured accurately on the dynamometer scale, for different values of terminal voltages, field currents and speeds. The readings are taken for ascending and descending values of power input and results so obtained, are averaged.

(2) Residual Magnetism

Residual Magnetism of the test machine was reduced to zero by applying d.c. current to the shunt field winding through potentiometer, in opposition to the residual magnetism when the armature is running at rated speed. The current was increased in trial steps until residual voltage was zero, with zero field current.

(3) Blondel's opposition test requires the brushes to be placed on the neutral position. The no-load neutral is located (approximately) by observing the voltage induced in the shunt field winding on cathode ray oscilloscope with the armature stationary and armature current supplied from a low-voltage alternating power source. The brush carriage is rotated until a position is found where minimum fundamental-frequency voltage is observed on the oscilloscope.

(4) Resistance measurement was made at room temperature by the procedure described under 5.1.

6.2 Experimental results and comments

(1) Short circuit test: The short circuit power input to the machine for the corresponding load currents and the total losses recognized by conventional methods are determined by the procedures described in 5.1. The results are tabulated on Table 6.2.1.

Sample Calculation:

Reading No. 4 (Table 6.1)

SHORT CIRCUIT TEST

Reading No.	Driving Motor Input V_a (volts)	I_a (amps)	I_f (amps)	Psc = Output of driving motor after correcting for the temperature rise	Machine Under Test I_{sc} (amps)	I_f (amps)	Speed R.P.M.	Total Losses (watts	Stray load loss (watts)	Temperature
1	187	9.7	0.2	1528	48	0.1	1200	1253	275.0	50°
2	207	4.8	0.2	883	34	0.065	1200	760.6	122.4	31°
3	208	3.32	0.2	603.0	24	0.05	1200	537	66.0	18°
4	205	2.2	0.2	390	12	0.03	1200	350.2	39.8	
5	209	1.8	0.2	260		0.1	1200			

TABLE 6.1

(1) Psc = short circuit power loss in watts at 40°C Temp. rise = 1498.0 watts

Psc = corrected to 50°C = 1528.0 watts (case 5.2.1)

(2) Running light loss = 280.0 watts (case 5.2.2)

(Because of small field currents of test machine, this is the same factor for all loads)

(3) D.C. ohmic loss (Armature winding) = $48^2 \times 0.382 = 877.0$ watts for 50°C temperature rise (case 5.2.3)

(4) Brush contact loss = 2 x 48 = 2 x 48 = 96.0 w.

Total losses = (2) + (3) + (4) = 1253.0 watts.

stray load loss =1528 - 1253 = 275.0 watts.

(2) Pump-Back load test: This test was performed according to the procedure described in 5.2 for the load currents corresponding to short circuit test. The results are given in Table 6.2

Sample Calculations: (Pump-Back load test)

Reading No. 4

Loss supply $V_L \times I_L$ = 3270.0 watts (case 5.2.1)

Running light loss = 579.0 w (case 5.2.2)

Copper loss:

Motor Armature $I^2R = 63.7^2 \times 0.32 = 1295.0$ (case 5.1.3)

Generator Armature $I^2R = 48^2 \times 0.32 = 737.0$ (case 5.1.3)

Brush contact loss:

Motor	= 63.7 x 2	= 127.4 (case 5.1.4)
Generator	= 48 x 2	= 96.0 (case 5.1.4)
	losses	2834.4

PUMP-BACK LOAD TEST

(Test Data Taken At Room Temperature)

Reading No.	Loss supply			Generator current	Motor current	Total losses of both machines (watts) (except SLL)	(SLL/machine) Stray load loss (watts)
	V_L (volts)	I_L (amps)	$V_L \times I_L$ (watts)	I_G (amps)	I_M (amps)		
1	231.0	3.75	865.0	12.0	16.0	763.0	51.0
2	239.0	5.50	1317.0	24.0	30.5	1180.0	68.5
3	232.0	8.90	2006.5	34.0	44.2	1715.0	146.0
4	251.0	12.90	3270.0	48.0	63.7	2834.4	218.3

TABLE - 6.2

BLONDEL'S OPPOSITION TEST

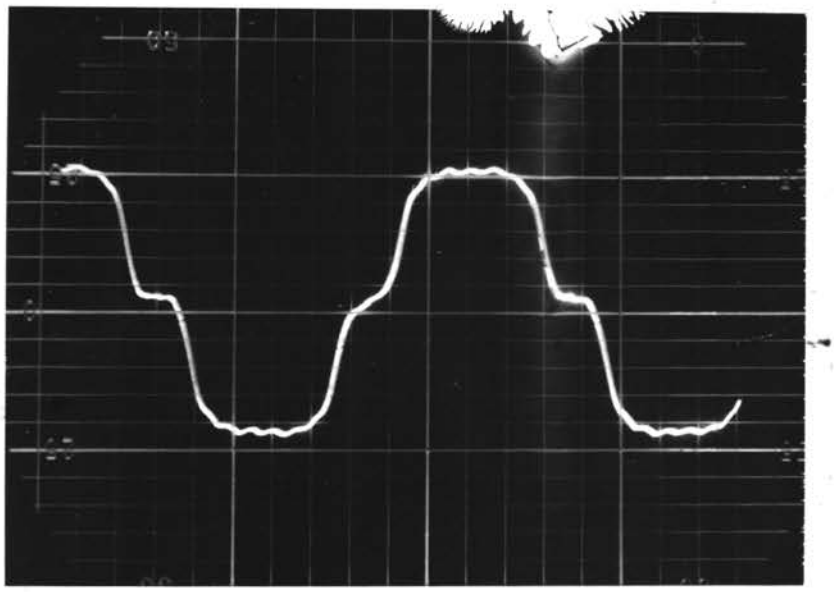
Driving Motor							Inserted Power				Speed	Remarks
Reading	V_A	I_A	I_f	$V_A \times I_A$	Average $V_A I_A$ (A+B/2)	Output	V_i	I_i	$V_i \times I_i$	Average $V_i I_i$		
						W_{d_1}				W_i		
A	207.5	7.21	0.2	1495	1490	1300	34	48	48 x 34	48 x 33.0	1200	Excitations adjusted to give rated voltage, Inserted Power adjusted for desired load current.
	211.2	5.8	0.21	1225	1180	1060	21	34	34 x 21	34 x 21.75	1200	
	212.0	4.95	0.21	1048	1000	900	15	24	24 x 15	24 x 16	1200	
	210.0	4.18	0.21	860	852	740	8	12	12 x 8	12 x 8.5	1200	
B	218.0	6.8	0.2	1485	--	--	32.0	48	48 x 32		1200	Same as set A but with armature current reversed in direction.
	210.0	5.45	0.2	1145.0	--	--	22.5	34	34 x 22.5		1200	
	207.5	4.6	0.18	954.0	--	--	17	24	24 x 17.0		1200	
	211.0	4.0	0.21	844.0	--	--	9	12	12 x 9		1200	

TABLE - 6.3

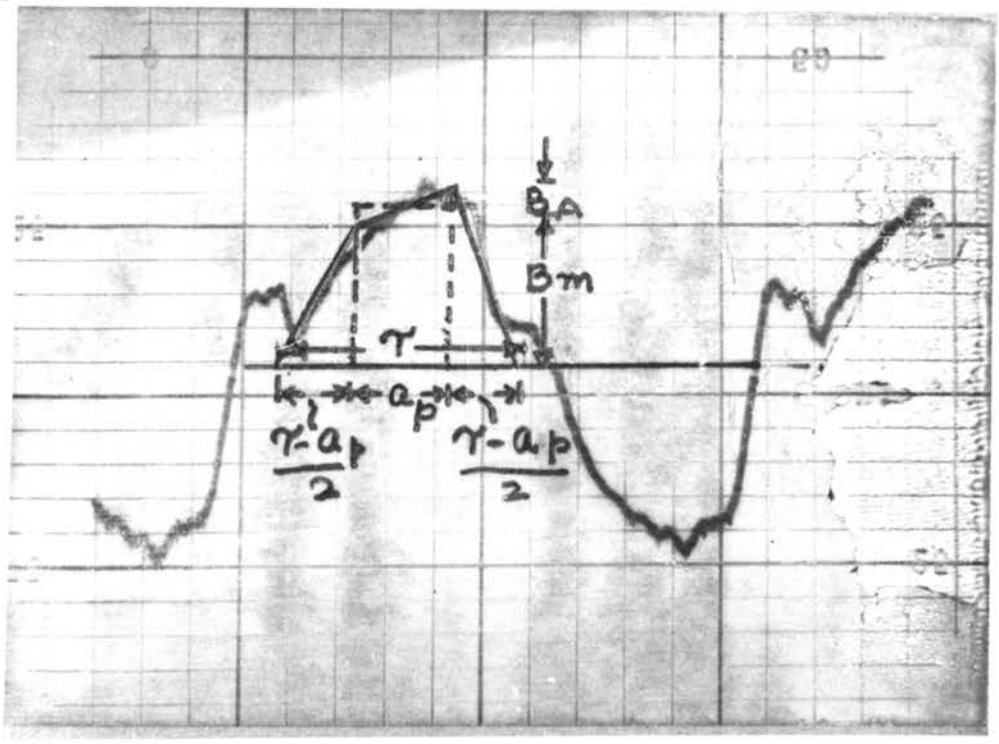
BLONDEL'S OPPOSITION TEST (Continued)

Driving Motor							Inserted Power			Speed	Remarks
Read-ing	V_A	I_A	I_f	$V_A \times I_A$	Average $V_A I_A$ (A+B/2)	Out-put	V_i	I_i	Average $V_i I_i$		
									Average = W_a		
C	--	--	--	--	--	--	37.5	48	48 x 37.5 = 1800	Low speed	Excitation reduced to zero, same current as A, B machine driven at very low speed.
	--	--	--	--	--	--	26	34	34 x 26.0 = 885		
	--	--	--	--	--	--	20.0	24	24 x 20.0 = 480		
	--	--	--	--	--	--	11.0	12	12 x 11.0 = 432		
D	200	4.0	0.2	800	--	W_{d2} 670	--	--	--	1200	Excitation same as 2; No Inserted Power.

TABLE - 6.3



Oscillogram of Flux Density Wave-form at NO-LOAD.



Oscillogram 1 showing Analysis for case 6.2.4.

Stray load loss of both machines = 3270 - 2834.4
(case 5.2.4)

= 436.6 watts

i.e. stray load loss of one machine $= \frac{436.6}{2} = 218.3$ watts.

(3) Blondel's opposition test: This test was performed as in 5.3 and results are tabulated in 6.3.

Sample Calculations:

Stray load loss: $= \frac{Wd_1 - Wa_2}{2} + \frac{Wi - Wa}{2}$

$= \frac{1300 - 670}{2} \quad \frac{48(33-37.5)}{2}$

$= 315 - 108 = 207$ watts

(4) Determination of additional core losses under load:

(1) Separation of core losses from the increased resistance loss component can be achieved by analyzing the oscillographs of field-forms at different load by Von Blittersdorf's method. Core losses obtained by this method are described in Table 6.5.

Sample Calculations:

(1) Full load current: (oscillograph 1)

$\mathcal{T} = 2.3$, $B_m + B_A = 1.975$ $B_A = 0.250$

$ap = 0.7$ $B_m = 1.725$, $\frac{B_A}{B_m} = 0.145$

W add hysterisis loss $= C_1 \times (2\ B_m\ B_A + B_A^2)$

$= C_1 \times (2 \times B_m^2 \times 0.115 + 0.022\ B_m^2)$

$= C_1 \times B_m^2 \times (0.29 + 0.0225)$

$= C_1 \times B_m^2 \times 0.3225$

$= 0.3225 \times 132.4$

(C_1 and C_2 are determined in Appendix.)

$= 41.4$ watts

W add eddy current loss in the teeth of iron

$$= C_2 \times \frac{}{ap} \times \frac{1}{-ap} \times B_A{}^2$$

$$= C_2 \times \frac{2.3}{0.7} \times \frac{1}{1.4} \times 0.0225 \times B_m{}^2$$

$$= \frac{C_2 \times B_m{}^2 \times 0.041}{2.35}$$

$= 3$ watts

(2) Blondel's opposition test: An attempt to separate the two components by this method was made but since the brushes of one of the machines were not in the exact neutral position (the amount of brush shift permitted by the mechanical design of the machine did not allow the brushes to be moved sufficiently to place them exactly on the neutral - a highly unusual situation!), the distribution of the copper losses and core loss was disturbed to the extent that at full load the increased resistance loss component was negative i.e. lesser than the resistance loss at no-load.

If this unusual distribution is due to unequal armature reaction, and this armature reaction is the result of brush shift only then it may be compensated, as suggested by Professor McPherson, Electrical Engineering Department, University of Missouri at Rolla, as follows:

(1) Blondel's test assumes $T_G = T_M = \frac{e_a\ i_a}{w}$, G = M

and $P_{Mech.}$ (1) = 2 x (Running light loss) + 2 Core loss

The subscripts "G" and "M" refer to the machines which are

	Input to driving motor				Booster Generator				
V_A (volts)	I_A (amps)	I_f (amps)	$V_A \times I_A$ (watts)	$I_a^2 R_a$ (watts)	V_i (volts)	I_i (amps)	S.L.L. (volts)	Core loss (watts)	Cu loss (watts)
209	3.37	0.24	705	5.29	45	48	245	191	54
204	3.9	0.235	796.0	7.08	30	33.9	128.7	140.5	-11.8
(A) 205	3.86	0.23	792.0	6.94	21.4	24.0	19	35	-16
207.5	3.56	0.23	739.0	5.91	13.0	12.0	-5.25	3.75	-9
206	3.7	0.235	762.0	6.39					
	Reverse rotation								
201	8.65	0.23	1740	34.9	29.4	48	1500		
199	6.72	0.225	1338	21.0	20.2	34	1180		
(B) 202	5.40	0.220	1009	11.3	14.7	23.8	900		
201	4.64	0.22	934.0	10.02	7.4	12.0	880		
202	4.43	0.22	895.0	9.11			800		

TABLE 6.4

generating and motoring respectively, and w = angular velocity.

(2) Now if the armature reaction is such as to reduce ϕ_G, then $\phi_G < \phi_M$; $T_G < T_M$

or

$$\frac{e_{a1} i_a}{W} < \frac{e_{a1} i_a}{W}$$

and $P_{mech}(2)$ = 2 Running light loss) + 2 Δ core loss $-(e_{a2}-e_{a1})i_a$

If the direction of rotation is reversed, but with i_a in original direction, then the roles of the two machines are interchanged and

$$T_M > T_G \text{ since } \phi_G > \phi_M$$

However,

$P_{mech\ (3)}$ = 2 (Running light loss) + 2 Δ core loss + $(e_{a2}-e_{a1})i_a$

After eliminating the effect of armature reaction we have:

$$\text{increased core loss} = \frac{P_{mech(2)} + P_{mech\ (3)} - 4(\text{Running light loss})}{4}$$

The results thus obtained are tabulated in Table 6.4. It is seen that the armature circuit loss is still negative in one case.

For this reason, the author has separated stray load loss into its components by Von Blittersdorf's method. Core loss, thus obtained, is modified for short circuit condition by using Hughes Equations as follows:

Equation (2) Page 5, is applicable for the calculation of iron losses in teeth under the short circuit condition where there is a reversal of flux. The oscillogram of short cir-

TABLE 6.5

No.	Oscillo-gram load current	W_{add} hystersis under load By Von	W_{add} eddy condition Blittersdorf	W_{add} Total	Incremental iron losses in teeth under short circuit in watts (By Hughes)
1	48	41.4	3.0	47.52	98.0
2	34	23.0	1.2	25.18	49.4
3	24	7.8	0.2	8.054	13.6
4	12	4.0	0	4.0	5.76

TABLE 6.6

Load current (amps)	Total stray load loss under short circuit (watts) (1)	Full load core loss obtained from Table 6.6 (watts) (2)	Increased core loss component (at short circuit) (watts) (3)	Resistance loss Component of stray load loss (watts) (1) - (3)
48	275	47.52	98	177.0
34	122.4	25.18	49.4	72.0
24	66.0	8.05	13.6	52.4
12	39.8	4.0	5.76	34.04

cuit test at I_A = 48 amps shows that B_2 = 2.25 units while oscillogram of full load condition shows B_1 = 5 units.

$$Wt1 = kf^{1.5} Vt\ B_1^2 \quad (1) \qquad Wt2 = kf^{1.5}\ (B_1 + B_2)^2\ Vt \quad (2)$$

$$\frac{Wt_2}{Wt_1} = \left(\frac{B_1 + B_2}{B_1}\right)^2 = \left(\frac{7.25}{5}\right)^2 = 2.1;$$

i.e., tooth iron losses under short circuit test are 2.10 times the losses under normal full load condition and since the tooth iron losses are a major part of total iron losses, the losses determined by this test are higher than full load condition. Table 6.6 shows the increased resistance loss and core loss under short circuit condition. Core loss for different values of armature current is obtained by the approach described above.

Figure 6.1 shows the stray load loss obtained by short circuit test for armature current. I_A = 48.0A plotted as functions of speed in r.p.m. It is seen that between points OP stray load loss increases with increase in speed while in the region RS it decreases with increase in speed and a dip at a point Q is observed. This indicates that though the stray load loss is a function of speed, it makes difficult to say in which way this loss is related to speed. This is the reason why it is not advisable to extrapolate line OP for zero speed to determine the hysterisis constant for the stray load loss.

Figure 6.2 Curve 1 shows the short circuit power loss in watts plotted against field excitation for different I_A

and with constant speed = 1200 rpm. This indicates that the Psc and stray load loss increased with I_f.

Figure 6.3 shows the stray load loss plotted against load current. This loss increases with increase in load current and from I_A = 24.0 on words, it is proportional to the square of the current. This is in agreement with the conclusion derived by Russian authors. (Ref. 5). Curve 2 is the variation of "increased resistance" loss component with respect to load current, obtained by subtracting the short circuit core-loss torque component from the total short-circuit stray load loss.

Curve 3 shows the core loss component against load current. The core loss is proportional to (load current)^X where X $\simeq$ 2.1. This indicates that under short circuit the core loss component varies greatly with the load current.

Fig. 6.4 shows the stray load loss in watts plotted against load current by all the three methods. Since the results obtained by pump-back test and Blondel's opposition test differ considerably, Curve 4 which is the average of these two methods is plotted. It is seen that the stray load loss obtained by short circuit test is in close agreement with the average of the other two methods up to I_A=48.0 amps. (i.e. up to 87.5% of the load). And at full load I_A = 48.0 amps, stray load loss obtained by this short circuit test is, as expected, higher than the other two methods.

The major part of this difference is due to the increase of core loss; and from Table 6.6, it can be seen that at full load, the iron loss in the teeth of iron differ by about 50.0 watts.

If this increase in core losses is subtracted from the results obtained by short circuit test, nearly the same stray load loss is obtained as was obtained by other existing methods.

Also iron loss in the armature core probably increases under short circuit conditions (Ref. 2). The magnitude of this component is difficult to measure.

Fig. 5 shows the stray load loss versus load current after applying correction faster to the results obtained by short circuit test.

Fig. 6 shows the oscillograms of the field forms obtained under normal load conditions. As we should expect, the distortion of the field form increases with increase in load current. The ripples are due to successive teeth coming under and passing away from the edge of the pole shoe.

In Figure 7, the oscillograms, obtained under short circuit condition, shows (1) the delinearation of the field form under the pole and (2) the field form reverses under the pole. The violent ripples are partly due to the reason given above but mainly because of the fact that the current collecting brushes were not making uniform contact with the brass rings.

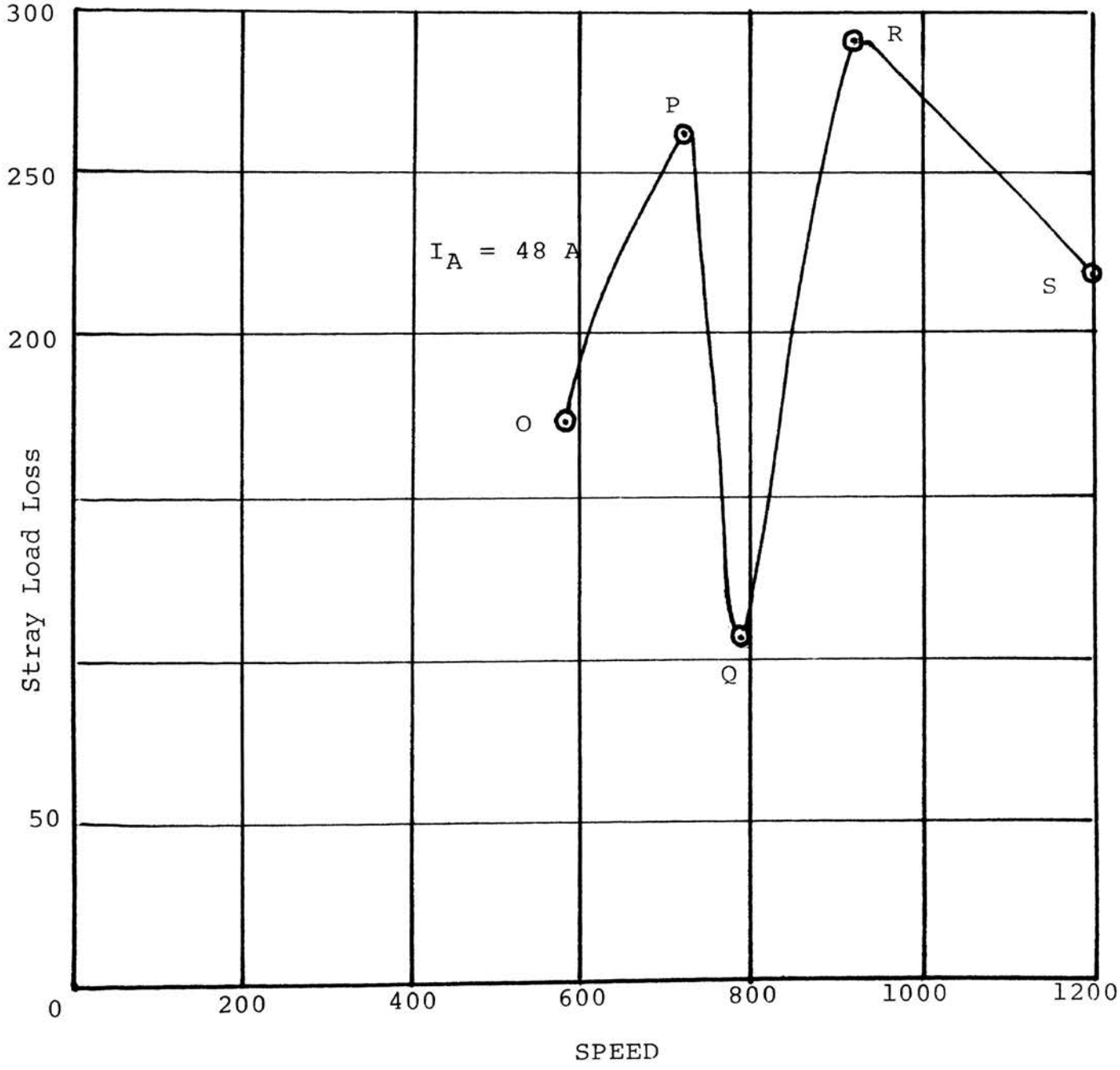


Fig. 6.1 Stray Load Loss Plotted Against Speed

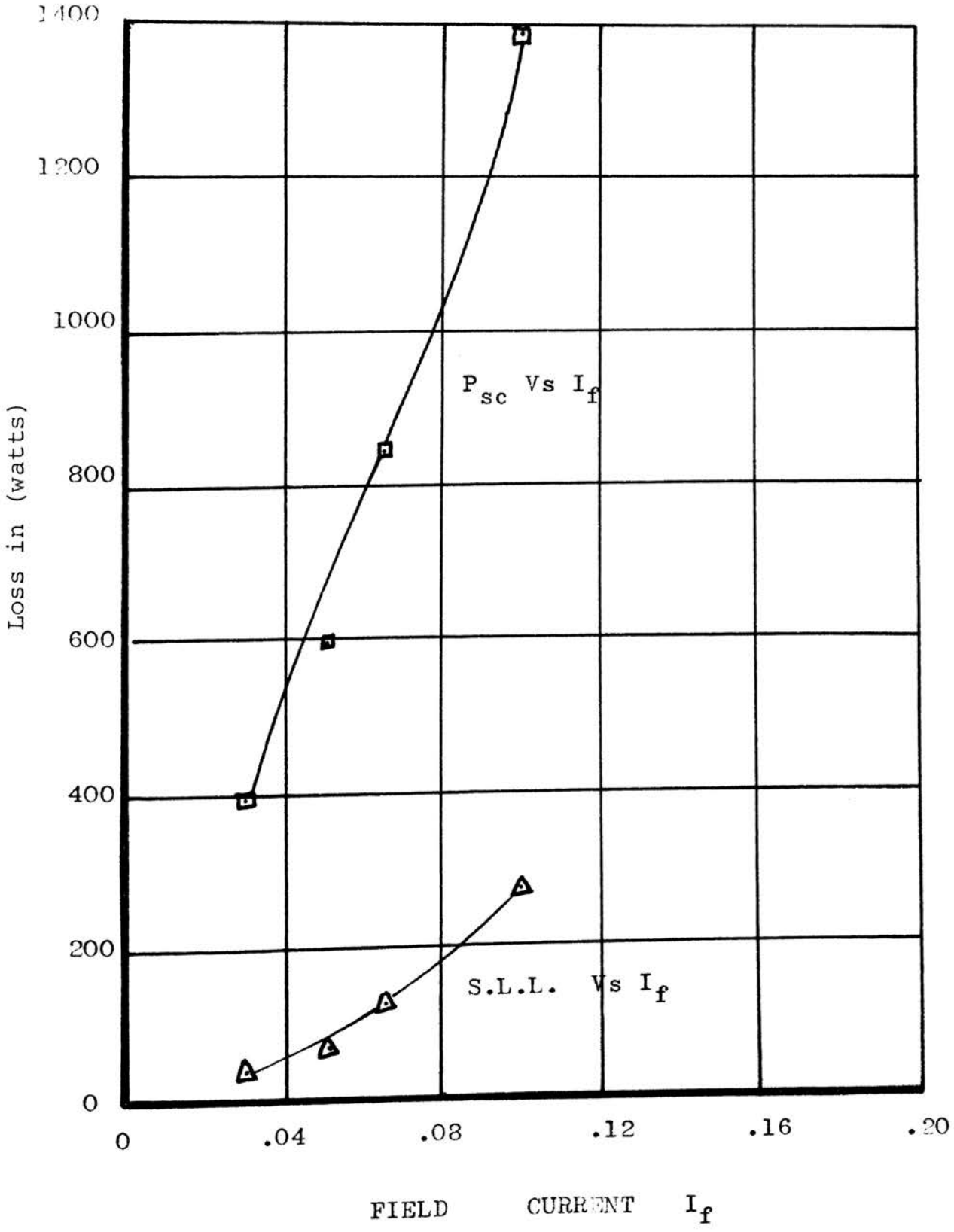

1400
1200
1000
800
600
400
200
0
Loss in (watts)
P_{sc} Vs I_f
S.L.L. Vs I_f
0
.04
.08
.12
.16
.20
FIELD CURRENT I_f

Fig. 6.2.

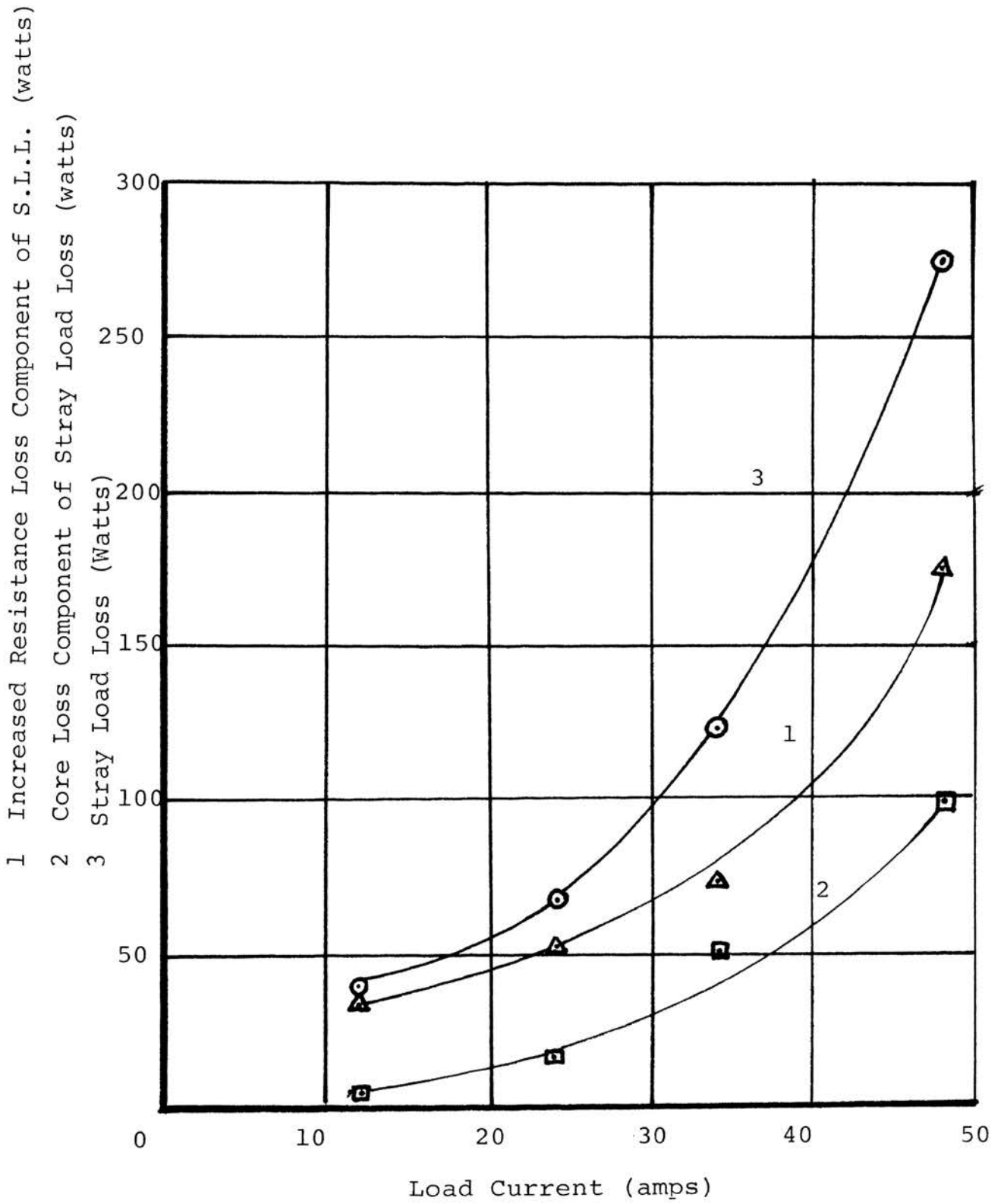

1 Increased Resistance Loss Component of S.L.L. (watts)
2 Core Loss Component of Stray Load Loss (watts)
3 Stray Load Loss (Watts)
300
250
200
150
100
50
0
10
20
30
40
50
Load Current (amps)
1
2
3

Fig. 6.3

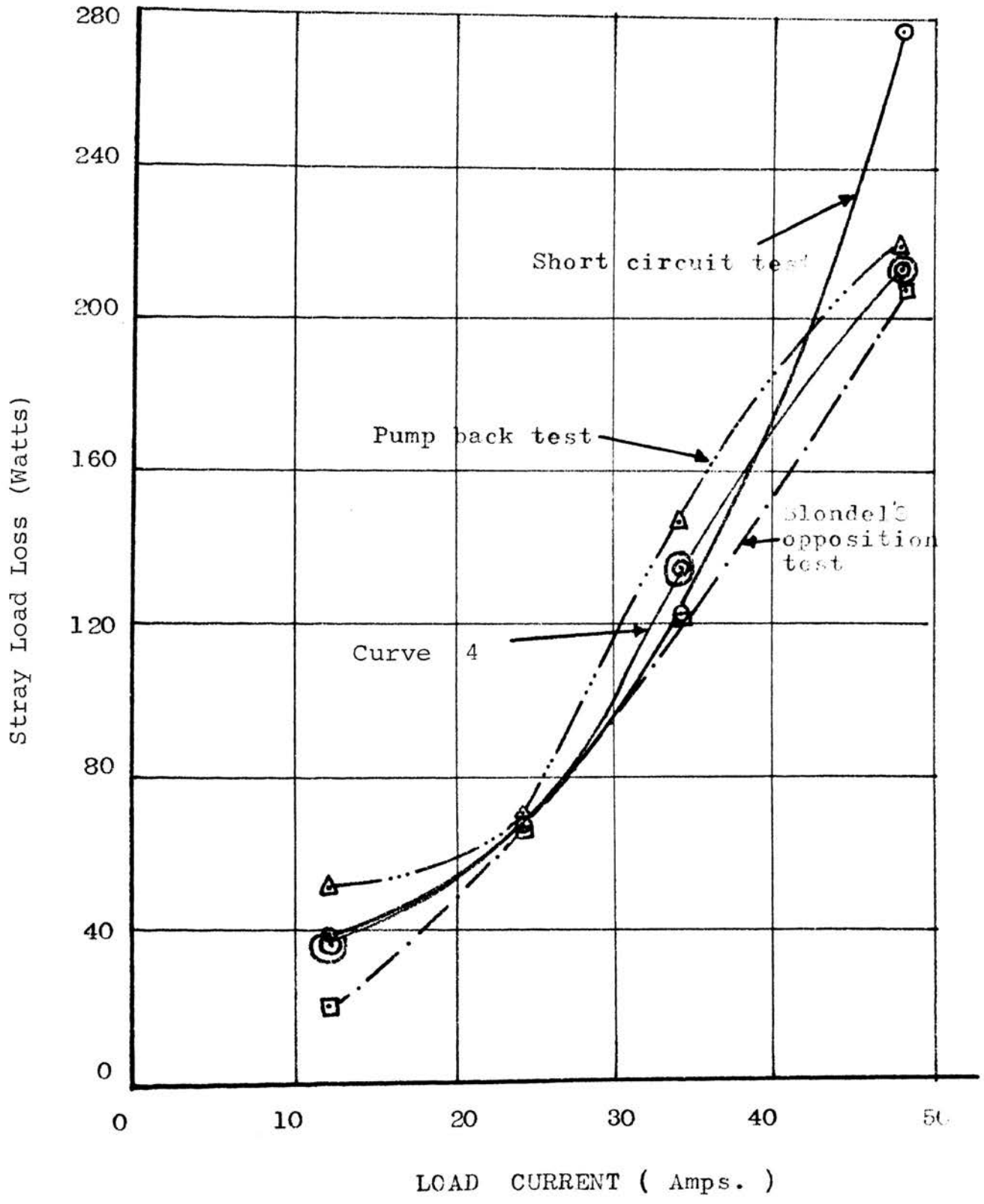
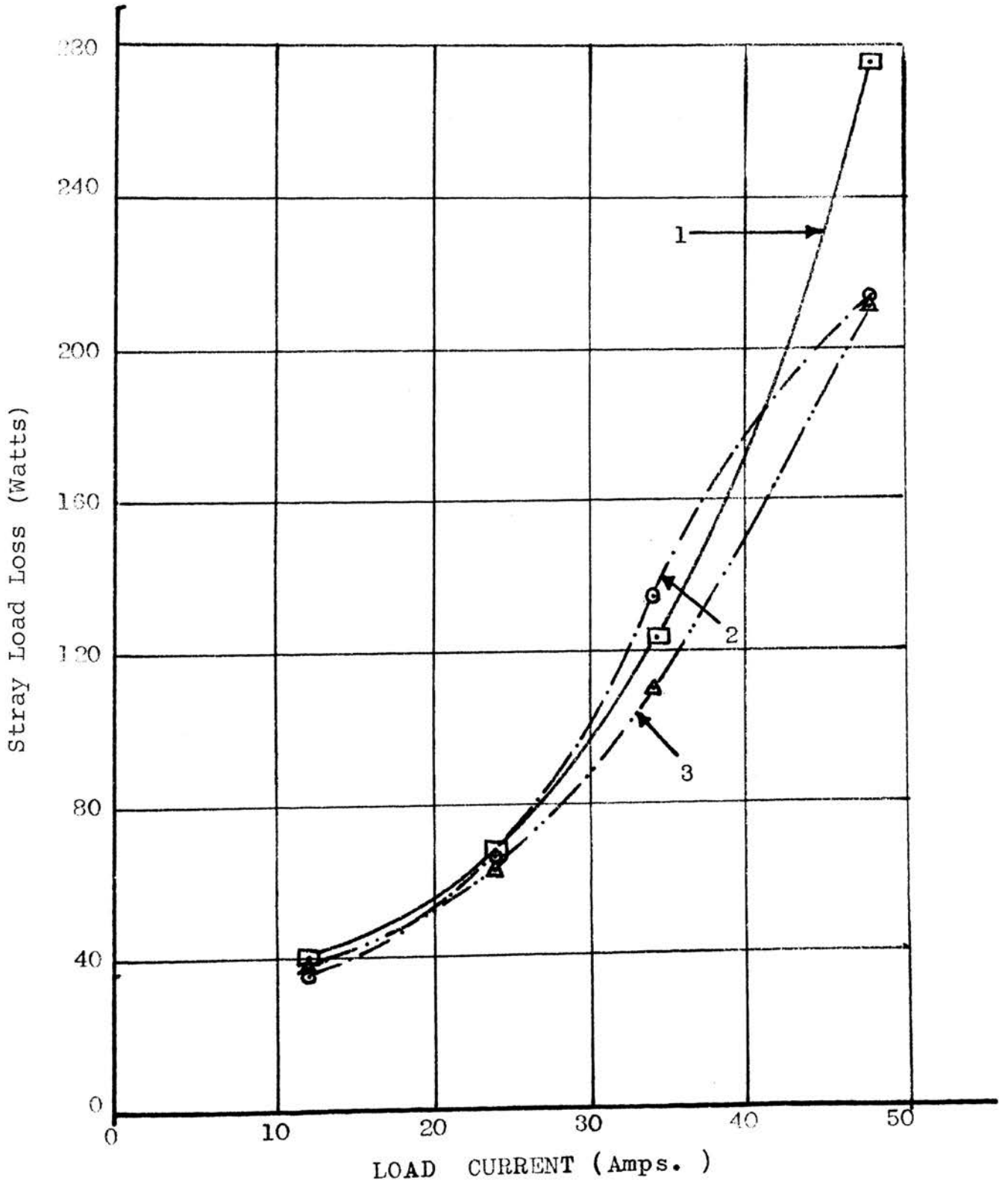


Fig.6.4. Comparision of S.L.L. by different methods

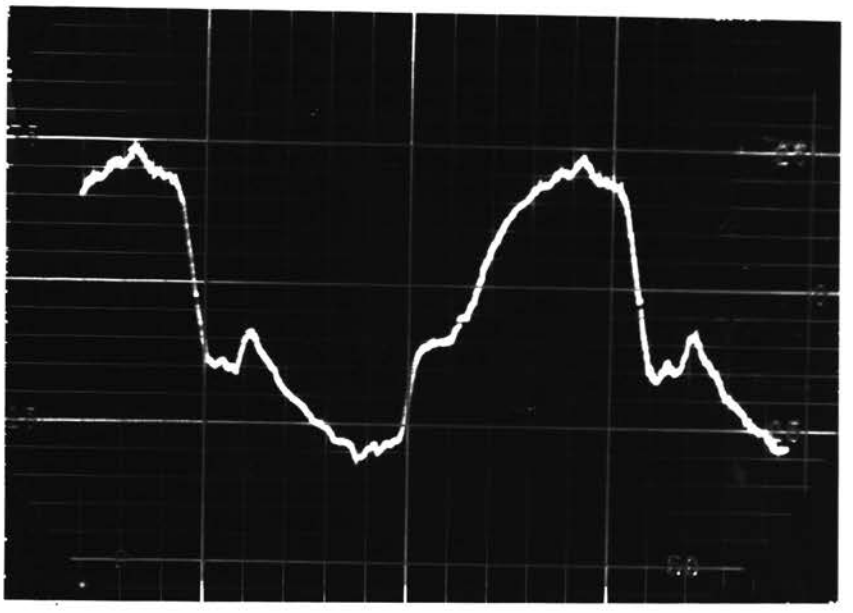


1 S.L.L. obtained by short circuit test

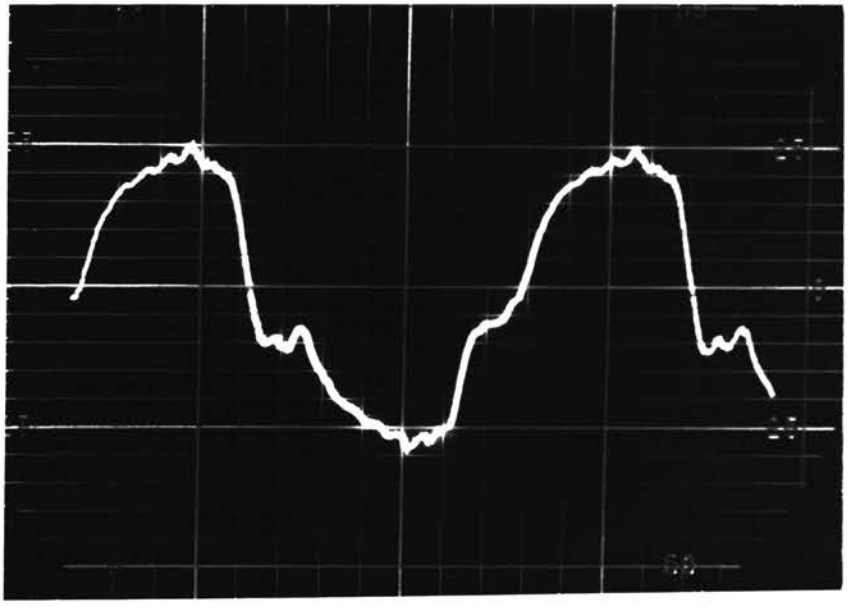
2 S.L.L. obtained by averaging the results of pump-back Blondel's opposition test

3 S.L.L. obtained after correction factor is applied.

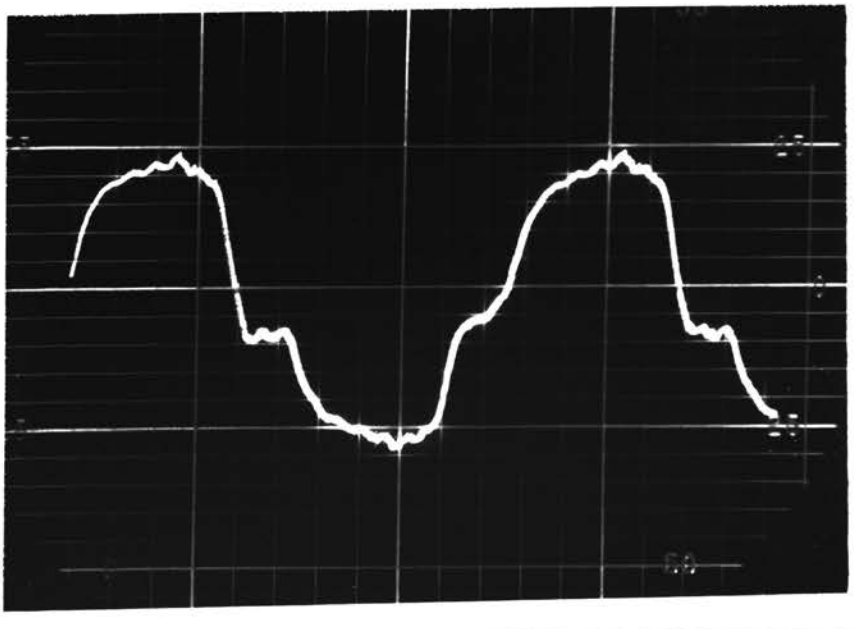
Fig. 6.5.- Stray load versus load current



Armature Current
= 48 Amps.

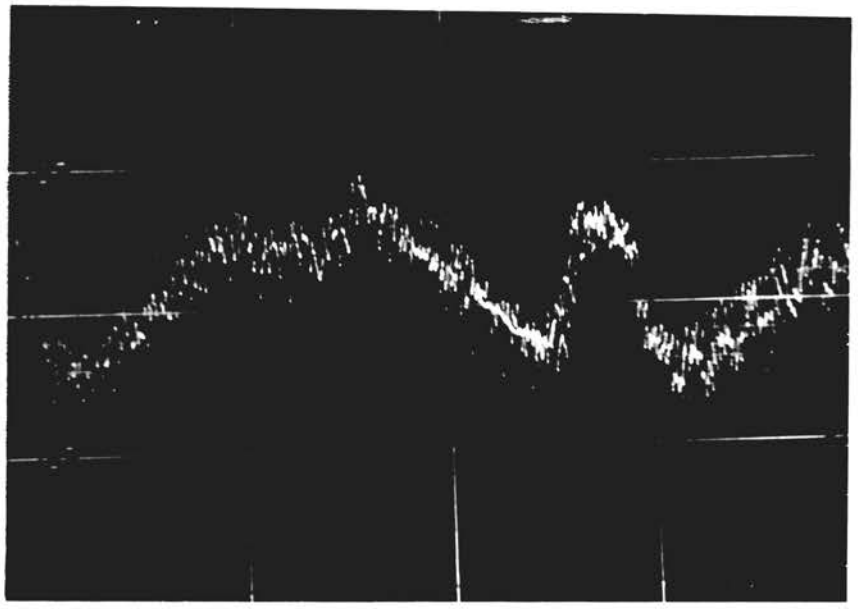


Armature Current
= 34 Amps.

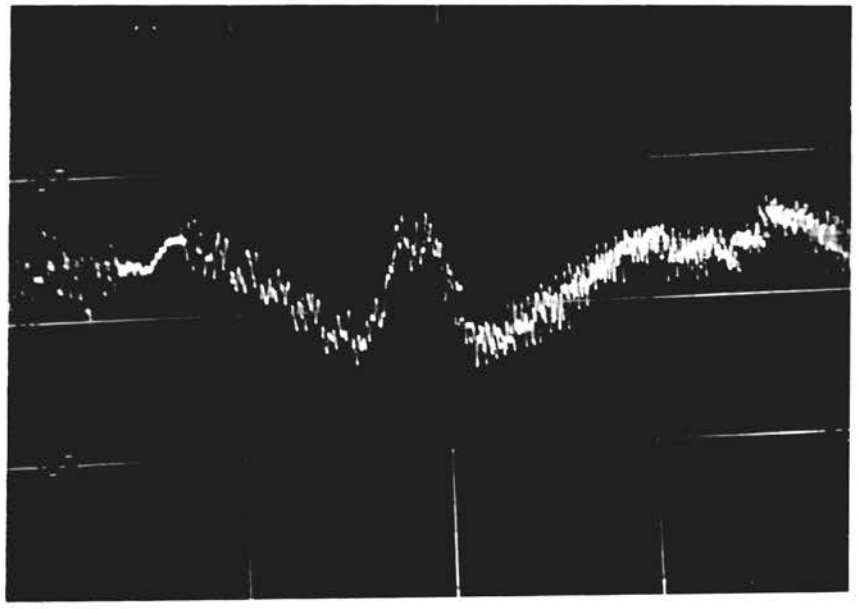


Armature Current
= 24 Amps.

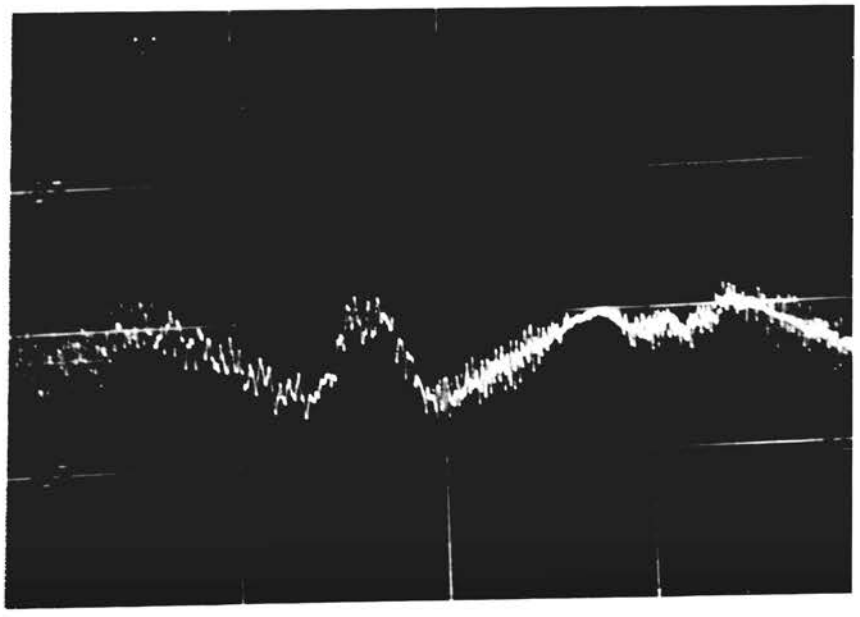
Fig. 6.6. Oscillogram under Load Condition.



Armature Current
= 48 Amps.



Armature Current
= 34 Amps.



Armature Current
= 24 Amps.

Fig. 6.7. Oscillograms under Short Circuit Condition.

6.3 Correction Factor for Short Circuit Test:

Since the stray load loss obtained by short circuit test is higher than the actual value under load the results obtained by short circuit test may be multiplied by a factor to get the corrected stray load loss. From inspection of Figure 6.3, it is observed that stray load loss is proportional to the square of armature current.

Therefore,

$$(\text{stray load loss})_{actual} = [(\text{stray load loss})]_{s.c.} \times [1 - K_{sc}\frac{I_A^2}{I_r^2}]$$

where I_A = corresponding load current

I_r = rated load current

K_{sc} = correction factor = 0.23 (for this machine)

The factor K_{sc}, however, may vary, depending upon the distortion of the flux density waveform caused by the armature m.m.f. or in other words it depends upon the ratio of field ampere-turns to armature ampere turns.

$$\text{i.e. } K_{sc} = K \times [\frac{\text{Field ampere turns}}{\text{Armature ampere turns}}]$$

The constant factor K may be determined if the turns in the brackets are known.

CONCLUSION

7.1 Stray load loss obtained by pump-back test and Blondel's opposition test is 1.75% of the machine output at full load for the uncompensated test machine. These methods measure the loss directly and give consistent results while the well known input-output test, even after taking the tests three to four times to check the data, gave losses which varied over a wide range. For this reason, this method is not discussed at all in this paper. However, it did show that the stray load loss is more than 1.0% of the output. Hence, irrespective of the method used, this loss is more than 1.0%. This agrees with the A.I.E.E.E. committee report (Ref. 1) and hence it would be better if the flat rule of 1.0% were changed. The Russian standard for SLL is one per cent of the output for uncompensated generators and .5 per cent of the output for the compensated machine. (Ref.5)

Now the question as to which method to use? Engineers always demand the reliable and least complicated method of measuring this loss for efficiency calculations in the absence of any reliable equations. Blondel's opposition test is tedious and if the brushes cannot be arranged into the exact no load neutral position, it gives wrong information as to presence of the core loss and resistance loss components. In addition, two identical machines, a calibrated drive motor and a booster generator are required. Hence this method should be given consideration only in very special

circumstances. Various modifications of the pump-back test have been described in literature and this test method gives consistent and accurate results; but it requires another identical machine, and if the other machine of duplicate design is not available, then it becomes difficult to assign the losses accurately.

The short circuit test with a correction factor should be given consideration because of the simplicity and reliability of the test method. It does not require another identical machine. A small calibrated motor is required to measure the losses directly. Thus it excludes the vagaries of brush friction and brush contact loss of another machine.

For uncompensated machines the stray load loss determined by short circuit test is corrected by formula (6). The factor K_{sc}, which depends on the flux density waveform may be determined accurately if some tests are made on the machines where design data are available. In a well designed machine, there is a limit to which this distortion is allowed since it reflects in commutation difficulties and armature reaction effects. If this distortion is too much (which happens in heavy duty and larger capacity machines), then compensating windings are used to reduce this distortion to a minimum. Therefore, the correction factor K_{sc} is approximately zero for such machines.

7.2 Future tests:

To find out the constant factor K accurately it may be

better if future tests are made on uncompensated machines of different sizes with the provision of the following:

(1) Since the brush friction loss decreases with load current, it is not proper to measure the brush friction at no-load and assume this to be constant for any load. Hence to measure this loss directly, the brush rigging would have to be supported on bearings so that the friction could be measured continuously and the brush-contact voltage (which is assumed constant) should read continuously through the use of an insulated brush (Ref. 1).

(2) The effective resistance of the armature conductors can be determined by analyzing the flux density waveform (either graphically, using Fourier series or by wave analyser) into a series of simple harmonic terms and applying voltages of magnitude and frequencies corresponding to the terms of Fourier series. The loss determined by this will be a check on the increased resistance loss component of stray load loss, since this is the major portion of increased resistance loss.

APPENDIX

Determination of Constants C_1 and C_2 (page 6, equations 4 and 5)

1. The open circuit core losses $[(W_h + W_e)_{oc}]$ are found by driving the machine at rated speed with the dynamometer, with the field excited at normal value but with armature open circuited and measuring the input power to the machine less the friction and windage losses.

Separation of hysteresis (W_h) and eddy current (W_e) component at no load is achieved by repeating the above test at different speed. From the test K_h and K_e are found to be equal to 3.31 and 0.093 respectively.

$$\therefore \quad W_h = K_h \times f = 3.31 \times 40 = 132.4 \text{ watts} \qquad (1)$$

$$W_e = K_e \times f^2 = 0.093 \times (40)^2 = 148.8 \text{ watts} \qquad (2)$$

2. Since hysteresis loss is proportional to peak flux-density, the additional hysteresis loss under load equals

$$K_h[(B_m + B_A)^2 - B_{mo}^2] \qquad (3)$$

where B_m and B_A are as defined on page 6 and B_{mo} is the peak flux density at no-load.

It was found (for our case) that $B_{mo} = B_m$ and $K_h = C_1$

$\therefore$ Equation (3) becomes

$$W_{add} \text{ hysteresis} = C_1 \; [(B_m + B_A)^2 - B_m{}^2]$$

if $B_A = \Delta B_m$, then

$$W_{add} \text{ hysteresis} = C_1 \; [2B_m{}^2 . \Delta + \Delta^2 B_m{}^2]$$

$$= (C_1 \; B_m^2)\,[2\,\Delta + \Delta^2]$$

$$= (\text{No load hysteresis loss}) \times [2\,\Delta + \Delta^2] - (4)$$

3. Eddy current loss component of core loss depends upon the flux density waveform and Von Blittersdorf gave the formula for incremental eddy current loss (equation 5, page 6)

$$\therefore \; W_{e(total)} = K_e \; B_m^2 + C_2 \; [\frac{\gamma}{a_p} \times \frac{1}{\gamma - a_p}] \; (B_A^2)$$

Let $X = [\frac{\gamma}{a_p} \times \frac{1}{\gamma - a_p}]$, then

$$W_{e(total)} = K_e \; B_m^2 + [C_2 \; X \times B_m^2] \; \Delta^2$$

$$= C_2 \; B_m^2 \; [\; X \; (1 + \Delta^2)] \text{ provided}$$

$$K_e \simeq C_2 \; . \; X$$

$\therefore$ Formula (5) on page (6) is modified as:

$$W_{add\ eddy\ loss} = [\frac{\text{no load eddy loss}}{\frac{\gamma}{a_p} \times \frac{1}{\gamma - a_p}}] \times \Delta^2 \; . X \qquad (5)$$

BIBLIOGRAPHY

1. A.I.E.E.E. Committee Report on Stray Load Losses Measured in D.C. Motors, Page 219, Vol. 68, 1949.

2. Calculation of Stray Load Losses in D.C. Machinery, Edward Erdelyi, page 129, A.I.E.E. Trans, Vol. 79, Part III, 1960.

3. Determination of Stray Load Losses in D.C. Machines, Sieron and Grant, Vol. 75, Part III, 1956.

4. Electromagnetic Principles of Dynamo, E. B. Moulin (book) Oxford Press, 1955.

5. Electrical Machines - M. Kostenko and L. Piotrovsky (book), Foreign Languages, Publishing House, Moscow.

VITA

The author was born on October 5, 1939, at Bhaner, Gujaret, India. He graduated from Sheth M. R. High School, Kathlal, in June, 1956. After completing one year - pre-requisite for entrance in Engineering - he enrolled in M. S. University of Baroda and received his Bachelor of Engineering (Electrical) in April, 1961. He received college studentship during his undergraduate work. After getting Government of India Scholarship, he passed his Master of Engineering in Electrical Machine Design in October, 1962. He was on training program for five months in Hindustan Electric Company in collaboration with Brown Boven Company, Switzerland. After being employed by Jyoti Ltd, Baroda, as a Development Engineer in A.C. Rotating Machine for 14 months, he enrolled as a graduate student at University of Missouri at Rolla.