

IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

Circuits and Devices

Communications Technology

Computer

*Electromagnetics and
Radiation*

IEEE Power Engineering Society

Sponsored by the
Electric Machinery Committee

Industrial Applications

IEEE Std 112-1991



Published by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017, USA.
March 10, 1991

SH14951

IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

Sponsor
**Electric Machinery Committee
of the
IEEE Power Engineering Society**

Approved December 5, 1991
IEEE Standards Board

Abstract: Instructions are given for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of polyphase induction motors and generators. Electrical measurements, performance testing, temperature tests, and miscellaneous tests are covered.

Keywords: Generators, motors, tests.

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Copyright © 1992 by the
Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 1992
Printed in the United States of America

ISBN 1-55937-188-9

*No part of this publication may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.*

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Foreword

(This foreword is not a part of IEEE Std 112-1991, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.)

This standard provides the basic test procedure for evaluating polyphase induction motors and generators of all sizes. This standard has been revised many times due to constant improvements in instrumentation and increasing knowledge of the art of measurement. As a result, this document has become difficult to read and hard to follow for anyone not familiar with its history.

The increasing emphasis on energy conservation and the international harmonization of standards has made it imperative that this basic test procedure be easy to interpret.

In this latest revision, the document has been completely reorganized to improve its readability. An effort has also been made to harmonize this standard with Canadian standard C390. This revision was carefully written so that references, in contracts, to certain types of tests for machines will apply equally to both this revision and its predecessor.

The most accurate procedures for measuring efficiency, verified by extensive comparative testing, conducted by NEMA and the Accredited Standard Committee C50 are included.

At the time that this standard was approved, the working group had the following membership:

W. J. Martiny, *Chair*

J. C. Andreas
S. Burns
R. W. Coffey
M. Costello
P. Cummings

R. H. Daugherty
N. K. Ghai
F. H. Grooms

G. R. Horrell
E. J. Michaels
G. K. F. Pepper
S. Stretz
S. B. Kuznetsov

At the time that it balloted and approved this standard for submission to the IEEE Standards Board, the Electric Machinery Committee of the IEEE Power Engineering Society had the following membership:

J. C. Andreas
R. H. Auerbach
R. G. Batheld
J. C. Botts
L. W. Buchanan
A. W. Cameron
C. C. Chan
M. V. Chari
J. L. Cohon
A. G. Conrad
P. G. Cummings
N. A. Demerdash
W. C. Dumper
J. S. Edmonds
J. S. Ewing
J. A. Fickling
C. Flick
N. K. Ghai
G. L. Godwin
B. E. B. Gott
D. R. Green
F. H. Grooms
C. A. Gross
B. Gupta
H. B. Hamilton
M. S. Helms
M. H. Hesse
T. J. Higgins

J. C. Hogan
C. H. Holley
V. B. Honsinger
R. F. Horrell
W. D. Jones
H. E. Jordan
E. I. King
J. L. Kirtley
L. Klataske
P. C. Krause
S. B. Kuznetsov
D. R. Lambrecht
P. R. H. Landrieu
I. M. Levy
T. A. Lipo
T. J. Lorenz
W. J. Martiny
C. H. Merrifield
E. F. Merrill
E. J. Michaels
J. R. Michalec
L. W. Montgomery
E. H. Myers
S. A. Nasar
T. W. Nehl
N. E. Nilsson
P. I. Nippes
D. W. Novotny

J. L. Oldenkamp
J. A. Oliver
W. B. Penn
M. Poloujadoff
J. Pospisil
E. P. Priebe
M. A. Rahman
C. M. Rowe
S. J. Salon
M. S. Sarma
P. W. Sauer
A. C. Seidl
D. K. Sharma
M. W. Sheets
E. P. Smith
J. F. Szablya
P. H. Trickey
P. J. Tsivitse
S. D. Umans
P. Walker
T. C. Wang
R. F. Weddleton
J. C. White
E. C. Whitney
J. J. Wilkes
R. L. Winchester
E. J. Woods
S. Zocholl

When the IEEE Standards Board approved this standard on December 5, 1991, it had the following membership:

Marco W. Migliaro, *Chair*

Donald C. Loughry, *Vice Chair*

Andrew G. Salem, *Secretary*

Dennis Bodson
Paul L. Borrill
Clyde Camp
James M. Daly
Donald C. Fleckenstein
Jay Forster*
David F. Franklin
Ingrid Fromm
Thomas L. Hannan

Donald N. Heirman
Kenneth D. Hendrix
John W. Horch
Ben C. Johnson
Ivor N. Knight
Joseph Koepfinger*
Irving Kolodny
Michael A. Lawler

John E. May, Jr.
Lawrence V. McCall
T. Don Michael*
Lloyd A. "Pete" Morley
Stig L. Nilsson
John L. Rankine
Ronald H. Reimer
Gary S. Robinson
Terrance R. Whittemore

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Fernando Aldana
Satish K. Aggarwal
James Beall
Richard B. Engelman
Stanley Warshaw

Adam Sicker
IEEE Standards Department Project Editor

Contents

SECTION	PAGE
1. Scope	7
2. References	7
3. Tests — General	8
3.1 Types of Tests	8
3.2 Choice of Tests	8
3.3 Use of This Standard	8
3.4 Testing With Load	8
3.5 Testing With Rotor Locked	8
3.6 Precautions	8
4. Measurements	9
4.1 Electrical	9
4.2 Resistance	10
4.3 Mechanical	11
4.4 Procedure	12
4.5 Safety	12
5. Types of Losses	12
5.1 Stator I^2R Losses	12
5.2 Rotor I^2R Losses	13
5.3 Core Loss and Friction With Windage Loss	13
5.4 Stray-Load Loss	14
5.5 Brush Contact Loss	17
6. Determination of Efficiency	18
6.1 General	18
6.2 Test Methods for Efficiency	18
6.3 Test Method A — Input-Output	19
6.4 Test Method B — Input-Output With Loss Segregation	19
6.5 Test Method C — Duplicate Machines	20
6.6 Test Method E or E1 — Electrical Measurement with Loss Segregation	22
6.7 Test Method F or F1 — Equivalent Circuit	23
6.8 Test Method C/F, E/F, or E1/F1 — Equivalent Circuit Calibrated With One Load Point	29
6.9 Power Factor Test Methods	30
7. Other Performance Tests	30
7.1 Rotor Voltage	30
7.2 Locked-Rotor Tests	30
7.3 Test for Speed-Torque and Speed-Current Curves	31
7.4 Correction of Data From Tests Run at Reduced Voltage	34
8. Temperature Tests	34
8.1 Purpose	34
8.2 General Instructions	35
8.3 Methods of Measuring Temperature	35
8.4 Temperature Readings	37
8.5 Measurement of Ambient Temperature	38

SECTION	PAGE
8.6 Test Procedure	38
8.7 Temperature Rise.....	39
9. Miscellaneous Tests.....	40
9.1 Insulation Resistance	40
9.2 High-Potential Test	40
9.3 Winding Resistance Measurements.....	40
9.4 Shaft Currents and Bearing Insulation	40
9.5 Noise	41
9.6 Balance and Vibration	42
9.7 Overspeed	42
10. Forms.....	43
10.1 Form A	43
10.2 Form B.....	44
10.3 Form C.....	46
10.4 Form E-E1.....	48
10.5 Form F-1	50
10.6 Form F-2	51
10.7 Form F-3	52
11. Bibliography.....	53
FIGURES	
Fig 1 Determination of Friction and Windage Losses.....	14
Fig 2 Equivalent Circuit	24
Fig 3 Total Reactance From No-Load Test	26
Fig 4 Typical Connection for Superimposed Equivalent Loading.....	36
TABLES	
Table 1 Specified Temperature	13
Table 2 Assumed Values for Stray-Load Loss	17
Table 3 Maximum Time Delay in Temperature Test	39
Table 4 Vibration Mounts	42
APPENDIXES	
Appendix A Typical Report Form for Routine Tests on Induction Machines	54
Appendix B Typical Report Form for Performance Tests on Induction Machines.....	55

IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

1. Scope

This standard covers instructions for conducting and reporting the more generally applicable and acceptable tests to determine the performance and characteristics of polyphase induction motors and generators. Additional tests, not specified herein, may be required to satisfy specific research or application needs. These procedures shall not be interpreted as requiring the performing of any specific test in a given transaction.

Many of the tests described may be applied to both motors and generators, as needed, and no attempt is made to partition the test procedure into sections applying to motors and sections applying to generators. Whenever the term “motor” is used, it is to be understood that it may be replaced by the term “generator,” if applicable.

2. References

The following standards shall be used in conjunction with this document. When these standards are superseded by an approved revision, the latest revision shall apply.

- [1] IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing (ANSI).¹
- [2] IEEE Std 43-1974 (Reaf 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).
- [3] IEEE Std 85-1973 (Reaf 1986), IEEE Standard Test Procedure for Airborne Sound Measurements on Rotating Electrical Machinery.
- [4] IEEE Std 118-1978, IEEE Standard Test Code for Resistance Measurements.
- [5] IEEE Std 119-1974 (Withdrawn), IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.²
- [6] IEEE Std 120-1989, IEEE Master Test Guide for Electrical Measurements in Power Circuits (ANSI).

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

²This standard has been withdrawn by the IEEE. Photocopies of this document are available from the IEEE Service Center.

3. Tests — General

3.1 Types of Tests. Polyphase induction machines are normally given a routine test, but they may also be given additional tests.

For typical routine tests refer to NEMA MG1-1987 [B3]³, parts 12 and 20.

A typical form for reporting routine test data is shown in Appendix A. A typical form for reporting additional test data is shown in Appendix B.

3.2 Choice of Tests. A complete list of tests covered by this standard is given in the table of contents. Alternate methods are described for making many of the tests suitable for different sizes and types of machines and different conditions. In some cases, the preferred method is indicated.

The schedule of factory and field tests that may be required on new equipment is normally specified by applicable standards or by contract specifications. The manufacturer's choice of method for factory or field tests on new equipment will govern in lieu of prior agreement or contract specification.

3.3 Use of This Standard. After the test method is chosen, all necessary data may be obtained by following the instructions and precautions given in the subsection describing the test. Many of these subsections include alternate methods for obtaining the necessary data. Unless otherwise specified, the manufacturer may choose the method best suited to the facilities available. It is anticipated that the development of improved practices and new equipment, such as electronic and automatic devices, will result in new or improved methods of carrying out the intent of these test procedures. New or modified methods may be used as substitutes when their results have been shown to be reliable and consistent with those obtained by the methods given in these test procedures.

3.4 Test With Load. Tests with load are made for the determination of efficiency, power factor, speed, current, and temperature rise. Some of the miscellaneous tests outlined in Section 9 are also made with load. For all tests with load, the machine shall be properly aligned and securely fastened. For readings to be used in performance determinations, the machine temperature rise shall be some value between 50% and 100% of rated temperature rise. The usual procedure is to take readings at higher loads first and then follow with readings at lower loads.

3.5 Tests With Rotor Locked. It should be recognized that the testing of induction machines under locked-rotor conditions with polyphase power involves high mechanical stresses and high rates of heating. Therefore, it is necessary that

- (1) The mechanical means of locking the rotor is of adequate strength to prevent possible injury to personnel or damage to equipment.
- (2) The direction of rotation is established prior to this test.
- (3) The machine is at approximately ambient temperature before the test is started.

The current and torque readings shall be taken as quickly as possible; and, to obtain representative values, the machine temperature should not exceed rated temperature rise plus 40 °C. The readings for any point shall be taken within 5 s after voltage is applied.

3.6 Precautions. Since the performance of an induction machine is dependent not only upon the value of voltage and frequency but also on the wave shape and the balance in magnitude and phase angle of the voltages, correct data can be obtained only by careful measurement and by employing a suitable source of power (see 4.1.2).

³The numbers in brackets, when preceded by the letter "B," correspond to the Bibliography in Section 11.

CAUTION: *Many of the tests described in these procedures subject the machine to thermal and/or mechanical stresses beyond normal operating limits. To minimize the risk of damage to the machine, it is recommended that all tests be performed either under the manufacturer's supervision or in accordance with the manufacturer's recommendations.*

4. Measurements

4.1 Electrical

4.1.1 RMS Quantities. All voltage and current measurements are root mean square values, unless otherwise indicated.

4.1.2 Power Supply. The power supply shall provide balanced phase voltages closely approaching a sinusoidal waveform. The voltage waveform deviation factor⁴ shall not exceed 10%. The frequency shall be maintained within $\pm 0.5\%$ of the value required for the test being conducted, unless otherwise specified. Any departure from the assumed frequency directly effects the efficiency obtained with methods A and B. When these methods are used, the average frequency shall be within $\pm 0.10\%$ of the specified test value.

4.1.2.1. Rapid changes in frequency cannot be tolerated during tests because such variations affect not only the machine being tested, but also the output measuring devices. Variations in frequency during a test shall not exceed 0.33% of the average frequency.

4.1.3 Instrument Selection. Calibrated, high-accuracy instrumentation and accessory equipment shall be used. Either analog or digital-type instruments may be used in testing. Factors effecting accuracy, particularly with nonelectronic analog instruments, are

- (1) Loading of the signal source
- (2) Lead calibration
- (3) Range, condition, and calibration of the instrument

Since instrument accuracy is generally expressed as a percent of full scale, the range of the instrument chosen shall be as low as practical.

The indicating instrument shall bear record of calibration, within twelve months of the test, indicating limits of the error no greater than $\pm 0.5\%$ of full scale. When several instruments are connected in the circuit simultaneously, additional corrections of the instrument indication may be required.

Electronic instruments are generally more versatile and have much higher input impedances than passive (nonelectronic) instruments. Higher input impedance reduces the need to make corrections for the current drawn by the instrument. However, high input impedance instruments are more susceptible to noise.

Common sources of noise are

- (1) Inductive or electrostatic coupling of signal leads to power systems
- (2) Common impedance coupling or ground loops
- (3) Inadequate common mode rejection
- (4) Conducted interference from the power line.

⁴The deviation factor of a wave is the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superposed in such a way as to make this maximum difference as small as possible. The equivalent sine wave is defined as having the same frequency and the same root mean square value as the wave being tested.

Good practice requires the use of shielded twisted pairs for signal leads, grounding the shield at only one point, and keeping the signal cables as far away as possible from power cables. All exposed metal parts of these instruments should be grounded for safety.

Instrument calibration requirements are similar to those of nonelectronic instruments. When suitable automatic data acquisition systems or high-speed recorders are available, they may be used.⁵

4.1.4 Instrument Transformers. When current and potential instrument transformers are used, corrections shall be made for ratio errors in voltage and current measurements and for ratio and phase angle errors in power measurements.⁶

The errors of the transformers used shall not be greater than 0.5%.

4.1.5 Voltage. The line voltages shall be measured with the signal leads connected to the machine terminals. If local conditions will not permit such connections, the error introduced shall be evaluated and the readings shall be corrected. Tests may be performed where the voltage unbalance does not exceed 0.5%. The percent voltage unbalance equals 100 times the maximum voltage deviation from the average voltage divided by the average voltage.

EXAMPLE: With voltages of 220 V, 215 V, and 210 V, the average voltage is 215 V, the maximum deviation from the average is 5, and the unbalance equals $(100 \cdot 5)/215 = 2.3\%$.

4.1.6 Current. The line currents to each phase of the motor shall be measured, and the arithmetic average value shall be used in calculating machine performance from the test data.

4.1.7 Power. Power input to a three-phase machine may be measured by two single-phase wattmeters connected as in the two wattmeter method, one polyphase wattmeter, or three single-phase wattmeters. Power readings shall be corrected for meter losses if they are significant.

4.2 Resistance

4.2.1 Reference Resistance. To obtain dc resistance measurements of stator (and rotor, in the case of wound-rotor machines), the procedures given in IEEE Std 118-1978 [4]⁷ should be used.

4.2.2 Reference Ambient. All performance determinations should be corrected to an ambient temperature of 25 °C.

4.2.3 Correction to a Specified Temperature. When the resistance, R_t , of a winding has been determined by test at winding temperature, t_t , the resistance may be corrected to a specified temperature, t_s , by Eq 1.

$$R_s = \frac{R_t(t_s + k)}{(t_t + k)} \text{ in } \Omega \quad (\text{Eq 1})$$

where

R_s = winding resistance, corrected to specified temperature, t_s , in Ω
 t_s = specified temperature for resistance correction, in °C (see 5.1.1)
 R_t = test value of winding resistance, in Ω , at temperature t_t

⁵Further information regarding the use of instruments is given in IEEE Std 120-1989 [6].

⁶See footnote 5.

⁷The numbers in brackets correspond to those of the references in Section 2.

- t_t = temperature of winding when resistance was measured, in °C
 k = 234.5 for 100% IACS conductivity copper, or 225 for aluminum, based on a volume conductivity of 62%

NOTE: For other winding materials, a suitable value of k (inferred temperature for zero resistance) shall be used.

4.3 Mechanical

4.3.1 Power. Mechanical power measurements shall be taken with the greatest care and accuracy. If a mechanical brake is to be used, the tare, if present, shall be carefully determined and compensated for. If dynamometer⁸ output measurements are used, coupling and bearing friction losses must be compensated for. Properly sized dynamometers should be used, such that the coupling, friction, and windage losses of the dynamometer measured at rated speed of the machine being tested should not be greater than 15% of the rated output of the machine being tested; and they should be sensitive to a change of torque of 0.25% of the rated torque.

When using a dynamometer, the dynamometer shaft power, in watts, is obtained from the following equation:

$$\text{power (in W)} = \frac{(T \cdot n)}{k} \quad (\text{Eq 2})$$

where

- T = torque
 n = rotational speed, in r/min.
 k = 9.549, if T is in N•m
 = 7.043, if T is in lb•ft

4.3.1.1 Bearing Loss Stabilization. Some motors may experience a change in friction loss until the bearings reach a stabilized operating condition. In grease lubricated antifriction bearings, stabilization will not occur until there is no excess grease present in the path of the moving parts. This may require a number of hours of running to completely stabilize the no-load input watts. Stabilization can be considered to have occurred whenever the power input at no-load (or coupled to a deenergized dynamometer) does not vary by more than 3% between two successive readings at the same voltage at half-hour intervals.

4.3.2 Speed and Slip

4.3.2.1 Instruments. Analog tachometers or speed counters are not sufficiently accurate for the measurement of slip. Therefore, stroboscopic or digital tachometer methods are recommended. When a stroboscope is used, the power supply for the stroboscope should have the same frequency as the motor power supply. Slip is the difference between synchronous speed and measured speed in r/min, but it is usually expressed in per unit as

$$s = \frac{\text{slip (in r/min)}}{\text{synchronous speed (in r/min)}} \quad (\text{Eq 3})$$

⁸A dynamometer is defined as a device for applying torque to the rotating member of the test machine. It is equipped with means for indicating torque and speed, and is not limited to a cradle base construction. An in-line torque transducer may be used to provide a direct measurement of torque at the test machine shaft.

4.3.2.2. Slip measurements should be corrected to the specified stator temperature as follows:

$$s_s = \frac{s_t(t_s + k)}{(t_t + k)} \quad (\text{Eq 4})$$

where

- s_s = slip corrected to specified stator temperature, t_s
- s_t = slip measured at stator winding temperature, t_t
- t_s = specified temperature for resistance correction, in °C (see 5.1.1)
- t_t = observed stator winding temperature during load test, in °C
- k (based on rotor conductor material)
 - = 234.5 for 100% IACS conductivity copper, or 225 for aluminum, based on a volume conductivity of 62%

NOTE: For other rotor winding materials, a suitable value of k (inferred temperature for zero resistance) must be used.

4.4 Procedure. Whenever a series of increasing or decreasing readings of data are made, care should be taken in each case not to overrun the desired setting in order to avoid reversing the direction of the test.

4.5 Safety

WARNING: *Because of the dangerous currents, voltages, and forces encountered, safety precautions shall be taken for all tests. No attempt is made here to list or review the manifold general safety precautions that are well established throughout industry. However, this standard includes special safety precautions applicable to the particular tests described. All tests should be performed by knowledgeable and experienced personnel.*

5. Types of Losses

5.1 Stator I^2R Loss. The stator I^2R loss (in watts) is equal to $1.5 I^2R$ for three-phase machines, where

- I = measured or calculated rms current per line terminal at the specified load
- R = dc resistance between any two line terminals corrected to the specified temperature (see 4.2.3)

5.1.1 Specified Temperature. The specified temperature used in making resistance corrections should be determined by one of the following, which are listed in order of preference:

- (1) Measured temperature rise by resistance from a rated load temperature test plus 25 °C (see Section 8). Rated load is the rating identified on the nameplate at 1.0 service factor.
- (2) Measured temperature rise on a duplicate machine as outlined in method (1).

NOTE: A duplicate machine must be one of the same construction and electrical design.
- (3) When the rated load temperature rise has not been measured, the resistance of the windings should be corrected to the temperature shown in Table 1.

Table 1
Specified Temperature

Class of Insulation System	Temperature in °C
A	75
B	95
F	115
H	130

This reference temperature should be used for determining I^2R losses at all loads. If the rated temperature rise is specified as that of a lower class of insulation system than that used in the construction, the temperature for resistance correction should be that of the lower insulation class.

5.2 Rotor I^2R Loss. The rotor I^2R loss, including brush-contact losses for wound-rotor machines, should be determined from the per unit slip, whenever the slip is accurately determinable, using Eq 5 and Eq 6.

$$\text{motor rotor } I^2R \text{ loss} = (\text{measured stator input power} - \text{stator } I^2R \text{ loss} - \text{Core loss}) \cdot s \quad (\text{Eq 5})$$

$$\text{generator rotor } I^2R \text{ loss} = (\text{measured stator output power} + \text{Stator } I^2R \text{ loss} + \text{Core loss}) \cdot s \quad (\text{Eq 6})$$

5.3 Core Loss and Friction and Windage Loss (No-Load Test). The test is made by running the machine as a motor at rated voltage and frequency without connected load. To ensure that the correct value of friction loss is obtained, the machine should be operated until the input has stabilized (see 4.3.1.1).

5.3.1 No-Load Current. The current in each line is read. The average of the line currents is the no-load current.

5.3.2 No-Load Losses. The reading of input power is the total of the losses in the motor at no-load. Subtracting the stator I^2R loss (at the temperature of this test) from the input gives the sum of the friction (including brush-friction loss on wound-rotor motors), windage, and core losses.

5.3.3 Separation of Core Loss from Friction and Windage Loss. Separation of the core loss from the friction and windage loss may be made by reading voltage, current, and power input at rated frequency and at voltages ranging from 125% of rated voltage down to the point where further voltage reduction increases the current.

5.3.4 Friction and Windage. Power input minus the stator I^2R loss is plotted versus voltage, and the curve so obtained is extended to zero voltage. The intercept with the zero voltage axis is the friction and windage loss. The intercept may be determined more accurately if the input minus stator I^2R loss is plotted against the voltage squared for values in the lower voltage range. An example is the dashed curve shown in Fig 1.

5.3.5. Core Loss. The core loss at no load and rated voltage is obtained by subtracting the value of friction and windage loss (obtained from 5.3.4) from the sum of the friction, windage loss, and core loss (obtained from 5.3.2).

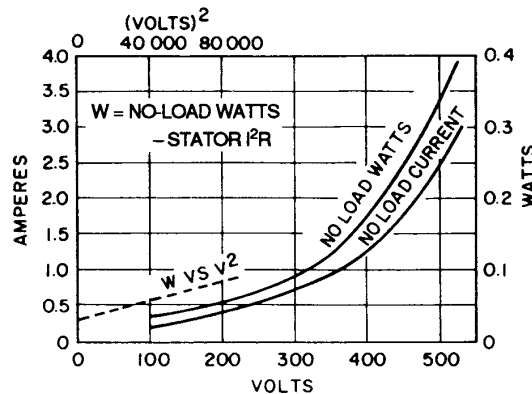


Fig 1
Determination of Friction and Windage Losses

5.4 Stray-Load Loss. The stray-load loss is that portion of the total loss in a machine not accounted for by the sum of friction and windage, stator I^2R loss, rotor I^2R loss, and core loss.

5.4.1 Indirect Measurement. The stray-load loss is determined by measuring the total losses, and subtracting from these losses the sum of the friction and windage, core loss, stator I^2R loss, and rotor I^2R loss. Indirect measurement is used in efficiency methods B, C, and C/F (see 6.4, 6.5, and 6.8).

5.4.1.1. The procedure for determining the stray-load loss (Method B) is described in 6.4.6.

5.4.1.2. The procedure for determining the stray-load loss (Method C) is described in 6.5.2.

5.4.1.3. The procedure for determining the stray-load loss (Method C/F) is described in 6.8.1.

5.4.2 Direct Measurement. Direct measurement is used in efficiency methods E, F, and E/F (see 6.6, 6.7, and 6.8).

5.4.2.1. The stray-load loss occurring at fundamental frequency is determined by applying balanced polyphase voltage to the stator-winding terminals with the rotor removed. The electrical input minus the stator I^2R loss at test temperature is equal to the fundamental frequency stray-load loss. During this test, bearing brackets and other structural parts in which current might be induced shall be in place. The currents used in making this test and that described in 5.4.2.2 should be identified as I_t and should have values established by Eq 7 for magnitudes covering the range of loads from 1/4 to 1 1/2 times rated load, as indicated by the appropriate test procedure.

$$I_t = \sqrt{(I^2 - I_o^2)} \quad (\text{Eq 7})$$

where

I_t = value of stator winding current during stray-load loss test

I_o = value of no-load current (see 5.3.1)

I = operating value of stator line current for which stray-load loss is to be determined

5.4.2.2. The stray-load loss occurring at high frequencies is determined by a reverse rotation test. With the motor completely assembled, balanced polyphase voltage at rated frequency is applied at the stator winding terminals. The rotor is driven by external means at synchronous speed in the direction opposite to the stator field rotation. (The correct speed may be determined easily by stroboscopic methods or by a digital tachometer.) The electrical input to the stator winding is measured.

The mechanical power required to drive the rotor is measured both with and without current applied to the stator winding terminals. For wound-rotor motors, the rotor terminals shall be short circuited.

5.4.2.3. The stray-load loss, W_{LL} , is calculated as follows:

$$W_{LL} = LL_s + LL_r \quad (\text{Eq 8})$$

In Eq 8, the values of LL_s and LL_r are calculated for the same values of line currents I_t , where

LL_s = W_s – the stator winding I^2R loss. The stator winding I^2R loss shall be the product of the number of phases, I_t^2 and r_1 , taken at each load point.

= fundamental frequency stray-load loss.

LL_r = $(P_r - P_f) - (W_r - LL_s - \text{stator winding } I^2R \text{ loss})$. The stator winding I^2R loss shall be the product of the number of phases, I_t^2 and r_1 , taken at each load point.

= higher frequencies stray-load loss.

r_1 = stator phase resistance. For a three-phase machine, this is taken as one-half of the resistance between terminals.

P_r = mechanical power required to drive rotor with voltage applied at stator winding terminals.

P_f = mechanical power required to drive rotor without voltage being applied at stator winding terminals.

W_s = electrical input to stator winding with rotor removed.

W_r = electrical input to stator winding during reverse-rotation test.

5.4.2.4. Smooth the test values of $(P_r - P_f)$, W_s , and W_r by using a regression analysis of the log of the power vs. the log of the current. Then,

$$(P_r - P_f) = A_1(I_t)^{N1} \quad (\text{Eq 9})$$

$$W_s = A_2(I_t)^{N2} \quad (\text{Eq 10})$$

$$W_r = A_3(I_t)^{N3} \quad (\text{Eq 11})$$

where

A = y intercept on a log-log plot (a constant)

N = slope on a log-log plot (approximately 2)

I_t = observed line current during the stray-load loss test

If the data are accurate, each curve will conform to a square-law relationship between power and current. Thus, the correlation factor from the regression and exponent for each curve both serve as indicators of data accuracy.

NOTE: The low power factors encountered during the tests specified in 5.4.2 through 5.4.3 make it imperative that phase-error corrections be applied to all wattmeter readings. Refer to IEEE Std 120-1989 [6].

5.4.2.5 Calculating Stray-Load Loss at a Specified Point

- (1) Determine an approximate value of rotor current I'_2 corresponding to the rated value of stator line current, I , as

$$I'_2 = (I^2 - I_o^2)^{1/2} \quad (\text{Eq 12})$$

where

I = rated value of stator line current
 I_o = value of no-load stator current

- (2) For the value of rotor current I'_2 , calculate a value of stray-load loss W'_{LL} for three-phase machines as follows:

$$W'_{LL} = A_1 \cdot (I'_2)^{N1} + 2A_2 \cdot (I'_2)^{N2} - A_3 \cdot (I'_2)^{N3} - 3 \cdot (I'_2)^2 \cdot (2 \cdot r_{1s} - r_{1r}) \quad (\text{Eq 13})$$

where

W'_{LL} = value of stray-load loss for approximate value of rotor current corresponding to rated load
 I'_2 = approximate value of rotor current corresponding to rated load from Eq 12
 r_{1s} = stator resistance per phase during rotor removed test at test temperature
 r_{1r} = stator resistance per phase during reverse rotation test at test temperature

The value of stray-load loss, W'_{LL} , reported in 10.4 or 10.5, corresponds to a value of I'_2 as calculated using Eq 12.

- (3) The value of stray-load loss, W_{LL} , for any load point, is then calculated as

$$W_{LL} = W'_{LL} \cdot \left(\frac{I_2}{I'_2} \right)^2 \quad (\text{Eq 14})$$

where

I_2 = value of rotor current appropriate to the load point for which stray-load loss is to be determined

- (4) The value of rotor current is calculated as

$$I_2 = \sqrt{I^2 - I_o^2} \quad (\text{Eq 15})$$

where

I = operating value of stator line current for which stray-load loss is to be determined
 I_o = value of no-load current