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NEMA STANDARDS PUBLICATION NO. MW 785

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Simulated Insertion Force Test for Film Insulated Round Magnet Wire

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 1300 North 17th Street, Rosslyn, VA 22209

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NEMA Standards Publication No. MW 785-1995

SIMULATED INSERTION FORCE TEST FOR FILM INSULATED ROUND MAGNET WIRE

Published by

National Electrical Manufacturers Association
1300 N. 17th Street, Suite 1847
Rosslyn, Virginia 22209

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Foreword

This Standards Publication was prepared by the NEMA Magnet Wire Section Technical Committee and reflects the input of various industries that use magnet wire. All information in this publication is Authorized Engineering Information.

All NEMA Magnet Wire publications are periodically reviewed by the NEMA Magnet Wire Section for revisions necessary to keep them current with technological changes. Proposed revisions should be submitted to:

Vice President, Engineering
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Introduction

As magnet wire is used to manufacture various electrical devices, particularly electric motors, it is quite often wound on a coil preform and then inserted into the proper stator slot through the use of various kinds of coil injection equipment which provides the mechanical force to place the coil in its final position. The insertion force required to place the coil in its proper position can have a dramatic effect on the quality of the finished electrical device. Excessive insertion forces may be related to excessive magnet wire insulation damage which can lead to electrical failures.

Past investigation into the factors related to the coil insertion force have shown that it depends upon the dimensions of the magnet wire, the softness or formability of the conductor, and the coefficient of friction and/or the smoothness of the outside surface of the film insulation.

History

Various devices and test methods have been used to measure some of the magnet wire characteristics, that affect the coil insertion force, independent of one another. Round Film Coated Magnet Wire Dimensions can be determined using NEMA MW 1000 Test Procedure 3.2.1.1 listed on page 1 of Part 3. The softness characteristics of various round film coated magnet wire samples (sizes 14–30 AWG) can be compared using NEMA MW 1000 Springback Test Procedure 3.7.1.1 listed on page 5 of Part 3. The coefficient of friction of various film insulated magnet wire samples (sizes 14-44 AWG) can be compared using the Dynamic Coefficient Test method as described in MW 750-1984 (R 1990).

However, the correlation of the various magnet wire test results with manufacturing performance to predict acceptably low coil insertion forces in motor manufacturing operations is difficult and has not always been successful. Also it is relatively expensive and inconvenient to evaluate various wires on production motor manufacturing equipment.

In a paper presented at the 1984 International Coil Winders Association (ICWA) Conference, Schmidt and Knoll described a Simulated Insertion Force Test (hereafter "SIFT") for magnet wire that identified differences between various film insulated magnet wires in their ability to be inserted into stators and in the forces associated with this insertion (See 1.6, Ref. No. 4). Test results using the method described were shown to correlate with actual measured coil insertion forces on production motor manufacturing equipment.

In a paper presented at the 1985 ICWA Conference, Schmidt and Knoll further explored the effects of test parameters and magnet wire characteristics on "SIFT" results (See 1.6, Ref. No. 5). Additional test results using the method over a broader range of sizes and types of magnet wire were shown to correlate with measured coil insertion forces while producing several sizes of motors.

As a result of the aforementioned presentations several members of the NEMA Magnet Wire Technical Committee became interested in the test procedure and in 1986 a decision was reached to conduct a round robin test series among four Technical Committee member companies to determine if the "SIFT" was capable of differentiating magnet wire construction in terms of insertion force. The results of the round robin testing were published in a paper presented by Schmidt and Scherrer at the 1987 Electrical/Electronic Insulation Conference (E/EIC), (See 1.6, Ref. No. 6). At that time it was determined that the "SIFT" could indeed differentiate between wire samples but there were differences in the level of test values between different test fixtures that could be attributed to dimensional or other design characteristic differences between test fixtures.

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In an effort to resolve previously mentioned differences in simulated insertion force between test fixtures a series of four test fixtures were produced in one machine shop. The results of this testing was published in a paper presented by Schmidt and Scherrer at the 1989 E/EIC (See 1.6, Ref. No. 7). It was concluded that three of the four test fixtures showed no significant difference in test results when testing like wire samples. Furthermore it was also demonstrated that the statistically higher "SIFT" values attributed to the one test fixture of the four that did not agree with the others could be attributed to a slightly smaller dimensional opening in the test fixture exit hole.

The 1989 paper also presented some test data showing differences in simulated insertion force between several different kinds of slot liner material. The test results from this paper and previous papers illustrated how the "SIFT" can evaluate the effects that various characteristics of magnet wire have on insertion forces. Because of these unique capabilities the NEMA Magnet Wire Section Technical Committee decided to publish the test procedure as NEMA Authorized Engineering Information. As a result of the rather rigorous test program that was followed in developing and evaluating the "SIFT" a great deal of information is available concerning the test procedure itself and the various wire test properties and other factors that affect the results. The primary advantage of this particular test is its ability to predict acceptable coil insertion performance once acceptable "SIFT" standards have been determined for a given stator coil injection process.

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Section 1
GENERAL

1.1 SCOPE

This Standards Publication describes a method and equipment used to determine the simulated insertion force of film insulated round magnet wire for wire sizes AWG 14–28.

1.2 REFERENCES

National Electrical Manufacturers Association
1300 N. 17th Street, Suite 1847
Rosslyn, Virginia 22209

NEMA MW 1000-1993 *Dimensions Test Procedure 3.2.1.1*

NEMA MW 1000-1993 *Springback Test Procedure 3.7.1.1*

MW 750-1984 (R 1990) *Dynamic Coefficient Test method as described on pages 3–9*

A Simulated Insertion Test for Magnet Wire, Schmidt, Paul J. and Knoll, Alan H., Proceedings of the 1984 ICWA Coil Winding Exposition, page 83.

Effects of Test Parameters and Magnet Wire Characteristics on Simulated Insertion Test Results, Schmidt, Paul J. and Knoll, Alan H., Proceedings of the 1985 ICWA Coil Winding Exposition, page 127.

Simulated Insertion Test Method Round Robin Results, Schmidt, Paul J. and Scherrer, Everett J., Proceedings of the 1987 Electrical Electronics Insulation Conference, page 55.

Results from Continued Interlaboratory Simulated Insertion ("SIFT") Round Robin Testing, Schmidt, Paul J. and Scherrer, Everett J., Proceedings of the 1989 Electrical Electronics Insulation Conference, page 68.

1.3 DEFINITIONS OF TERMS

Since this document contains a number of terms peculiar to the magnet wire and electric motor industry, the following definitions have been provided in an attempt to promote a better understanding of the information contained within.

1.3.1 Coefficient of Friction

A term relating to the slipperiness of a surface. Generally it is dimensionless coefficient relating the force required to start (static) or sustain (dynamic) movement between two surfaces to the force being exerted to hold the surfaces together.

$$COF = \frac{\text{Force} \rightarrow}{\text{Normal Force}}$$

Force → | Normal Force v

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1.3.2 Formability

A magnet wire property relating to the ease with which the wire may be shaped into a wound form. This property is related primarily to the metallurgical softness or state of anneal of the conductor. Hard drawn wire that has not been annealed exhibits high yield and tensile strength, is springy and difficult to form.

1.3.3 Injection or Insertion

The physical act of placing preformed coil windings into the proper slots in a stator through the use of mechanical force.

1.3.4 Insertability

A term relating to the ease with which a wire sample may be wound on a coil preform and then inserted into the proper slot in a motor stator. Generally this property depends on the softness of the conductor and the coefficient of friction of the outside surface of the magnet wire. However, the relationship between the outside diameter of the conductor, combined with the number of turns required for the winding and the size of the stator slot is also a critical consideration.

1.3.5 Preform or Coil Preform

With respect to motor manufacturing A particular part of magnet wire winding equipment that the magnet wire is initially wound upon to provide a series of winding turns containing the proper length of magnet wire and correct physical winding dimensions to conform with characteristics of the motor stator the windings are intended for.

1.3.6 Preformed Test Coil

With respect to the "SIFT" — The wire sample prepared for performing the "SIFT" by winding the wire specimen to be tested on the test coil preform mandrel.

1.3.7 Shipping Package

The spool or reel the magnet wire is wound upon for the purpose of transporting the product from its manufacturing location to a customer using location.

1.3.8 Simulated Insertion Force (hereafter "SIF")

The maximum or peak force that occurs when a preformed test coil is pulled through the Simulated Insertion Force Test (hereafter "SIFT") fixture.

1.3.9 Softness

A term relating to the metallurgical state of the magnet wire conductor. Drawing and other mechanical deformation processes increase the frequency and density of crystal lattice defects in the conductor. Some of the energy expended in metal deformation processes is stored in the metal in the form of greater than equilibrium numbers and arrangements of defects which tends to inhibit further deformation of the conductor. This phenomena is known as work hardening.

Magnet wire conductors are annealed (heated under controlled conditions) during the manufacturing process to remove the cumulative effects of work hardening and provide soft windable magnet wire. The energy stored in the metal due to work hardening works as a thermodynamic driving force which tends to return the metal to the undeformed state provided that the metal is raised to a temperature where the required reactions can occur at the desired rate. The energy provided by annealing increases the temperature of the metal and allows the greater than equilibrium number and arrangement of defects to relax toward their equilibrium state and promotes the formation and growth of new strain-free grains in the conductor. The degree to which this occurs determines the conductor's softness.

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1.3.10 Springback

A magnet wire test property that relates to the softness or formability of the conductor. In general terms the test involves winding a wire specimen a number of revolutions around a specified mandrel under a specific tension. Then the end of the conductor where the tension weight has been attached is cut and bent to form an indicator which is released gently until the wound wire has sprungback to its equilibrium point. The springback value is recorded in total degrees using the indicator end as a pointer on the scale provided on the test device. For more information on this subject see NEMA MW 1000-1993, Springback Test Procedure 3.7.1.1 listed on page 5 of Part 3.

1.3.11 Stator

The stationary motor framework constructed from steel laminations containing a series of slots for the magnet wire windings.

1.3.12 Description of Test and Equipment

In brief, the test involves pulling a small coil, consisting of a pre-determined quantity of wire, through a highly polished, chrome-plated, truncated triangular chute having a roughly elliptical opening. This requires the coil of wire to deform and slide in the fixture, thus combining the elements of "formability" and "slipperiness". The maximum force needed to pull the coil through the fixture is recorded as a measure of the insertability of the wire sample.

The opening size, angle, and length of the test chamber were chosen to provide a convenient force level which easily differentiates various wire constructions. The recommended "SIFT" fixture is shown in figure 1-1. This fixture was developed as a result of evolutionary work as reported earlier in the technical reference documents.

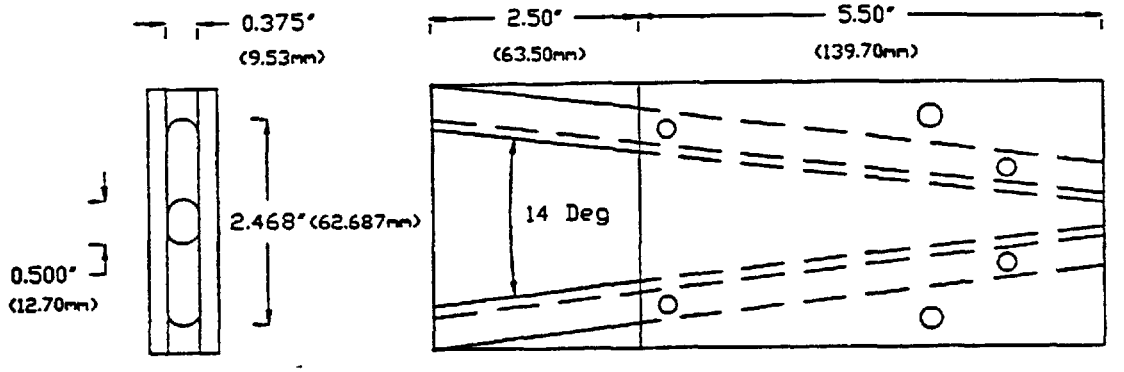


Figure 1-1
SIMULATED INSERTION FORCE TEST FIXTURE

NOTE—Besides the test fixture, a hook, as illustrated in figure 1-2, is required to pull the coiled wire specimens through the test fixture. The U-shaped area of the hook is placed through the test coil and the other two ends of the hook are attached to the pulling device.

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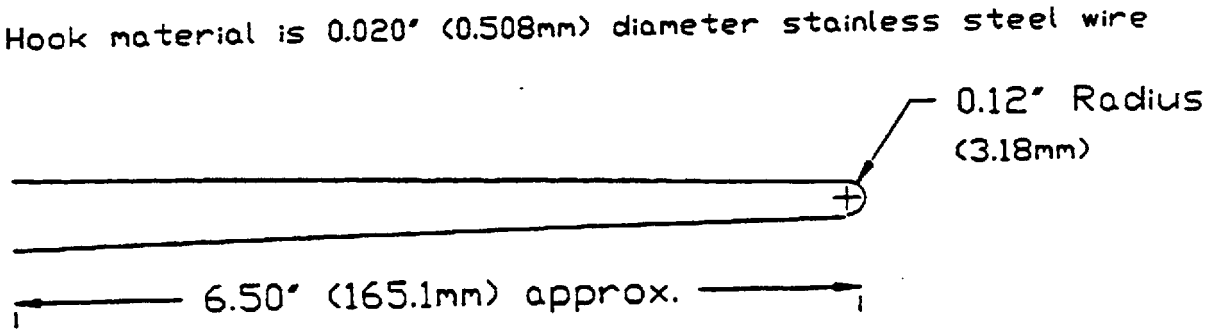


Figure 1-2
TEST SAMPLE PULL HOOK

NOTE—The coiled wire specimens required for testing are prepared by random winding a specified number of turns in accordance with the wire size being tested on a 0.25" (6.35 mm) wide mandrel having a barrel diameter of 1.25" (31.75 mm) and a flange diameter of 1.75" (44.45 mm), (see figure 1-3). The coils are secured after winding by wrapping the end of the wire around the pre-wound coil through a slot in the mandrel. One flange of the preferred winding mandrel design should be detachable so that the coils can be easily removed from the mandrel, as shown in figure 1-4.

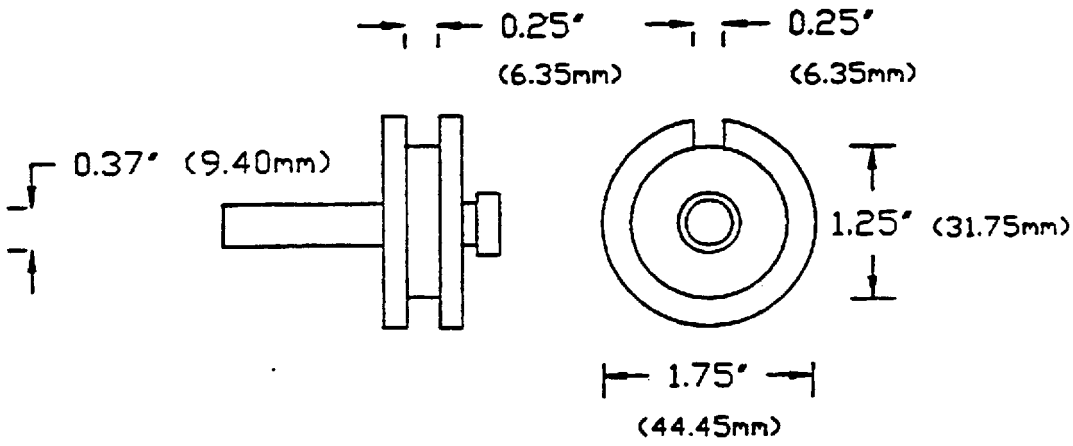


Figure 1-3
SIMULATED INSERTION FORCE TEST COIL MANDREL

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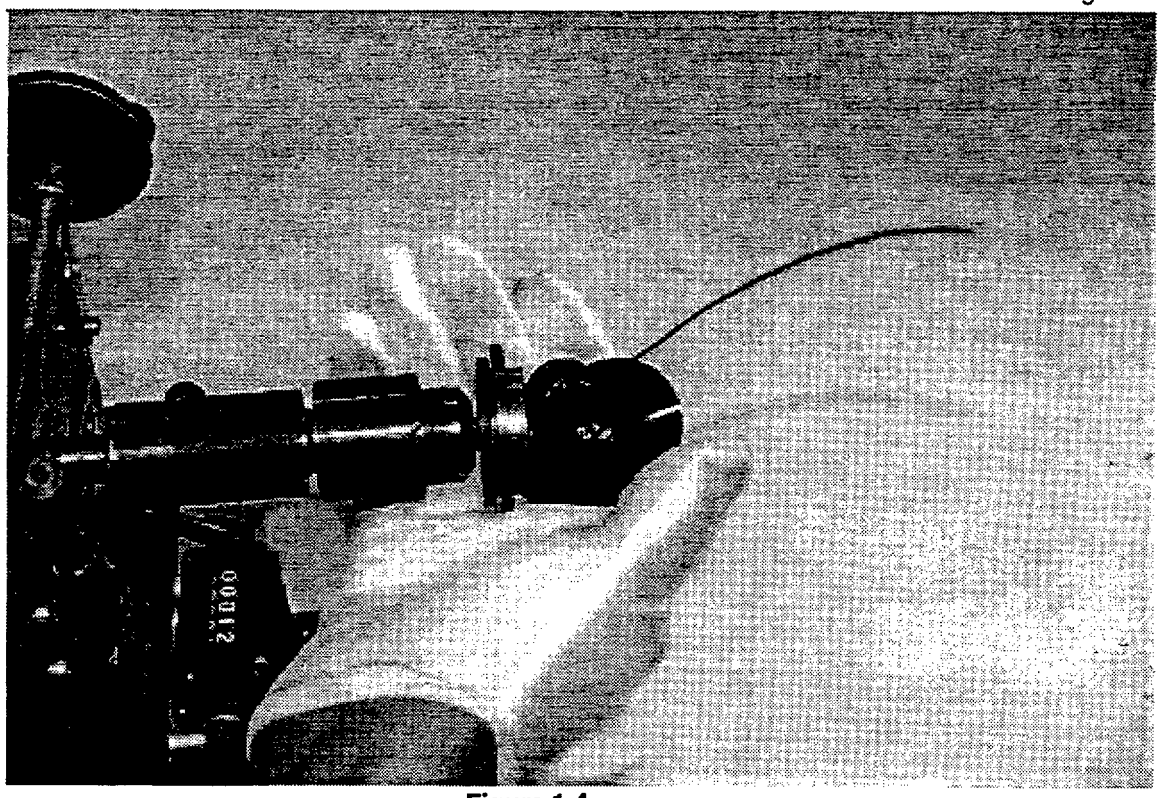


Figure 1-4
REMOVING TEST SPECIMENS FROM THE TEST COIL MANDREL

The required number of mandrel turns for a number of sizes is listed in table 1-1. A considerable amount of test data has been generated using 18 AWG samples of MW 35-C and MW 24-C magnet wire. Extensive work with sizes 22 AWG and 25 AWG of MW 35-C and MW 24-C has been presented in the Schmidt and Knoll references. The mandrel turn specifications for the other sizes in table 1-1 are presented as logical size/turn combinations which should produce comparable "SIFT" data to past efforts.

Table 1-1 – Recommended "SIFT" coil turns versus AWG size

AWG Size	Nom. Bare Dia. In.	Conductor Cross Sectional Area SQ	Recommended Turns
14	0.0641	0.0097	2
15	0.0571	0.0102	3
16	0.0508	0.0103	4
17	0.0453	0.0113	7
18	0.0403	0.015	12
22	0.0253	0.020	40
25	0.0179	0.025	100
28	0.0126	0.031	250

Several different devices have been used to pull the test coils through the "SIFT" fixture. The main requirements for the pulling device are the ability to provide and record the maximum force and the ability to pull the coil through the test fixture at a constant reproducible rate. The maximum force required for most testing will be less than 20 lbs. (89.3 Newtons). While a great deal of testing has been conducted using a Scott IP4 stress strain analyzer operating at 8 in/min (20.3 cm/min), other stress strain analyzers have been used operating at pull rates up to 20 in/min (50.8 cm/min). Past data seems to indicate a slight trend toward higher test values being realized at higher pull rates.

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1.4 DISCUSSION

Typical values for the "SIFT" will vary considerably with characteristics of the magnet wire used for the testing. The type of lubricant and the slipperiness and/or smoothness of the outside coating, the softness and/or formability of the conductor and to a lesser extent the outside diameter of a magnet wire within in a given AWG size will all have some effect on the "SIFT" values achieved. Past work with various slot liner materials has shown a strong tendency toward increased "SIFT" values when these materials are used in conjunction with the testing.

18 AWG MW 35-C magnet wire with wax type lubrication will produce "SIFT" values in the range of 12–15 lbs. (53.6–67.0 Newtons). 18 AWG MW 76-C magnet wire with wax type lubrication will produce "SIFT" values in the range of 11–13 lbs (49.1–58.0 Newtons). Work with 18 AWG MW 35-C wax lubricated magnet wire and various types of slot liner material including Mylar, DMD 100, rag paper, Nomex and fish paper has produced "SIFT" values in the range of 13–20 lbs. (58.0–89.3 Newtons).

Various 18 AWG MW 24-C samples tested with wax, mineral oil, and no lubricant and type 6/6 topcoat produced "SIFT" values in the range of 10–12 lbs. (44.6–53.6 Newtons) for wax lubrication, 12–14 lbs. (53.6–62.5 Newtons) for mineral oil lubrication and 17–19 lbs. (75.9–84.8 Newtons) for no lubrication.

Various 18 AWG MW 24-A (aluminum conductor) samples with identical turn count and similar dimensions to the MW 24-C samples produced "SIFT" results that were about 45% lower than comparable copper samples. The turn count of aluminum conductor samples had to be increased about 65% to produce results similar to copper conductor when the dimensions of the copper and aluminum samples was similar. When 16 AWG MW 24-A was substituted in the test in place of 18 AWG MW 24-C with the same test coil turn count (as would be case in an attempt to match conductor conductivity) the "SIFT" values averaged about 24% higher.

Various 25 AWG MW 24-C and MW 35-C samples with low springback (good) and high springback (bad) properties produced "SIFT" values in the range of 7-10 lbs. (31.3-44.6 Newtons) for the low springback property group and "SIFT" values in the range of 8-12 lbs. (35.7-53.6 Newtons) for the high springback property group.

Various 22 AWG MW 24-C samples with single and triple insulation builds produced "SIFT" test values in the range of 7-8 lbs. (31.3- 35.7 Newtons) and 8-9 lbs. (35.7-40.2 Newtons) for the single and triple build respectively.

It is assumed that the wire will be de-reeled from the shipping package without coming into contact with surfaces other than the "SIFT" mandrel and the shipping package. The use of white cotton lint free gloves is recommended in guiding the wire during the test coil winding procedures and while handling the test coils themselves. The least amount of handling and contact will produce the best results. It should be noted that the natural level of dust and dirt may have an effect on maintaining the equipment and white gloves in the optimum condition. If dust and dirt problems are suspected, one or two outer layers of wire should be removed from the samples before proceeding with the testing.

The condition of the test coil mandrel and the test fixture surfaces that come in contact with the wire sample is very important. These surfaces should be clean and dry at the start of each separate test.

An environmentally safe solvent suitable for removing the type of magnet wire lubrication being used and that will dry rapidly to produce a film free surface is a great aid in maintaining the test equipment in the optimum condition. Please refer to Section 2.1 Safety Statement for relevant information concerning the safe use of solvents.

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This authorized engineering information is presented as a primer on the operation of the "SIFT" and test procedure. It is anticipated that the method will be a useful reference tool when comparisons are required.

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Section 2
SIMULATED INSERTION FORCE TEST METHOD

2.1 SAFETY STATEMENT

This test procedure requires personnel with adequate training in safety and general test lab procedures.

WARNING: *Mechanical Hazard.* Certain parts of the test procedure require the cutting of various wire samples and the handling of cut samples. Care should be exercised in cutting wire samples and to avoid damage or injury to bodily parts such as hands and fingers which might accidentally come into contact with the cutting devices. Furthermore the cut ends of wire samples pose a hazard in terms of sharp ends which might cause cuts or puncture wounds. Care must be exercised to protect eyes, fingers, hands, and other bodily parts from injury.

The simulated insertion part of the test procedure where the prepared sample coil is pulled through the "SIFT" fixture poses a potential pinch hazard. Care should be exercised to avoid any bodily parts from being exposed to potential pinch damage during this phase of the test procedure.

WARNING: *Chemical Hazard.* Equipment maintenance may require the use of certain solvents which could pose a chemical hazard. Solvents should be selected and used with full knowledge of all potential environmental and safety hazards. Material Safety data sheets for any potential solvents should be reviewed carefully to determine what hazards may exist before the solvents are selected or used. Care should be exercised to comply with all environmental regulations, avoid all hazards, and to provide adequate ventilation and other protective clothing or measures that may be required.

It is not the intent of this Authorized Engineering Information to address all of safety issues associated with its use. It is the responsibility of the user to train personnel, establish proper health and safety procedures, and be aware of local, state, and national regulatory restrictions which may apply.

2.2 SUMMARY OF METHOD

A pre-wound test coil of the sample wire is pulled through the "SIFT" Fixture at a constant rate. The maximum force that occurs as the coil is pulled through the fixture is recorded.

2.3 SIGNIFICANCE

The simulated insertion force of film insulated magnet wire has been shown to directly correlate with coil insertion forces experienced during production motor manufacturing operations. High coil insertion forces may be related to excessive film insulation damage which can lead to electrical failures. The simulated insertion force of a given magnet wire sample is influenced by the smoothness and coefficient of friction of the outside surface of the magnet wire, by the softness and formability of the magnet wire, and to a lesser extent by the outside diameter. While many test methods exist to measure each individual wire test property, none of the aforementioned individual wire test properties has been correlated with coil insertion forces in motor manufacturing operations.

2.4 APPARATUS

The recommended Simulated Insertion Force Test fixture is shown in figure 1-1. Besides the test fixture itself a hair pin shaped hook as illustrated in figure 1-2 is required to pull the coiled wire specimens through the test fixture.

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A test coil mandrel as shown in figure 1-3 is required to prepare the test coil. The slot in the flanges of the Test Coil Mandrel is there to allow for the lead end of the test wire to be wrapped around the coiled test specimen to secure it.

The wire test specimen is wound on the test coil mandrel mounted in a chuck as shown in figure 2-1. The number of coil turns required for the test coil are specified for various wire sizes in table 1-1. A turn counter similar to the one shown in figure 1-4 is an aid to monitoring the number of turns wound.

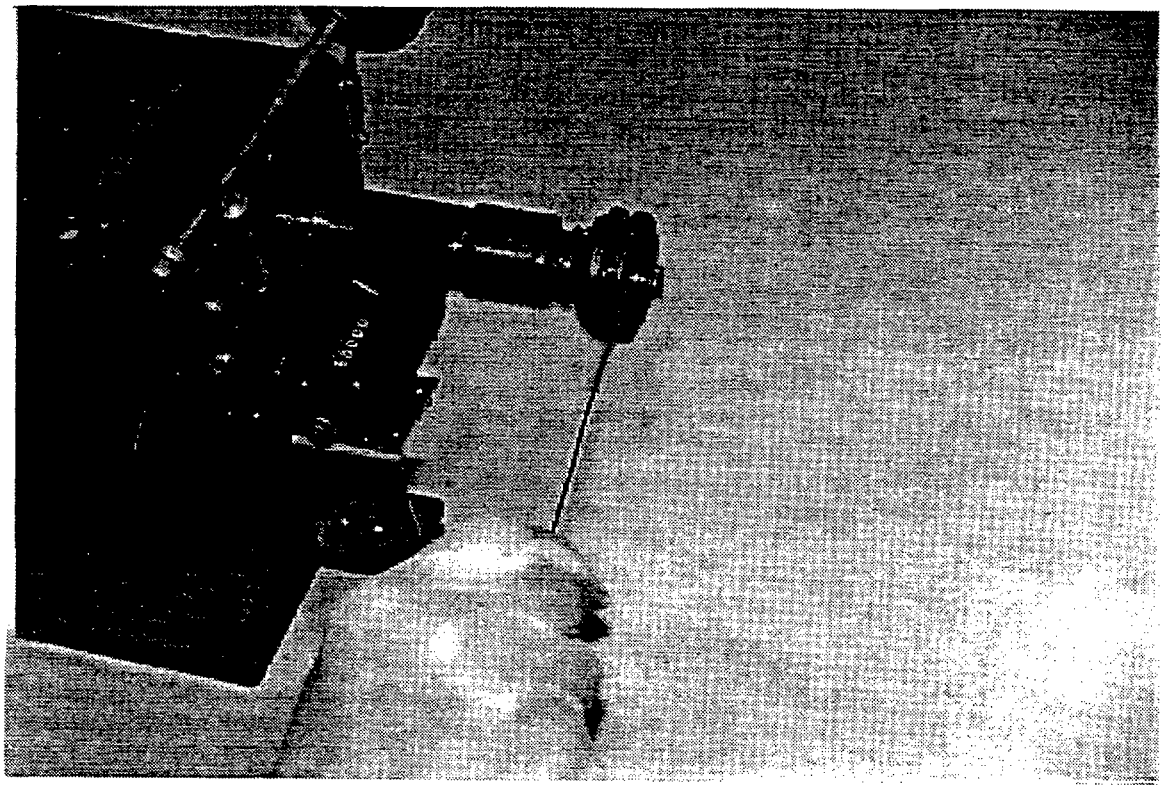


Figure 2-1
WINDING THE TEST SPECIMEN

The use of white cotton lint-free gloves as shown in figures 1-4 and 2-1 is recommended in guiding the wire during the test coil winding procedures and while handling the test coils themselves to avoid undue influence of extraneous factors upon the test results.

Several different devices have been used to pull the test coils through the "SIFT" fixture. The main requirements for the pulling device is the ability to provide and record the maximum force and the ability to pull the coil through the test fixture at a constant reproducible rate. The maximum force required for most testing will be less than 20 lbs. (89.3 Newtons). A great deal of testing has been conducted using a stress strain analyzer operating at 8 in./min. (20.3 cm/min.), other pull rates up to 20 in./min. (50.8 cm/min.) have been used. An environmentally safe solvent suitable for removing the type of magnet wire lubrication being used and that will dry rapidly to produce a film free surface is a great aid in maintaining the test equipment in the optimum condition. However, solvents should be selected and used with full knowledge of all potential environmental and safety hazards. Material Safety Data Sheets for any potential solvents should be reviewed carefully to determine what hazards may exist before the solvents are selected or used. Care should be

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exercised to comply with all environmental regulations, avoid all hazards, and to provide adequate ventilation and other protective clothing or measures that may be required.

2.5 TEST SPECIMEN

The wire test specimen should be removed from the shipping package by de-reeling over the end flange or pulling from the pail or drum. If the wire specimen has been contaminated by dust or dirt, the top wire specimen layer of the spool should be removed before testing.

2.6 PROCEDURE

The wire to be tested is wound on a mandrel to form a circular shaped test coil. The required number of mandrel turns for a number of sizes is listed in table 1-1. When the required number of coil turns have been wound the lead end of the test coil wire is wrapped around the prewound coil through a slot in the mandrel to secure the test coil before it is removed from the mandrel. One flange of the preferred winding mandrel design should be detachable so that the coils can be easily removed from the mandrel as shown in figure 1-4. Typically, a number of test coils are prepared from each wire specimen so that enough "SIFT"s can be conducted to provide statistically sound data.

The preformed test coil is then placed in the "SIFT" fixture with one end of the hairpin shaped pulling device through the coil. Care must be exercised to orient the preformed test coil so that the secured side of the coil is 180 degrees across the pull point as shown in figure 2-2.

The ends of the pulling hook are threaded through the exit hole in the test fixture which is then firmly attached to the moving end of the stress strain analyzer.

The stress strain analyzer is operated at a constant elongation rate until the preformed test coil is pulled through the test fixture and the maximum force that occurred has been recorded.

The test fixture should be cleaned after each test cycle to avoid lubricant contamination.

2.7 REPORT

The test report should include wire specimen identification (source, size, insulation grade, film type, and type of lubrication) and an average "SIFT" value based on an appropriate number of tests to produce statistically significant values.

2.8 PRECISION AND ACCURACY

While the test is capable of producing precise and accurate data, individual users should assess the precision and accuracy of the test with their test equipment and operators.

2.9 INSPECTION OF TEST EQUIPMENT

While the chrome plating on the "SIFT" Fixture is somewhat wear resistant, the integrity of the chrome plating on the interior of the fixture should be visually checked for excessive wear with 10X magnification at regular intervals.

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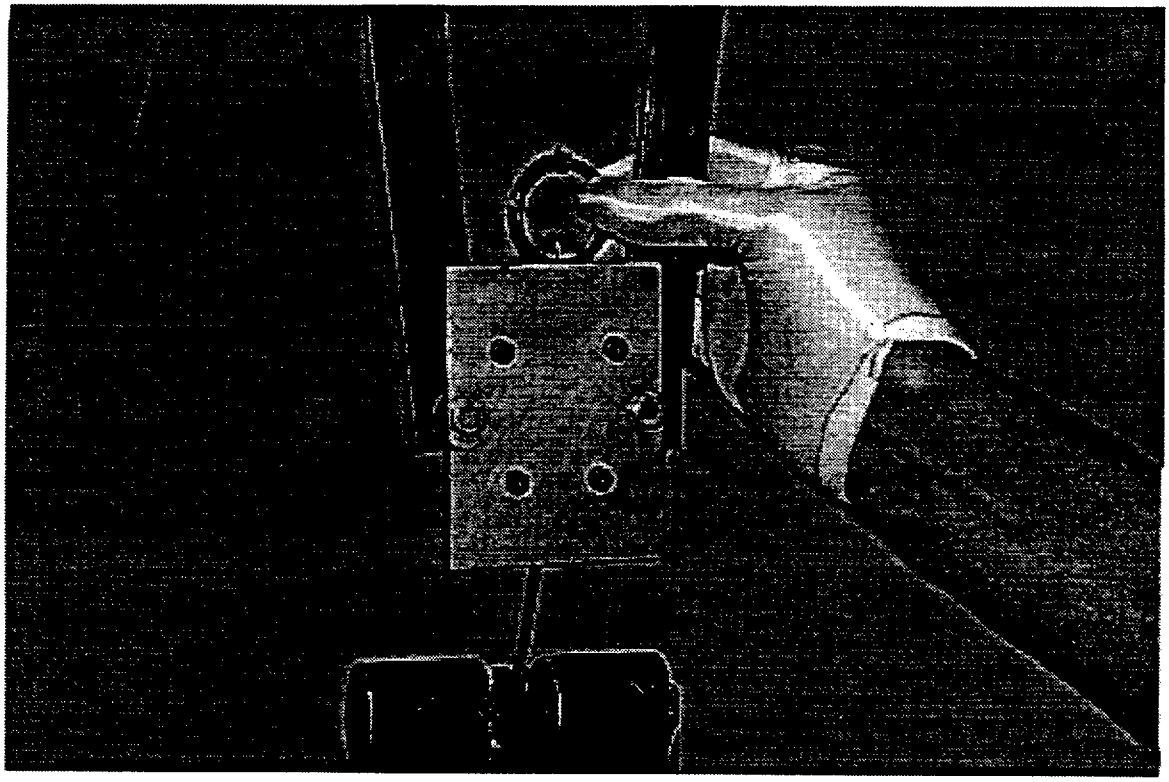


Figure 2-2
COIL ORIENTATION IN THE "SIFT" FIXTURE

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following; nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, p. 5)

Authorized Engineering Information

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(Standardization Policies and Procedures, p. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

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