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NEMA STANDARDS PUBLICATION NO. MW 750

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Dynamic Coefficient of Friction of Film-Insulated Magnet Wire

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA MW 750–1984 (R 1990)

MW 750

DYNAMIC COEFFICIENT OF FRICTION OF FILM-INSULATED MAGNET WIRE

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Foreword

Dynamic Coefficient of Friction of Film-Insulated Magnet Wire, MW 750-1984 (R 1990), was prepared by the NEMA Magnet Wire Technical Committee and reflects the input of representatives for various industries that use magnet wire. In addition, the test procedure and apparatus described herein have been reviewed by the Winding Wire Committee of the International Electrotechnical Commission.

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:

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Scope

A method and equipment used for determining the coefficient of friction of film-insulated round magnet wire for sizes AWG 14–44 are covered in this NEMA Standards Publication.

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DYNAMIC COEFFICIENT OF FRICTION OF FILM-INSULATED MAGNET WIRE

(Approved as Authorized Engineering Information 7-11-1984)

Section 1
GENERAL

1.1 INTRODUCTION

As magnet wire is transferred from package to coils, the designed path takes the wire over, around, and through guides, blocks, corners, and so forth, all of which are intended to help place the wire at a precise location in the coil.

The force required to pull the wire through the designed winding path, exclusive of the bending force, is that which is necessary to overcome the friction developed between the magnet wire and the various surfaces that come in contact with the wire. This force is directly related to the surface characteristics of the film insulation, the contact surfaces, and the applied lubrication.

1.2 HISTORY

Various devices have been used to measure coefficient of friction of magnet wire. Several were discussed in Paper #4 at the NEMA session of the 1971 Electrical/Electronics Insulation Conference.*

In 1961, Parussel* described a tester to measure the coefficient of friction of film insulated magnet wire. This design was subsequently standardized and incorporated in the DIN specifications.* A tester similar to the Parussel design and made by Excel Industries was demonstrated to the NEMA Magnet Wire Technical Committee. At that time an interest was expressed in redesigning the tester to simplify the operation.

In 1973, NEMA Magnet Wire Section Engineering Bulletin #4 was developed which described the subject of coefficient of friction testing and provided a test method which included the final equipment description. Eventually, the original supplier of this equipment discontinued its interest in supplying equipment, and the Research Department of Indiana Institute of Technology supplied a new design. In 1978, at an International Electrotechnical Commission Winding Wire Committee meeting, this test method was introduced for discussion.

One of the critical elements was the selection of the surface which would be in contact with the wire specimen. The cost of supplying and maintaining a prescribed steel surface ground to the applicable specifications was found to be excessive. Representatives from The Netherlands recommended the use of synthetic sapphire elements for the load block surface. Their experience indicated that these synthetic sapphires would provide excellent life at low cost. The elements were subsequently adopted for the test surface.

1.3 DEFINITION OF FRICTION

Friction is the resistance to motion existing when solid object is moved tangentially over the surface of another solid object which it touches, or when an attempt is made to produce such a motion. If a normal load (L) presses two surfaces together, a tangential force may be applied up to some limiting value X_s and the surfaces will still remain at rest. Sliding only starts when the tangential force exceeds the static friction force F_s. Almost as soon as the motion starts, the tangential force takes on a characteristic value F_d which always acts in the direction opposite to the relative velocity of the surfaces. F_s is often approximately 30 percent larger than F_d, but sometimes F_s equals F_d. The ratio F_s/L is the static coefficient of friction μ_s, while the ratio F_d/L is the dynamic coefficient of friction μ_d. The coefficients of friction are essentially a material property of the contacting surfaces and of the contaminants and other films (such as lubricants) at their interface. The coefficients of friction are independent of the load and the contact area; the dynamic coefficient of friction is also independent of the sliding velocity. This last law does not apply when the presence of a lubricant creates viscous flow in the intermediate liquid layer; in this case the dynamic coefficient of friction normally increases with increasing sliding velocities.

1.4 EQUIPMENT DESCRIPTION

The equipment design is illustrated in Figures 1-1 and 1-2. Figures 1-3 and 1-4 are detailed drawings of the synthetic sapphires and the load block. The tester is supplied with a wire guiding system and a take-up which pulls the wire over the test bed at 50ft/min (15m/min) as shown

*See 1.6.

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in Figure 1-5. The test block is aligned so it is parallel with the test bed and the test weights are perpendicular to the wire specimen.

As the wire is pulled under the test block (synthetic sapphires), the friction between the wire surface and the sapphire surface develops a longitudinal force which is transferred to the measuring system, by a shaft which is supported by two sets of linear ball bearings, in contact with the measuring system. The force indicated by the measuring system is divided by the load on the test surface to obtain the dynamic coefficient of friction.

The measuring system shown in Figure 1-2 is a dynamometer. One of two ranges is used depending on the wire size being tested. The value is read by an operator during the test. Since the value on the dynamometer continually varies, it is necessary for the operator to estimate the average force which occurs during the test. At times a more critical analysis may be required, such as the comparison of peak to average coefficient of friction between specimens or within one specimen. For this work, recorded data are required. The dynamometer is then replaced with a force transducer which supplies a signal to a recorder. The force transducer selected for this work is a linear variable differential transformer (LVDT). Figures 1-1 and 1-6 show the dynamic coefficient of friction tester with the LVDT in place. The output from the electrical portion may be recorded as shown in Figure 1-7. An LVDT with recorder is the preferred type of measuring system.

1.5 DISCUSSION

Typical values for dynamic coefficient of friction vary considerably with the type of lubrication and the wire specimen surface. Normally, large variations in dynamic coefficient of friction among wire sizes have not been found. Wire lubricated with standard mineral oil will have a dynamic coefficient of friction range of 0.09-0.15. Wire lubricated with standard paraffin will have a dynamic coefficient of friction in the range of 0.04-0.06. Figure 1-7 illustrates this difference and also shows the difference in uniformity between the two types of lubricants.

The test procedure attached is designed to provide a measure of the lubrication and film surface smoothness as a combined value. It is assumed that the wire will be dereeled from the sales package without coming in contact with surfaces other than those associated with the tester and sales package.

It should be noted that the natural level of dust and dirt may have an effect on the coefficient of friction. If this is suspected, one or two outer layers of wire should be removed from the package and the sample retested.

The condition of the test surfaces in contact with the wire is very important. They should be clean and dry at the start of each separate test. The solvent used to clean the test load surface is also important. The solvent should remove the various types of lubricants used and should dry without leaving a film.

This Authorized Engineering Information is presented as a primer on the new coefficient of friction equipment and test procedure. It is anticipated that this method will become a useful reference tool when comparisons are required.

1.6 REFERENCES

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Section 2
DYNAMIC COEFFICIENT OF FRICTION TEST METHOD

2.1 DEFINITIONS OF TERMS

Dynamic coefficient of friction (μ_d) is the ratio of the force (F) developed between a moving wire surface and the test block surface, to the test load (L),

$$\mu_d = \frac{F}{L}$$

2.2 SUMMARY OF METHOD

The wire specimen is pulled over a test bed surface under a test load (L). A frictional force (F) is developed between the wire surface and the test block surface and transferred to an appropriate measuring device. The reading (F) in gf (N) is divided by the test load (L) in gf (N) to obtain the dynamic coefficient of friction (μ_d).

2.3 SIGNIFICANCE

The dynamic coefficient of friction (μ_d) of film-insulated magnet wire is primarily a measure of lubricity and the smoothness of the insulation surface. The combination of these factors represented by the coefficient of friction value affects windability, lay of wire, fill factor of electrical coils, and the spooling quality during manufacture of film-insulated magnet wire.

2.4 APPARATUS

The dynamic coefficient of friction tester should resemble the design shown in Figure 1-1.

A motor (Figure 1-1, #3) should pull the wire specimen at 50±5 ft/min (15±1.5 m/min) across a smooth surface (Figure 1-1, #10) using a motor driven takeup (Figure 1-1, #6).

Various load weights (Figure 1-2, #7) should be available, which will provide 100-1000 gf (0.98-9.81 N) force.

The test block should be synthetic sapphire and have a surface roughness of not more than 0.5 micrometers (20 μin.). The sapphires are described and should be mounted in accordance with Figures 1-3 and 1-4.

There should be a means to guide the wire (Figure 1-1, #4, and Figure 1-2, #9) and a means to maintain a slight tension (Figure 1-1, #1 and #5), if needed.

Electronic force measuring devices or transducers (Figure 1-1, #2) incorporated with a chart recorder measure the force due to friction. The electronic force measuring device will provide a record indicating the peak variation along the surface of the wire. A force transducer with a range of 0-500 gf (0-5.0 N) and a chart recorder with a 0-5 V range and a 0.5-second full-scale response time should be satisfactory.

Figure 1-2, #5, illustrates the use of a mechanical dynamometer to replace an electronic force transducer and chart recorder. Two dynamometer ranges, 0-50 gf (0-0.5 N) and 0-200 gf (0.2.0 N), are satisfactory.

A dampening system (Figure 1-2, #4) consisting of a paddle and a container filled to a depth of 2±0.2 in (5±1 mm) with oil having a viscosity of 10,000±500 cps (10±0.5 Pa.s) at 25 °C is also required.

A cleaning solvent appropriate for the lubricant being tested should be used for cleaning sapphire surfaces.

2.5 TEST SPECIMEN

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

2.6 PROCEDURE

Referring to Figure 1-2, level off smooth surface (6) using the leveling leg screws (2) and float level (8).

The electronic force transducer (Figure 1-1, #2) sensitivity should be adjusted to the appropriate range, and the chart recorder full-scale should be set for the wire size being tested using a calibrating weight (Figure 1-1, #9). The calibrating weight should be removed after the transducer and chart recorder have been adjusted.

If the mechanical dynamometer (Figure 1-2, #5) is used, the correct range for the size wire being tested should be installed: AWG 14-35, 0-200 gf (0-2.0 N); AWG 36-44, 0-50 gf (0-0.5 N).

The sapphire surfaces located on the load block (Figure 1-2, #3) which are in contact with the wire should be cleaned with an appropriate cleaning solvent and allowed to dry thoroughly.

The dampening paddle (Figure 1-2, #4) should be lowered into the oil: immersed completely for AWG 14-30; immersed one-half paddle for AWG 31-44.

The wire should be threaded over the payoff pulley, tension capstan, and appropriate guide pulleys (Figure 1-1, #1, #4, and #5) and between test bed guides (Figure 1-2, #9), such that the wire is in contact with the two sapphires.

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The appropriate test load should be applied (Figure 1-2, #7): AWG 14-24, 1000 gf (9.87 N); AWG 25-35, 600 gf (5.88 N); AWG 36-40, 200 gf (1.96 N); and AWG 41-44, 100 gf (0.98 N). The test load (Figure 1-2, #7) should be positioned on the test bed (Figure 1-2, #6) where no reading is indicated on the force transducer or dynamometer.

If the mechanical dynamometer is used, it should be zeroed.

The calibrated dial (Figure 1-2, #1) should be adjusted to make the test load parallel with the test bed surface.

The tester should be turned on to move the test wire through the apparatus.

Slight tension should be applied by the tension capstan (Figure 1-1, #1) to keep the wire traveling smoothly.

To allow time for the start-up variations to cease, the average dynamometer reading to the nearest gf (Newton) should be recorded no sooner than 15 seconds after start-up.

2.7 CALCULATION

The average dynamic coefficient of friction (μ_d) should be calculated as follows:

$$\mu_d = \frac{F}{L}$$

where:

F = average dynamometer force reading, gf (N), and

L = test load, gf (N).

2.8 REPORT

The test report should include wire specimen identification (size, insulation grade, film type, and type of lubrication) and average dynamic coefficient of friction value (μ_d).

2.9 PRECISION AND ACCURACY

The precision and accuracy of this method are under study by the NEMA Magnet Wire Technical Committee.

2.10 INSPECTION OF CONTACT BLOCKS

Although the wear resistance of the sapphire contact blocks exceeds that of steel, the surfaces of the blocks should be inspected at regular intervals under 100 × magnification.

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1. Tension Capstan
2. Transducer
3. Motor
4. Wire Guide Pulleys
5. Payoff Pulley
6. Wire Takeup
7. Leg Levelers
8. Float Level
9. Calibration Weight
10. Test Bed

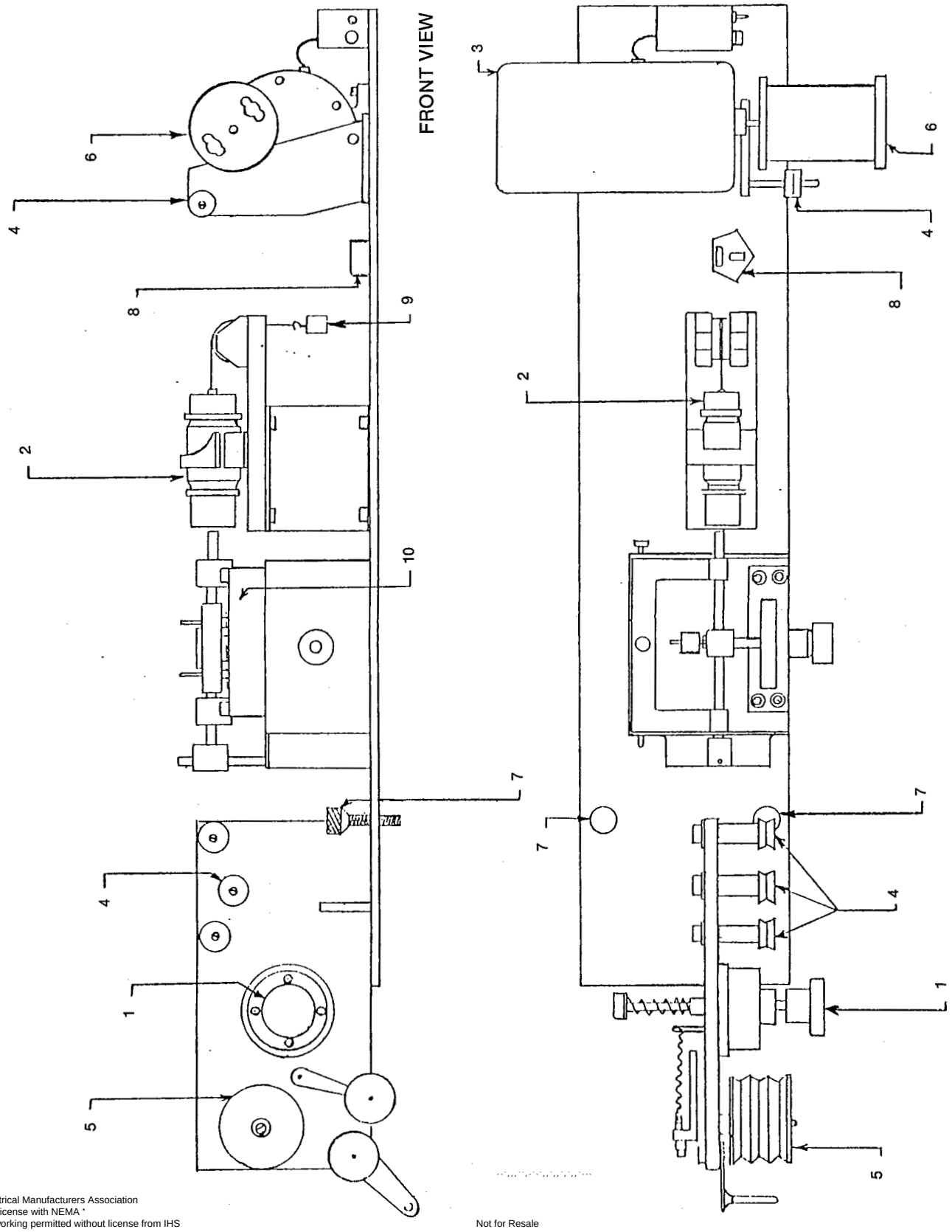


Figure 1-1
COEFFICIENT OF FRICTION TESTER

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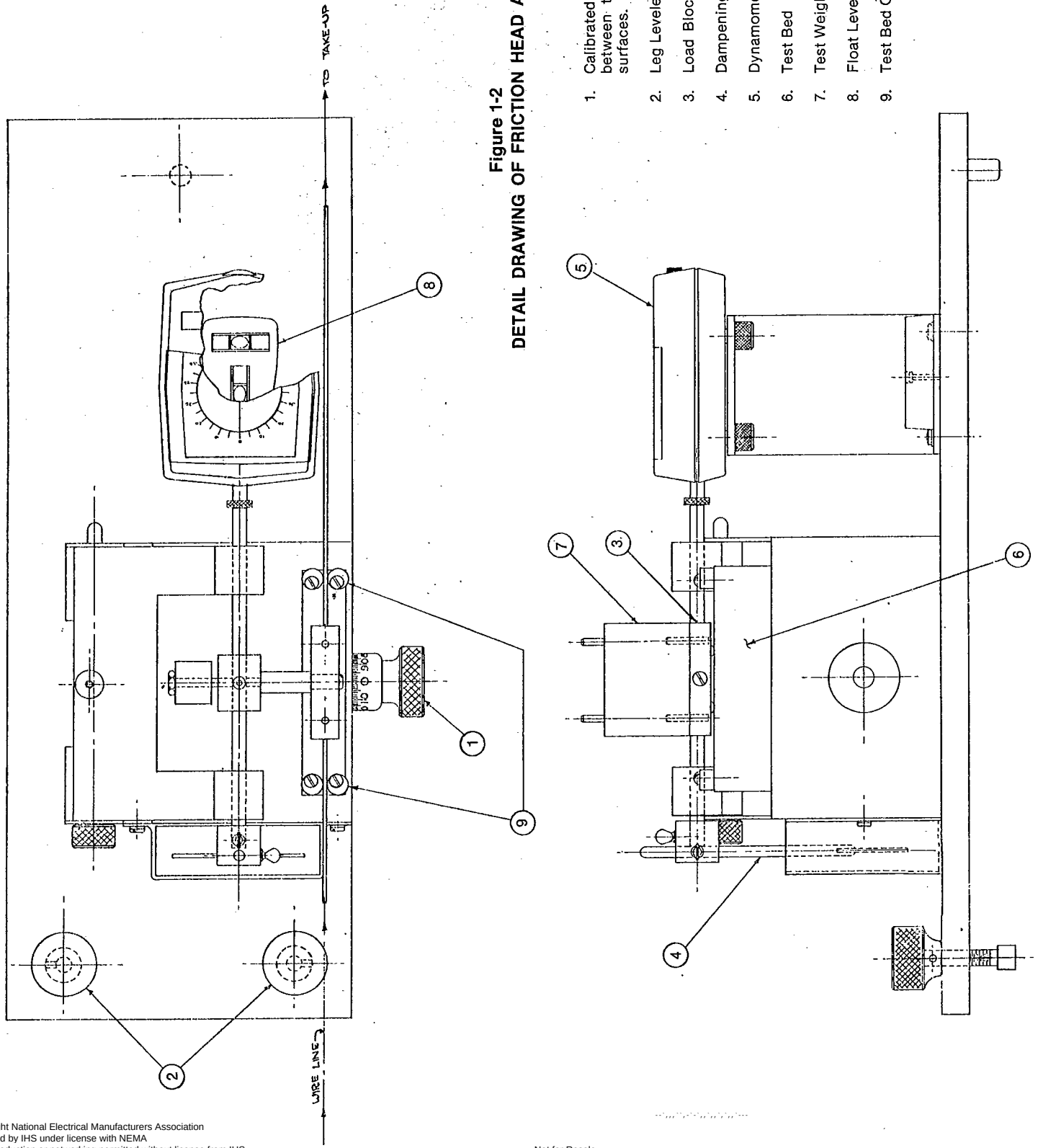


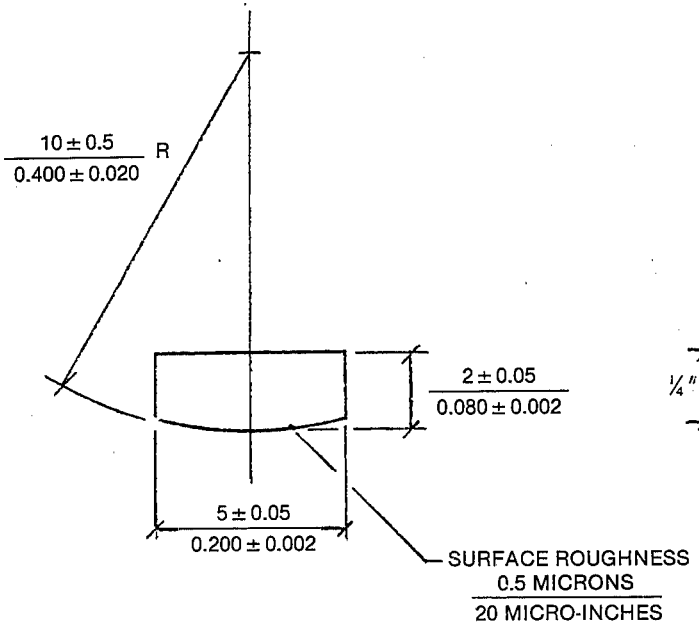
Figure 1-2
DETAIL DRAWING OF FRICTION HEAD ASSEMBLY

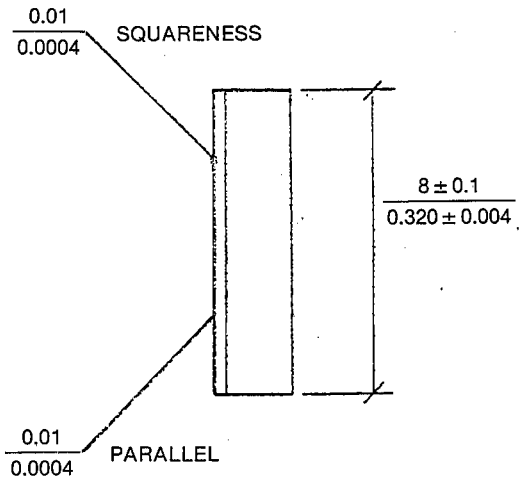
1. Calibrated adjustment for parallelism between the test load and test bed surfaces.
2. Leg Levelers
3. Load Block—Also Figures 1-3 and 1-4
4. Dampening System
5. Dynamometer
6. Test Bed
7. Test Weights
8. Float Level
9. Test Bed Guides

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NOTE: TOP FIGURE DENOTES MILLIMETERS; LOWER FIGURE DENOTES DECIMALS OF AN INCH.

Figure 1-3
MATERIAL—SAPPHIRE (SYNTHETIC)

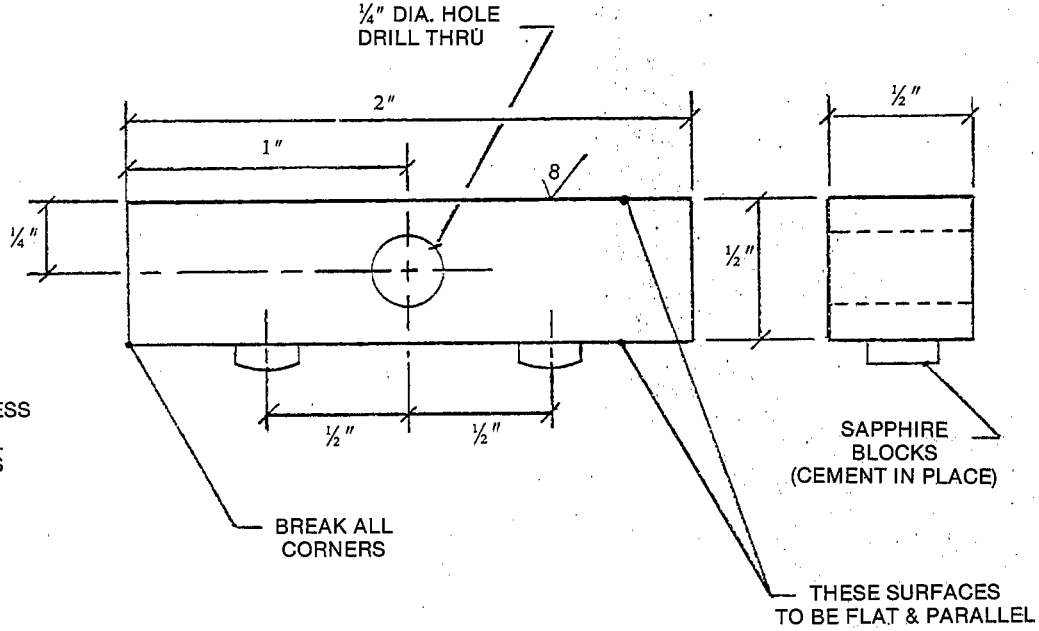


Figure 1-4
LOAD BLOCK—3 FROM FIGURE 1-2

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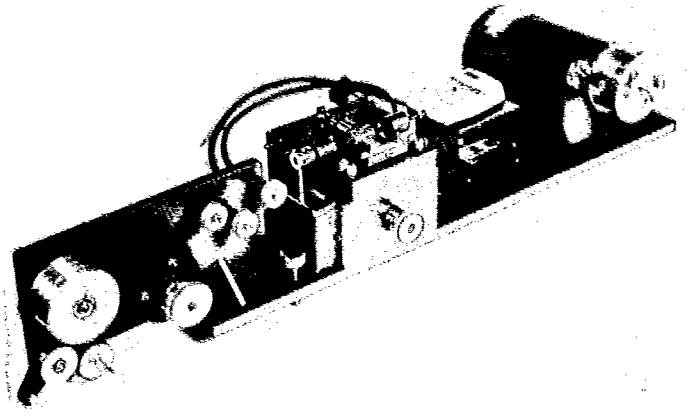


Figure 1-5
NEMA COEFFICIENT OF FRICTION TESTER INCLUDING TAKE-UP, LOAD BLOCK, TEST BED, DYNAMOMETER, AND THE WIRE GUIDING SYSTEM

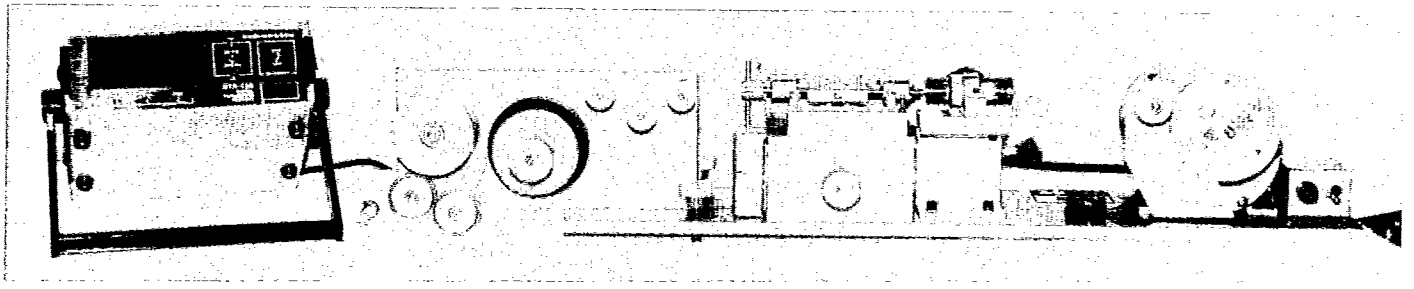


Figure 1-6
NEMA COEFFICIENT OF FRICTION TESTER WITH FORCE TRANSDUCER IN PLACE OF DYNAMOMETER SHOWN IN FIGURE 1-5

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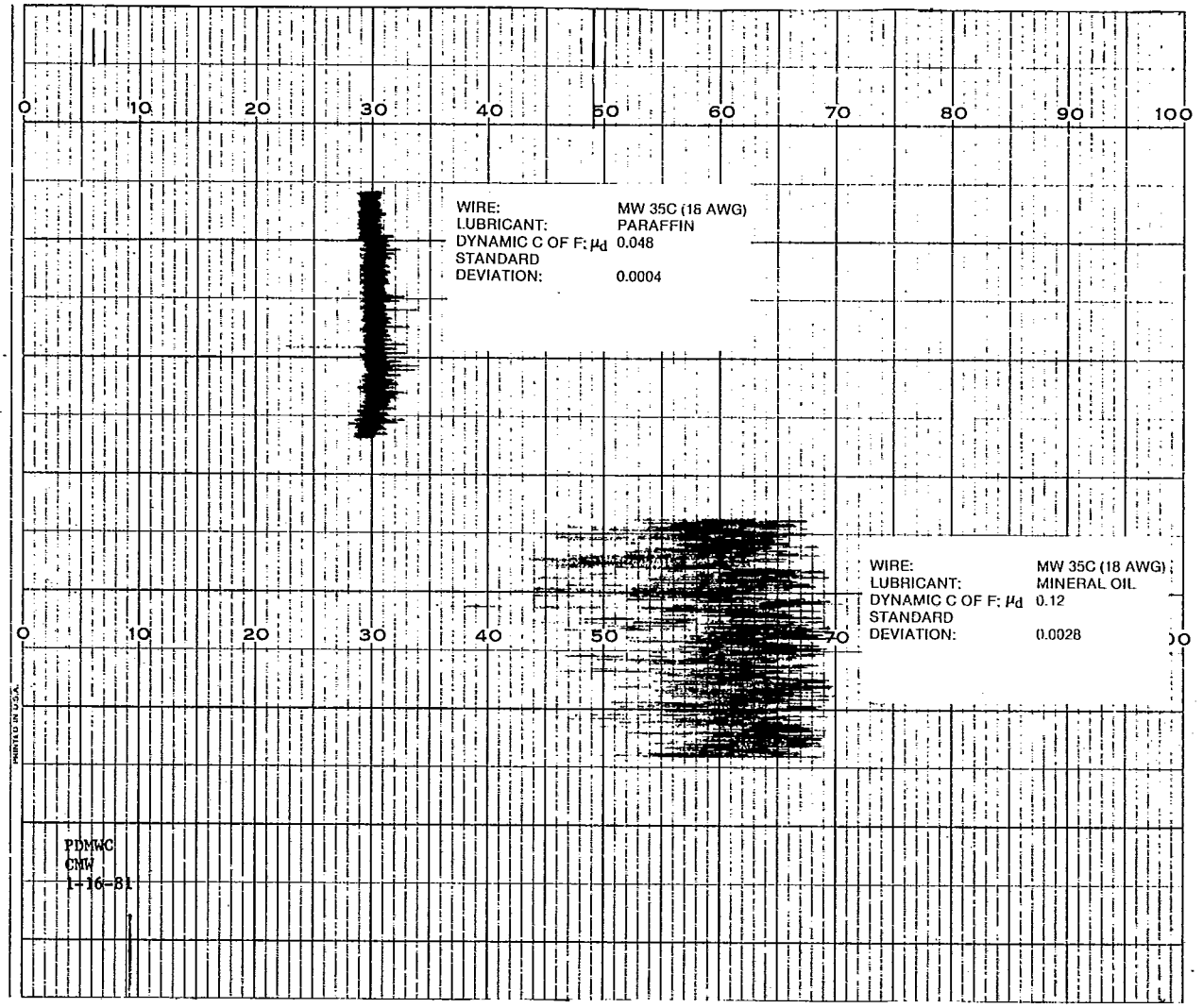


Figure 1-7
ELECTRICAL OUTPUT RECORDING

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NEMA STANDARDIZATION

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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 purchasers 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. *(Standardization Policies and Procedures, p. 1)*

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, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

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.8)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
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, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.
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, pp. 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

(Standardization Policies and Procedures, pp. 7 & 16)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment, and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 7 & 16)

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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