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NEMA STANDARDS PUBLICATION

NEMA MW 750

DYNAMIC COEFFICIENT OF FRICTION OF FILM-INSULATED MAGNET WIRE

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DYNAMIC COEFFICIENT OF FRICTION OF FILM-INSULATED MAGNET WIRE

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FOREWORD

MW 750-1996 was prepared by the NEMA Magnet Wire Technical Committee.

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

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This Standards Publication was developed by the NEMA Magnet Wire Section. Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the Magnet Wire Section was composed of the following members:

Alcatel Canada Wire, Inc.—La Grange, KY
American Wire Corporation—Sandy Hook, CT
Bridgeport Insulated Wire Company—Bridgeport, CT
Elektrisola, Inc.—Boscawen, NH
Essex Group, Inc., Magnet Wire and Insulation Division—Fort Wayne, IN
Magnetek, Inc.—Gallman, MS
Optec D D USA, Inc.—St. Louis, MO
Phelps Dodge Magnet Wire Company—Fort Wayne, IN
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INTRODUCTION

As magnet wire is transferred from the supply 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 the designed 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.

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. The 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 describes 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.

Earlier versions of this equipment used a dynamometer to measure the tangential force or F_d. Since the value on the dynamometer continually varies, it was necessary for the operator to estimate the average force which occurs during the test. More precision, and accuracy are required so that the gage repeatability and reproducibility can be improved for this test. The dynamometer has been replaced with a force transducer selected for this work which is a linear variable differential transformer (LVDT). The data is collected from the pressure transducer readout by a computer or microprocessor. Statistical analysis can be performed on this data set resulting in mean, min, max, and standard deviation.

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Section 1
GENERAL

1.1 SCOPE

This document describes a method and the equipment used for determining the dynamic coefficient of friction of film-insulated round magnet wire of sizes 14-44 AWG.

1.2 DEFINITION OF FRICTION

Friction is the resistance to motion existing when a 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, and the surfaces will still remain at rest. Sliding only starts when the tangential force exceeds the static 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 ration 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 velocity.

1.3 EQUIPMENT DESCRIPTION

The equipment design is illustrated in Figures 1-1 and 1-2. Figures 1-3 and 1-4 are detailed drawings of 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 50 ft/min (15 m/min). 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 Figures 1-1 and 1-2 shows the dynamic coefficient of friction tester with the LVDT in place. The electrical output from the LVDT is feed into a pressure transducer monitor and into a computer or into a microprocessor which collects data measurements, usually 1000 points. Statistics are performed on this data set so that proper interpretation of the results can be made.

1.4 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 a mineral oil typically will have a mean dynamic coefficient of friction in the range of 0.09 to 0.16. Wire lubricated with a paraffin wax will typically have a dynamic coefficient of friction in the ranges of 0.03 to 0.06. Figure 1-5 illustrates this difference and also shows the difference in uniformity between two types of lubricants. The maximum value and standard deviation value can also be used to evaluate the application of the lubricant to the wire and smoothness of the wire surface.

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The test procedure attached is designed to provide a measure of the lubrication and the film surface smoothness as a combined value. It is assumed that the wire will be dereeled from the sales package with minimal contact with surfaces other than those associated with the tester and the 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 residue.

1.5 REFERENCES

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A/Z Tech Sales Literature

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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).

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 transferred to an appropriate measuring device. The reading (F) in grams-force is divided by the test load (L) in grams-force to obtain the dynamic coefficient of friction m_d.

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

2.3 SIGNIFICANCE

The dynamic coefficient of friction m_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 the manufacture of film-insulated magnet wire.

2.4 SAFETY STATEMENTS

WARNING—*Mechanical Hazard*: This test uses mechanical equipment which may expose the operator to mechanical hazards. Care shall be exercised to protect the eyes, fingers, hands, and other body parts from injury.

WARNING—*Chemical Hazard*: This test may use materials which local, state, and national regulatory agencies have determined to be hazardous. This test shall be performed under controlled conditions which allow for proper safety and protection of personnel. Information and instructions contained in the Material Safety Data Sheet (MSDS) for handling, working and disposal of hazardous chemicals shall be followed.

It is not the intent of this authorized engineering information document to address all of the safety issues associated with this test procedure and equipment. 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 that may apply.

2.5 APPARATUS

The dynamic coefficient of friction tester should resemble the design shown in Figure 2-1 and Figure 2-2, with the friction head assembly having the functionality of Figure 2-3.

A motor should pull the wire specimen at 50 ±5 ft/min (15 ±1.5 m/min) across a smooth surface using a motor driven takeup.

Various load weights should be available that will provide 100-1000g force.

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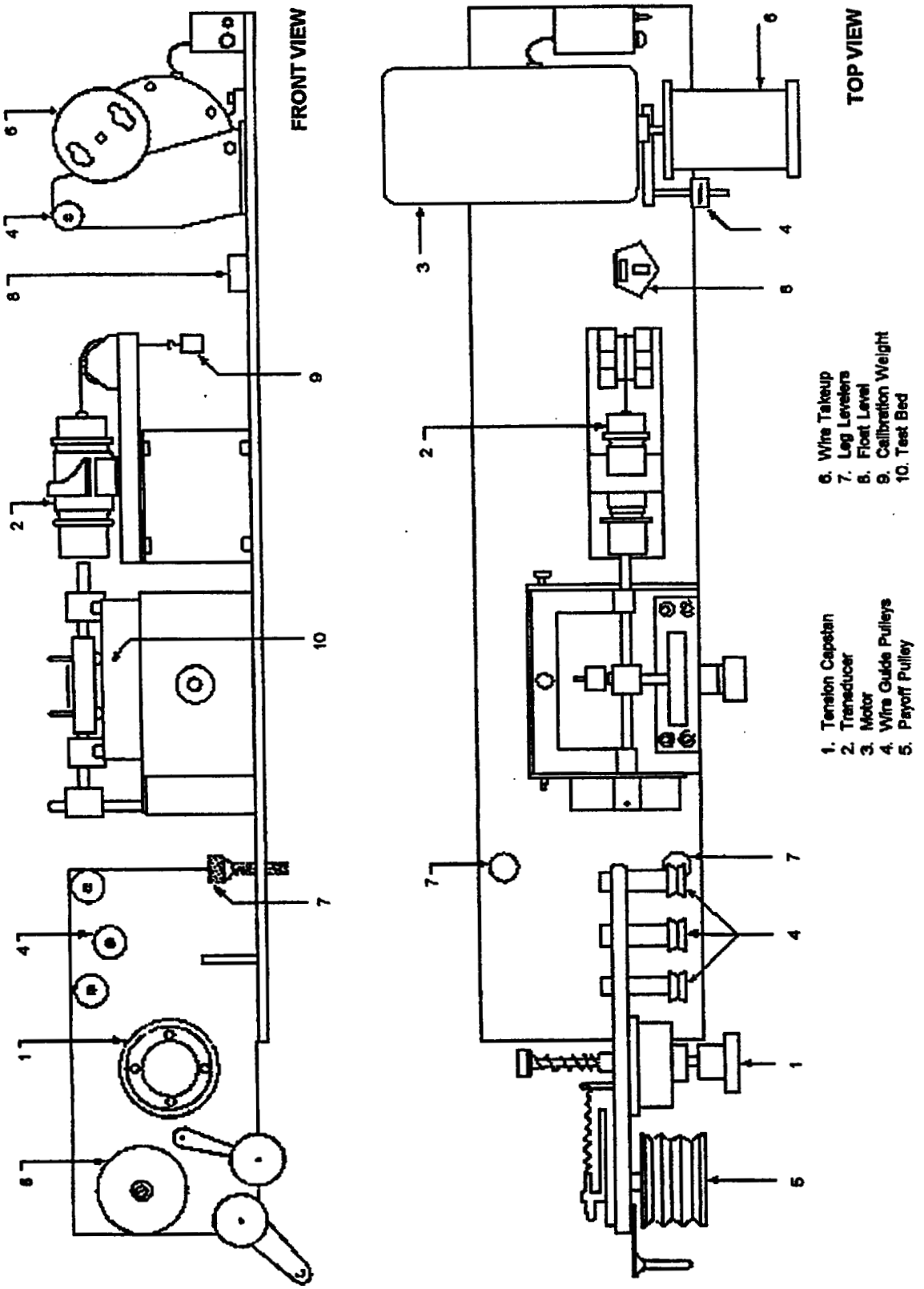


Figure 2-1
DIAGRAM OF COEFFICIENT OF FRICTION TESTER

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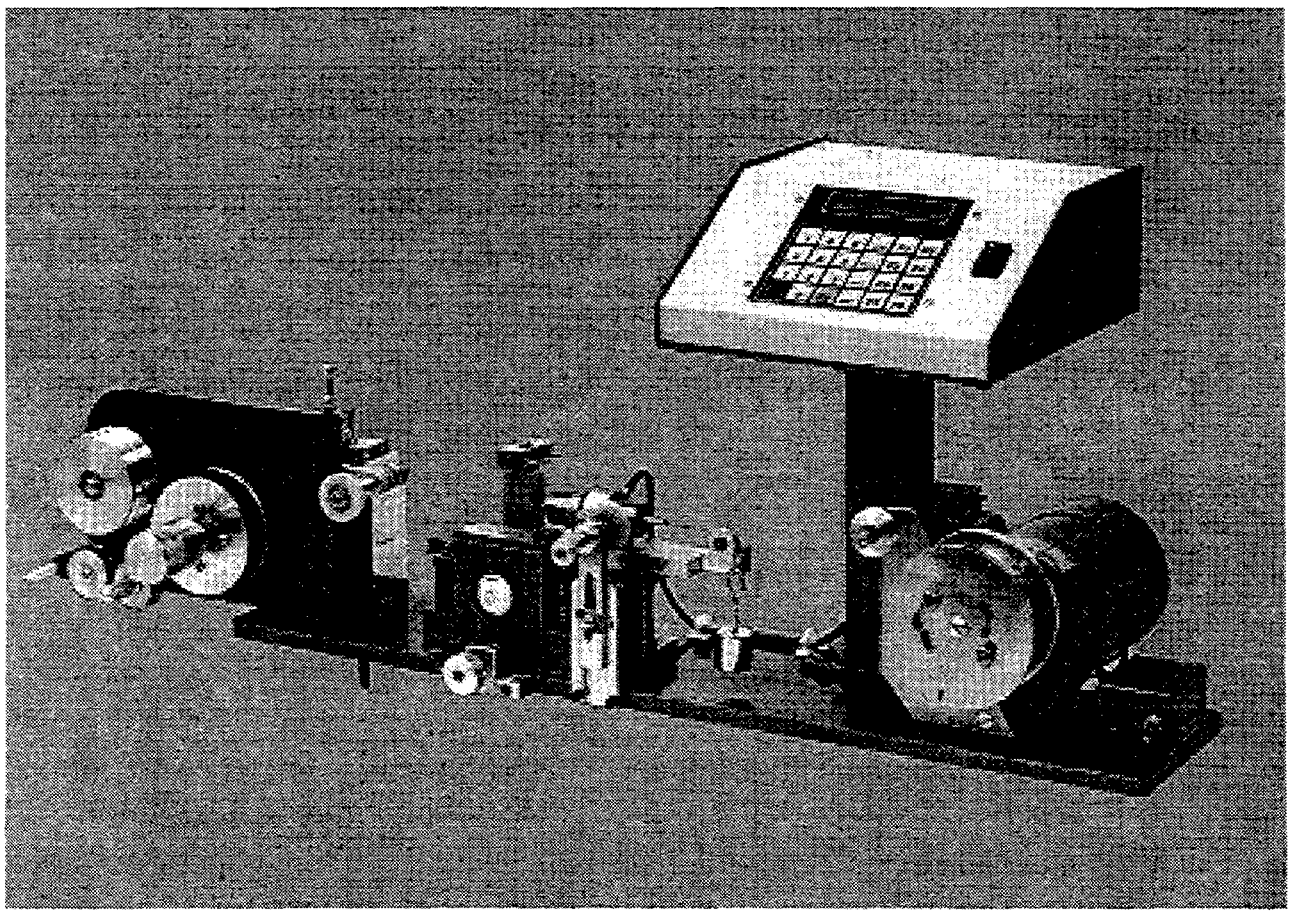


Figure 2-2
TYPICAL COEFFICIENT OF FRICTION TESTER

The test block should be synthetic sapphire and have a surface roughness of not more than 2.4 microns. The sapphires are described and should be mounted in accordance with Figure 2-4 and 2-5.

There should be a means to guide the wire and a means to maintain a slight tension if needed.

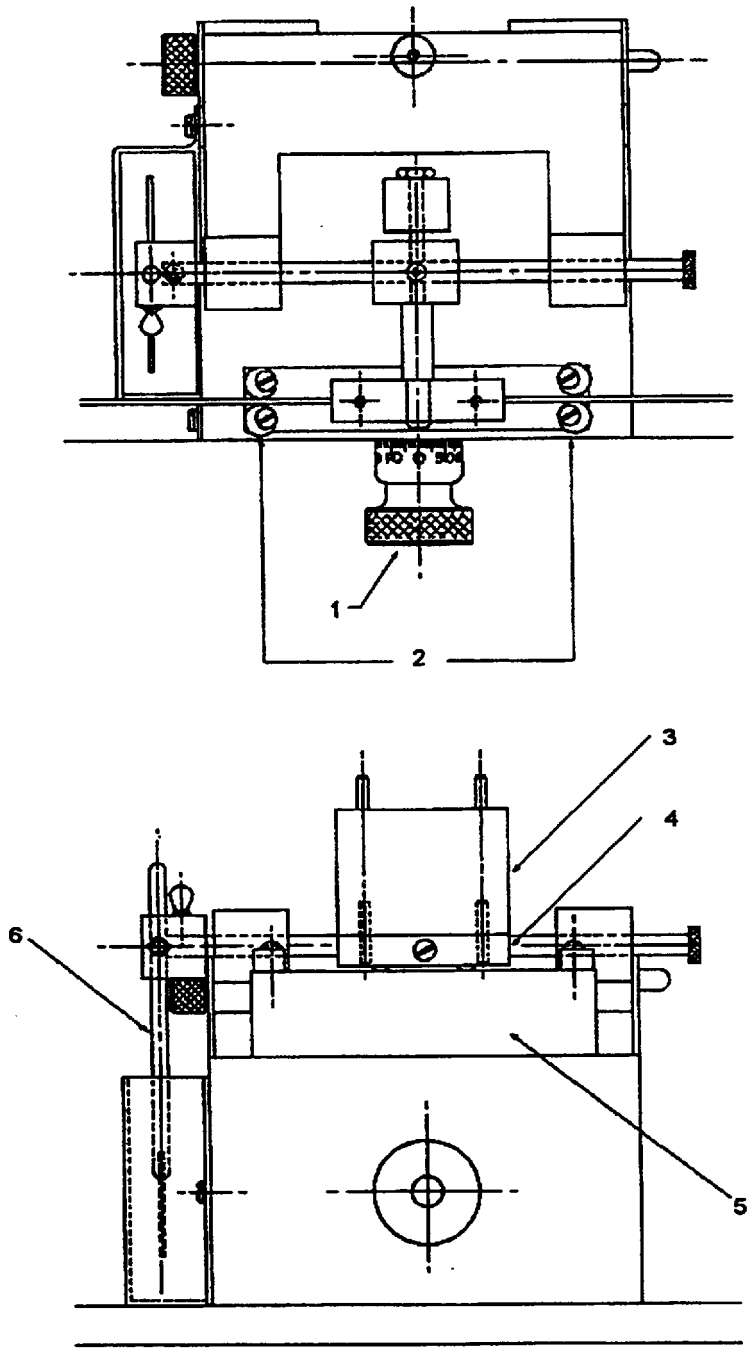
An electrical force measuring device or transducer measures the force due to friction. A force transducer with a range of 0–500 grams-force, a data storage device, and a microprocessor or computer to statistically analyze the data sets should be installed.

A mechanical dampening system consisting of a paddle and a container filled with oil may be used. The electrical signals from the LVDT can also be dampened electronically.

A cleaning solvent appropriate for dissolving the lubricant being tested should be used for cleaning the sapphires and metal surfaces.

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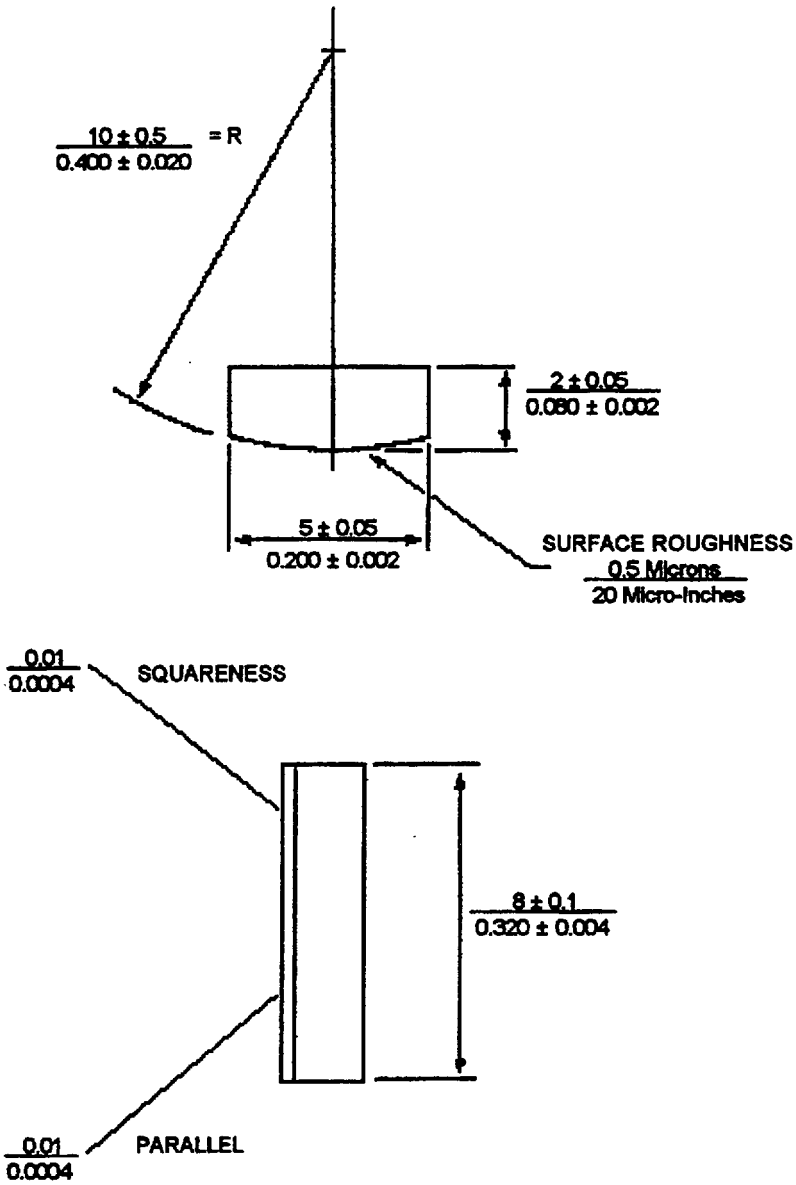


1. Calibrated Adjustment for parallelism between the test load and test bed surfaces.
2. Test Bed Guides
3. Test Weight
4. Load Block - See Figures 2-4 and 2-5
5. Test Bed
6. Dampening System

Figure 2-3
DETAIL DRAWING OF FRICTION HEAD ASSEMBLY

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

Figure 2-4
MATERIAL—SAPPHIRE SYNTHETIC

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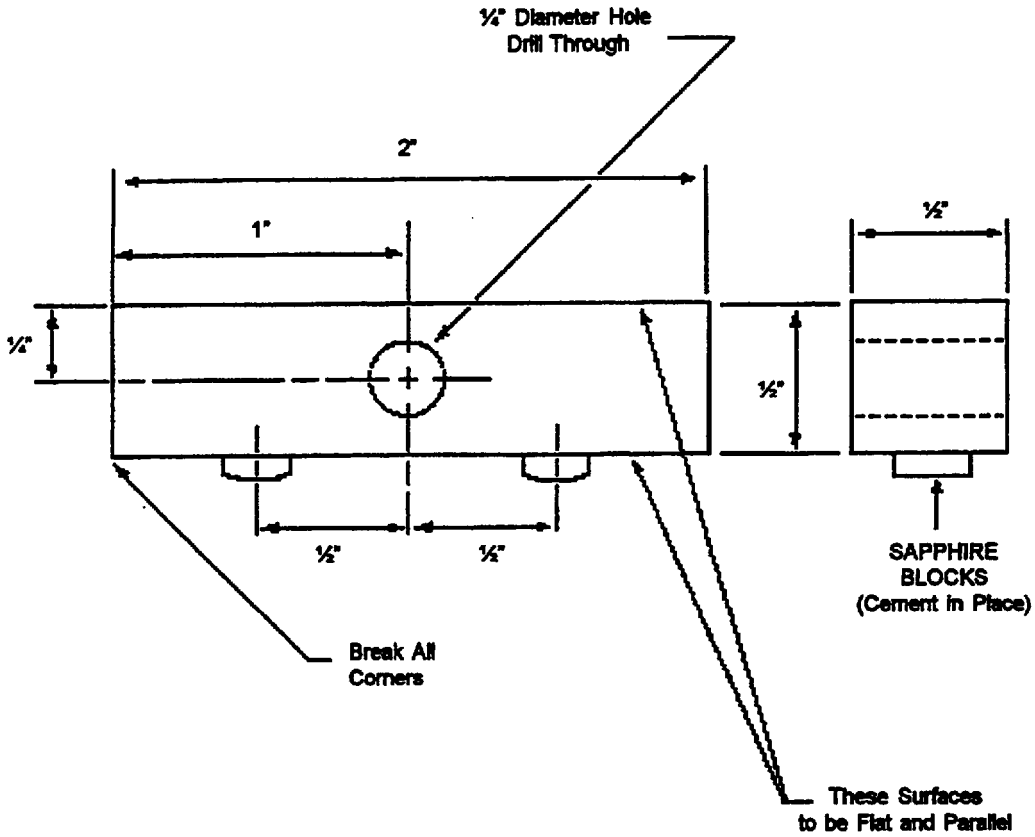


Figure 2-5
LOAD BLOCK

2.6 TEST SPECIMEN

The surface of the wire should be examined for damage, tangles, or excessive dust or dirt. If any of these conditions are present, the top wire specimen layer of the spool should be surfaced off before testing. The wire test specimen should be removed from the shipping package by dereeling over the end flange or pulling the wire from a pail or drum.

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2.7 PROCEDURE

The coefficient of friction tester should be level so that the only force being measured by the pressure transducer is perpendicular to the load being applied and that gravity is not a factor.

Calibrate the pressure transducer by setting the zero without any load, and setting the span by hanging a 100 or 200 gram weight. Remove the weight and the display should again read zero.

Enter the parameters of the test into the microprocessor or personal computer.

Dereel the wire from the sales package by pulling the wire over the flange, through the tensioning device, through the guides, and onto the takeup spindle.

Adjust the guide pulleys so that the wire is parallel with the test bed. Clean the test bed, any guide pulleys, and the sapphire surfaces with a suitable solvent.

Place the appropriate weight onto the load block:

Size Range	Weight (g)
14–24	1000
25–35	600
36–40	200
41–44	100

Adjust the test bed to make the test load parallel with the test surface. Turn the wire take up on and start collecting data after the set up is stable and aligned. Continue collecting data until the desired number of data point have been stored.

Analyze the data for minimum reading, maximum reading, mean value, and standard deviation.

2.8 CALCULATION

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

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

Where:

F = force reading in grams force
L = test load in grams force

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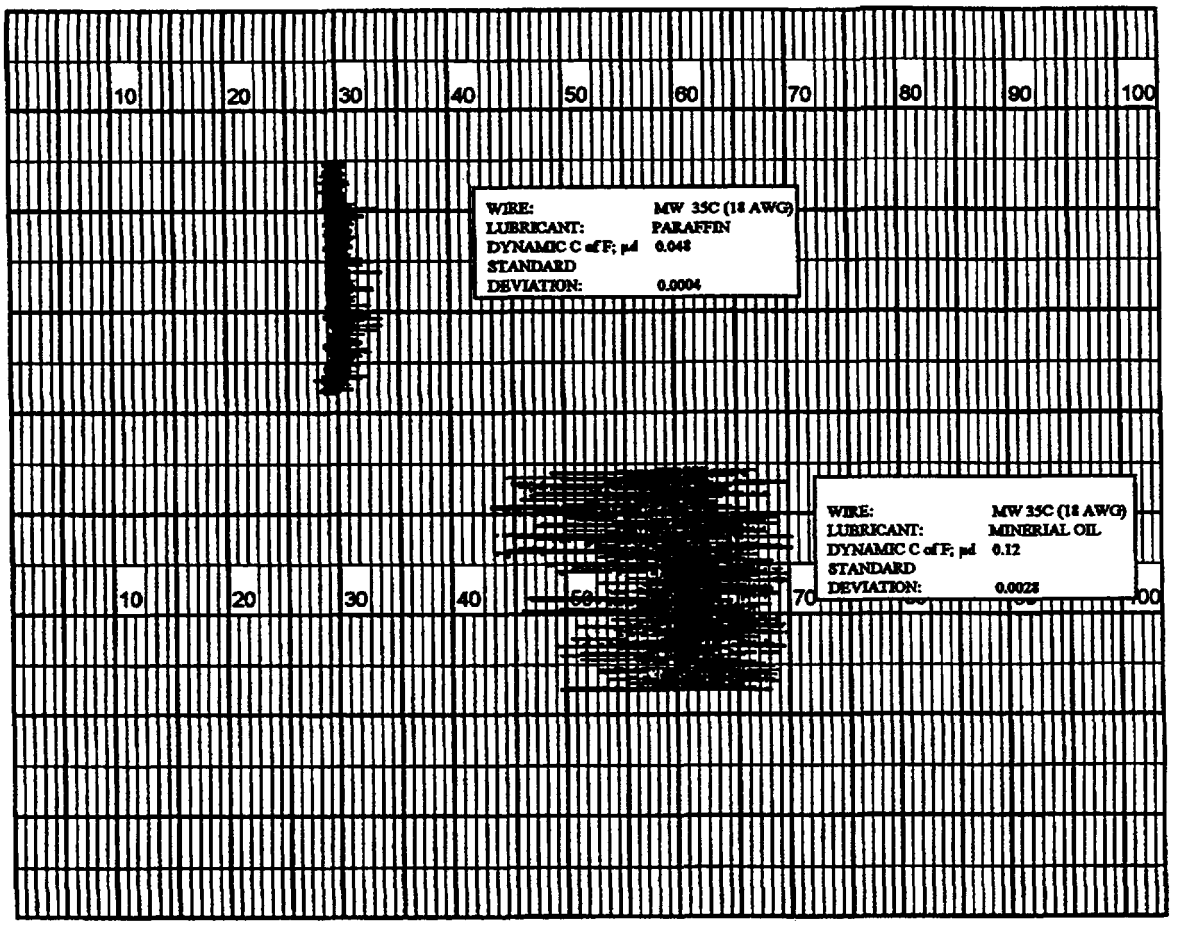


Figure 2-6
ELECTRICAL OUTPUT RECORDING

2.9 REPORT

The test report should include wire specimen identification (size, insulation grade, film type, and type of lubrication), the desired statistical results, the mean, maximum, minimum, and standard deviation of the dynamic coefficient of friction μ_d.

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