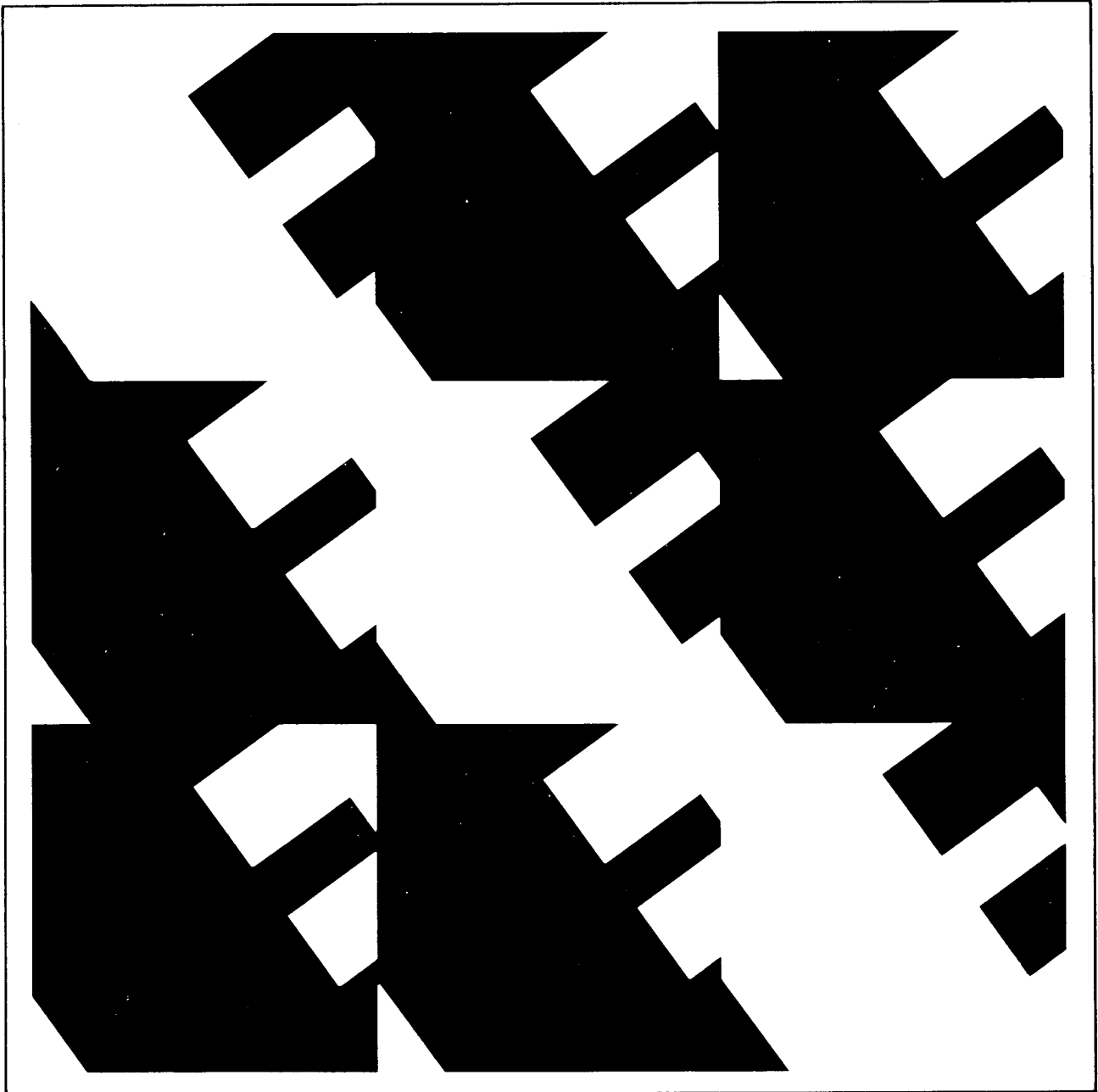


# IEEE Standard Test Procedure for Carbon Brushes



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**IEEE Standard**  
**Test Procedure for Carbon Brushes**

Sponsor

**Rotating Machinery Committee of the  
IEEE Power Engineering Society**

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## Foreword

(This foreword is not a part of IEEE Std 116-1975, IEEE Standard Test Procedure for Carbon Brushes.)

A working group was formed by the Direct Current Machinery Subcommittee of the Rotating Machinery Committee of the IEEE Power Engineering Society to revise and update AIEE Std 508-1958, AIEE Test Code for Carbon Brushes (now IEEE Std 116-1958, IEEE Test Procedure for Carbon Brushes). The purpose of this working group was to delete from AIEE 504-1958 those sections dealing with properties of brush materials and shunt connections, thereby eliminating conflict with ANSI C64.1-1970, Brushes for Electrical Machines (NEMA CB1-1970), and to update the sections dealing with operating characteristics of brushes.

The working group has maintained the principle established in the original version of the test procedure which embodied standard procedures and equipment for making tests while avoiding specifications concerning acceptable test results. It should also be noted that the section on commutating ability, while considerably expanded, still points up the need for further research and development and is therefore not defined as a standard test procedure.

The members of the working group preparing this test procedure were:

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The working group acknowledges its indebtedness to T. J. Ryan, Secretary of the Carbon Section, NEMA, for assisting in its formation and coordinating its efforts with the NEMA Carbon Section and its Technical Committee whose suggestions have been incorporated in this standard.

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# IEEE Standard

## Test Procedure for Carbon Brushes

### 1. Purpose and Scope

It is the purpose of this standard to provide a procedure for determining certain operating characteristics of carbon, carbon-graphite, electrographite, graphite, and metal-graphite brushes under prescribed test conditions for all types of rotating ac and dc motors and similar apparatus. The operating characteristics covered in this standard are: voltage drop, coefficient of friction, wear ratio as affected by low humidity, and commutating ability.

The test procedures for properties of materials and properties of shunt connections are defined in ANSI C64.1-1970, Brushes for Electrical Machines (NEMA CB1-1970). Dimensions, tolerances, and descriptive terminology of brushes for test procedures should conform to ANSI C64.1-1970.

Quantities expressed in parentheses are in the International System of Units (commonly called SI units).

### 2. Effect of Operating Conditions on Brush Performance

Brush performance is influenced by operating and ambient conditions such as spring pressure, current density, brush-face to collector-surface contact, surface film, absolute humidity, ambient temperature, atmospheres, collector material, etc. Because of the many variables involved, it is impractical to establish specific values of performance characteristics or to expect reproducible values under differing application conditions. Since many of the factors involved in testing brushes are not easily controllable (with precision), and since the performance characteristics may vary significantly, the test procedures defined will not give entirely consistent results. To minimize inconsistencies, conditions of test-

ing must be carefully controlled. Brush characteristics are commonly expressed in terms of (1) a measured range of values, (2) minimum or maximum measured values, or (3) relative values which can be classified by words such as "high," "low," "medium," etc.

### 3. Equipment

Tests for coefficient of friction and voltage drop and the effect of humidity are made on the same equipment with the same test brushes. In many cases it will be convenient to make the test simultaneously.

The standard test ring is made of electrolytic copper with a minimum of 99.90 percent purity and has a diameter of 10 in (254 mm) and a width of 3 in (76.2 mm). It shall have 128 evenly spaced axial slots on the surface, each slot being 0.030 in (0.76 mm) wide. The test ring shall be mounted on 2 ball bearing pedestals on a heavy base.

When data is required on ring material other than copper, a substitution for copper may be made. For slip ring investigations, the axial slots may be omitted. Brushes of opposite polarities should be run in different tracks. Where test conditions differ from this procedure, the results should be fully annotated with test conditions.

The assembly shall be driven by a 1 – 2 hp adjustable speed dc motor through a flexible coupling to obtain a steady ring surface speed up to 6000 ft/min (30.5 m/s). A surface speed of 5000 ft/min (25 m/s) is used for the standard tests. Other speeds may be used for special tests.

A total of 4 suitable brush holders shall be used, 2 positive and 2 negative holders being arranged in one track. The positive and negative holders shall be spaced 90° ( $\pi/2$  rad) apart. The radial clearance between brush holder and test ring surface shall be 0.063 in (1.60 mm).

**Table 1**

Brush Material Type	Current Density*		Shunt Cable Size	
	A/in <sup>2</sup>	(A/cm <sup>2</sup> )	Circular mil (mm <sup>2</sup> )	
Carbon (C), carbon-graphite (CG), graphite (G)	40	(6.2)	6475	(3.28)
Electrographite (EG)	75	(11.6)	6475	(3.28)
Metal graphite (less than 50 percent metal)	90	(14.0)	13125	(6.65)
Metal graphite (50 percent or greater metal)	125	(19.4)	13125	(6.65)

\*Values used to standardize the test. Actual application values may vary from those listed.

The holders shall be equipped with springs to allow for variation in brush length without appreciably affecting brush pressure. The holders shall be either rigidly supported or floating, depending on whether the friction is to be measured by electrical or mechanical means. Dimensionally the brush holders shall be suitable for use with the standard test brushes. Spring force shall be capable of providing 4 lbf/in<sup>2</sup> (27.6 kPa) ± 5 percent brush pressure with the standard test brushes. The tolerance on brushes and clearance between brush and holder recommended by ANSI C64.1-1970 should be followed.

The 4 standard test brushes shall be 1.75 in long, 1.00 in wide, and 0.50 in thick (44.5 mm by 25.4 mm by 12.7 mm) with a 30° ( $\pi/6$  rad) top bevel and a zero degree (radial type) bottom bevel. The specimen shall have an extended Type A clip 0.375 in (9.5 mm) wide and measuring 0.81 in (20.6 mm) along the top bevel. A 2.5 in (63.5 mm) long shunt cable sized as listed in Table 1 shall be used.

All equipment shall be housed to provide for operating in clean air.

One brush of each polarity shall be provided with a thermocouple, electrically insulated, placed 0.12 in (3.2 mm) from the contact face, in a hole in the brush. The size of the thermocouple wire shall not affect either the motion or temperature of the brush. Temperature readings shall be taken continuously, or not less than hourly, and the maximum and minimum readings recorded.

## 4. Test Procedure

**4.1 Test for Coefficient of Friction.** The purpose of this test is to determine the coefficient

of friction of a particular grade of carbon brush when sliding on a smooth commutator having a stable film. The coefficient of friction is of importance in the prediction of heat loss caused by brushes sliding on a commutator or ring and in determining the magnitude of friction forces acting in conjunction with applied spring pressure on a brush.

The test is made by mounting the brushes to be tested in brush holders which locate the brushes on the standard rotating copper ring. Brush friction may then be determined from the difference between the driving motor output with the test brushes in contact with the copper ring and with the test brushes lifted, or by using floating brush holders and measuring the tangential force necessary to restrain them from rotating with the copper ring.

The coefficient of friction is subject particularly to wide variation with temperature, current density, humidity, and commutator surface. Consequently, for reproducible results and accuracy in comparing data, it shall be necessary to control these factors carefully.

The test shall be conducted in air free of dust and fumes and at a controlled temperature and relative humidity of 21 to 27°C (294 to 300 K) and 30 to 40 percent, respectively. When equipment for control of humidity is not used, it shall be recognized that the results will be affected. Under all circumstances, wet and dry bulb readings shall be recorded at the location of the tests throughout the operation.

Suitable instrumentation shall be provided to measure power input when required.

To prepare the copper ring for test, the surface shall be ground with a finish grade 180 grit or finer dresser stone and the slots raked clear of copper drag and burrs. The ring shall have a maximum of 0.0005 in (0.013 mm) diametrical eccentricity, as determined with a dial indicator. The test brushes shall be sanded, using 100 grit sandpaper to fit the ring. To

complete the fit, 220 or 240 grit sandpaper shall be used.

Spring force shall be approximately 4 lb<sub>f</sub>/in<sup>2</sup> (27.6 kPa) [2 lb (8.9 N) radial component or 2.3 lb (10.2 N) perpendicular to beveled top of standard 1.75 by 1.00 by 0.50 in (44.5 by 25.4 by 12.7 mm) brush]. The brushes shall be run in for a period of 24 h or until the brushes are fully seated and the friction is constant. The run-in shall be at approximately 5000 ft/min (25 m/s) surface speed with a current density as listed in Table 1. Rotation of the copper ring shall be into the front or short side of the brush. The test shall be run for 48 h at approximately 5000 ft/min (25 m/s) surface speed with a current density as listed in Table 1.

Hourly readings shall be taken of armature voltage and current to the drive motor or friction torque, or both. When the power input method is used, the test brushes shall be raised every 8 h to check no-load input, and the motor speed shall be brought to the same value as that when the brushes are lowered. Without disturbing the brush face or commutator film, the test shall then be repeated for 48 h with no current. The coefficient of friction is the ratio of the tangential force required to restrain the brushes from rotating with the copper ring to the radial force exerted by the brushes on the ring.

When the test equipment permits measurement of friction torque by means of torque arm and scale, the coefficient of friction shall be determined by the following formula:

$$\mu = \frac{wd}{npr \cos \theta}$$

where

- $d$  = length of torque arm or the distance from scale to commutator in inches (millimeters)
- $n$  = number of brushes
- $p$  = average spring force in ounces avoirdupois (newtons) perpendicular to brush clip
- $r$  = radius of commutator in inches (millimeters)
- $\theta$  = angle of brush top bevel in degrees (radians)
- $w$  = scale reading in ounces avoirdupois (newtons).

Alternatively, the coefficient of friction shall be determined from dc motor input by the following formula:

$$\mu = \frac{k[E_l I_l - E_r I_r - (I_l^2 - I_r^2) R]}{nprs}$$

where

- $k$  = 26 when American units are used and 0.184 when SI units are used
- $E$  = voltage of drive motor armature in volts; subscript l indicates test brushes lowered, subscript r indicates test brushes raised
- $I$  = current of drive motor armature in amperes; subscript l indicates test brushes lowered, subscript r indicates test brushes raised
- $R$  = resistance of armature circuit in ohms at operating temperature
- $n$  = number of test brushes
- $p$  = average force in ounces avoirdupois (newtons) perpendicular to brush clip
- $r$  = radius of commutator in inches (meters)
- $s$  = speed in revolutions per second.

In reporting the test results, the average coefficient of friction, as determined by the preceding equation, shall be included with the brush temperature, both with current and without current, and identified by letter code as given in Table 2.

**Table 2**

Coefficient of Friction	Rating Code
0.3 and higher	H: high
0.2 to 0.3	M: medium
0.1 to 0.2	L: low
Less than 0.1	VL: very low

**4.2 Test for Brush Voltage Drop.** The purpose of this test shall be to determine the voltage drop between brushes with the passage of current. Since the same test equipment used in the test for coefficient of friction should be used for determining voltage drop, the two tests may be made together.

A voltmeter having a resistance of 1000 Ω/V or more shall be used for measuring the voltage drop between the positive and negative brushes. The test shall be conducted in air free of dust and fumes and at a controlled temper-

ature and relative humidity of 21 to 27°C (294 to 300 K) and 30 to 40 percent, respectively. The ring and test brushes shall be prepared and run in with the current density given in Table 1.

After checking the spring pressure and readjusting to 4 lb<sub>f</sub>/in<sup>2</sup> (27.6 kPa) if necessary, the test shall be run for 48 h at approximately 5000 ft/min (25 m/s) surface speed with a current density given in Table 1. Hourly readings of voltage drop shall be made. Voltage shall be read from positive to negative brush terminals. In reporting the test results, the average voltage drop, as measured, shall be included with the brush temperature. The voltage drop values shall be identified by letter code as given in Table 3.

**Table 3**

Voltage Drop	Rating Code
2.5 and higher	VH: very high
1.9 to 2.5	H: high
1.3 to 1.9	M: medium
0.7 to 1.3	L: low
Less than 0.7	VL: very low

**4.3 Test for Effect of Low Humidity on Brushes.** The purpose of this test is to determine the effect of low humidity on brushes used for other than aerospace applications. It is a well-known fact that low humidity conditions may cause increased brush wear.

The test consists of 2 parts run with the same set of brushes. Part 1 is run at a test humidity of 30 to 40 percent in a controlled temperature of 21 to 27°C (294 to 300 K). It shall be run in the same manner as that covered by Sections 3, 4.1, and 4.2, but requires additional brush length measurements. It may be convenient to run part 1 simultaneously with tests for coefficient of friction (Section 4.1) and voltage drop (Section 4.2). For part 2, the test is similar with the exception that it is run in air with a -35°C (238 K) dew point.

After the run-in period, the length of each brush shall be measured on its center-line plane at the middle of the brush and 0.12 in (3.1 mm) from each side using a jig with a built-in micrometer which has a spindle with a rounded end of 0.12 in (3.1 mm) radius. At the end of the test, measurements shall be made in a similar manner. The wear for each

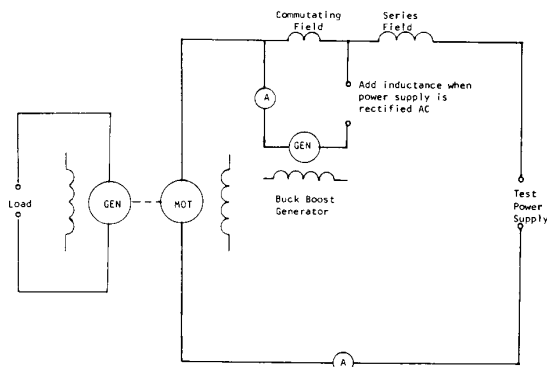
brush shall be the average difference between the 3 initial and 3 final micrometer readings. The rate of brush wear shall be determined by dividing the brush wear by the number of hours the test was run.

For the low humidity conditions, the test results reported will be those specified in Sections 4.1 and 4.2, and in addition, the ratio of the brush wear rate under the higher humidity conditions (part 1) to the wear rate under the low humidity condition (part 2). If it is necessary to use test equipment or test conditions other than those specified here, the results should be fully annotated.

**4.4 Commutating Ability Test.** Commutating ability is a highly important property. Commutation of dc and ac motors is a complex phenomenon, and a basic measurement of commutating ability of a brush is difficult to make. A practical, successful standard test procedure for this property would be helpful; however, no method at present will permit a general ranking of brush grades with respect to this characteristic. The following is offered for purposes of information rather than as a standard test procedure.

It is common practice to arrive at the optimum adjustment of a motor or generator having interpoles by using the "black-band" method [1]. The method is also useful for testing commutating ability of different brush grades. It has not been recognized as a standard procedure due to the difficulty of establishing a test machine with all of its complex design details standardized in full. Furthermore, evaluation of commutation by observing visible arcing introduces the element of judgment by the observer, and this type of evaluation does not lend itself to standardization.

The phenomenon of "resistance commutation" has been suggested as a better indicator of commutating ability than the black-band method. A commutation simulator as a means of simplifying and standardizing the test equipment has been proposed [2]. Application of the principle to practical machines with relatively simple equipment employing a counting technique has been demonstrated in experimental work to equate brush wear to the energy dissipated at the brush-commutator interface [3]. Using this technique, a correlation with calculated arc-



**Fig 1**  
**Black Band Test Arrangement**

ing voltage has been shown [4]. Ultimately, a combination of the above methods could be expected to result in a practical standardized test of commutating ability based on quantitative measurements.

It is possible to make qualitative determinations of the comparative commutating ability of different brushes on a particular machine under controlled conditions utilizing the black-band approach. Fig 1 shows a typical setup. Ideally the test should be performed on the machine for which the brushes are required. The power supply may be dc or filtered or unfiltered rectified ac as required with appropriate instrumentation. Significant tests for the comparative commutating ability of brushes as a function of speed, load, and ripple current (rectified ac) can be readily performed.

To be of practical significance to the user, it is essential that the tests for a given installation be repeatable. Such factors as humidity, temperature, fitting and run-in of the brushes, accuracy of the instruments, and experience of the observer all enter into consideration. For each series of tests a control grade of brush should be selected and tests run to establish repeatability. Thereafter the test method and conditions can be standardized.

It has been found helpful from the standpoint of repeatability to employ as a criterion for the black band a level of visible sparking that will not cause visible damage to the commutator surface or brush face during the period of the test.

In evaluating the effect of ripple currents due to rectified power, care should be taken to exclude ripple from the buck and boost power supply. An inductance of approximately 30 times the inductance of the machine on which the brushes are being tested, placed in series with the buck and boost power supply (Fig 1) will assure that substantially all of the ripple will appear in the interpole field of the test unit. Instrumentation to measure the ripple must also be selected with care and properly applied. Noninductive shunts with the output connected to a good quality laboratory type oscilloscope are recommended. With the exercise of reasonable care, satisfactory results can be obtained for any type of power supply under widely varying conditions of operation.

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