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Standard Test Methods for Measuring Contact Resistance of Electrical Connections (Static Contacts)¹

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1. Scope

1.1 These test methods cover equipment and techniques for measuring the resistance of static electrical connections such as wire terminations or splices, friction connectors, soldered joints, and wrapped-wire connections.

1.2 Measurements under three distinct levels of electrical loading are described. These levels are: (1) dry circuit, (2) standard test current, and (3) rated current. Any one or more of these levels of loading may be required in specific cases.

1.3 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 It is the responsibility of the user to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet for this product/material as provided by the manufacturer.

2. Referenced Document

2.1 ASTM Standard:

E 122 Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process²

3. Terminology

3.1 Definitions:

3.1.1 *bulk resistance*—the resistance a contact assembly would have if it were solid metal of an identical geometry so that the nominal contact area offered zero resistance. When measuring *contact resistance* one attempts to include as little *bulk resistance* as possible in the measurement, by placing measuring probes as close to the contact interface as possible.

3.1.2 *contact resistance*—the total resistance to current flow offered by closed contacts. It is the electrical resistance associated with the junction between two conductors, and is the difference between the measured resistance across a contact junction and the resistance which would be measured if the contact assembly were solid metal of an identical geometry (*bulk resistance*). *Contact resistance* consists of *constriction resistance* and *film resistance*.

3.1.2.1 The term *contact resistance* is often imprecisely used. When *film resistance* is negligible, as it is in many

practical cases, *contact resistance* and *constriction resistance* become numerically equal, and the terms are used interchangeably. A potentially more serious misuse, however, is when *contact resistance* is used to indicate the summation of *constriction resistance*, *film resistance*, and *bulk resistance*. In these cases the *contact resistance* quoted is actually an overall resistance. In some cases the *bulk resistance* can be made a small and negligible portion of the measured values, and the designation of the overall resistance as *contact resistance* is essentially correct. In other cases the sample geometry and test conditions are such that the *bulk resistance* is unavoidably a large portion of the measured value, and the designation of this value as *contact resistance* is incorrect. These test methods require reporting of complete data regarding test conditions and sample geometry such that *bulk resistance* can be calculated or estimated, such that the measurements can reflect accurately the magnitude and variation of *contact resistance*.

3.1.3 *constriction resistance*—that portion of *contact resistance* which arises from the constriction of current flow lines in order to pass through small areas of physical contact at the contact interface.

3.1.4 *dry circuit*—a circuit in which the *open-circuit* voltage is low (20 mV or less). Current is usually low in a *dry circuit*, but a *low-current circuit* is not necessarily a *dry circuit*. When the applied voltage (*open-circuit voltage*) is too low to cause any physical changes in the contact junction, such as break-down of thin insulating films or softening of contact asperities, the circuit is said to be a *dry circuit*.

3.1.5 *film resistance*—that portion of *contact resistance* which results from oxide or contaminate films at contact surfaces that prevent pure metallic contact. Current must flow through thin films of high-resistivity nonmetallic material. Film resistance is important only when little or no metallic contact exists.

3.1.6 *open-circuit voltage*—in contact technology, the steady-state voltage which would appear across the contacts if they were opened.

3.1.7 *static contacts*—electric junctions designed for infrequent separation and connection, and intended to perform their function only when contacting members are stationary relative to each other. This definition includes crimped, welded, brazed, riveted, or soldered joints; friction connections such as pin and socket connectors or taper pins, twisted-wire splices; and connections made with screws, or bolts and nuts between electrical wiring and components. The definition excludes relay contacts, slip rings and commutators, and switches and circuit breakers.

3.2 Descriptions of Terms for Level of Electrical Loading:

3.2.1 *dry circuit*—This method provides for measurement

¹ These test methods are under the jurisdiction of ASTM Committee B-4 on Metallic Materials for Thermostats and for Electrical Resistance, Heating and Contacts and are the direct responsibility of Subcommittee B04.04 on Electrical Contact Materials.

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² *Annual Book of ASTM Standards*, Vol 14.02.

of contact resistance under very low levels of electrical excitation, with applied voltages and currents selected to be too low to cause breakdown of thin oxide films or other contaminants in the contact interface or to cause formation of metallic bridges across the interface where none may otherwise exist. Dry circuit testing is intended to determine whether the test contact will function properly in circuits of arbitrarily low levels of electrical excitation. Dry circuit testing procedures should be used when the possibility of films or contaminants in the contact interface exists or when the test sample is ultimately intended for use in a low-level circuit. This testing must precede other tests on the same samples at high levels of electrical loading.

3.2.2 rated current—The rated current for a static contact device is determined or specified by the vendor or user of the device. The rated current may be large enough to cause significant heating of the test samples. When rated current measurements of contact resistance are required, using either a-c or d-c test currents, the procedures outlined for temperature stabilization in 9.5.3 must be followed.

3.2.3 standard test current—Most contact resistance tests are made with a *standard test current* in the test sample. The standard test current is selected with respect to the physical size and electrical capacity of the test samples, and is chosen in each case to be large enough to allow accurate measurement of resistance, yet small enough that no significant heating of the test sample or its wiring in the test circuits will occur. A standard current of 1 A is satisfactory, except for very small or very large samples. For detailed guidelines for selection of the standard test current, see Section 9.

4. Summary of Test Methods

4.1 The test methods described herein are characterized as four-terminal resistance measuring techniques, wherein a measured and controlled test current is introduced into the sample using two "terminals" or connecting points, and two other points are selected on the sample across which a voltage drop is measured. This voltage drop, divided by the test current, is the effective overall resistance of the sample included between the voltage probes. The voltage-measuring points are chosen so as to measure as closely as possible the voltage drop due only to the contact resistance of the sample and to eliminate from the measurement as much as possible the resistance of the metal pieces comprising the contact and the resistance of the wires and connections used to introduce the test current into the sample.

4.2 Three different levels of test current are specified. The choice of which level to use is governed by the application and requirements of the electrical connection being tested. Electronic signal-circuit connections may require low-level (dry-circuit) testing, whereas power-handling wire connectors should be tested at rated current. General-use connections may be tested at the standard test current of 1 A.

4.3 Either a-c or d-c test currents may be used, with appropriate instrumentation and precautions.

5. Significance and Use

5.1 As stated in 3.1.2, contact resistance is comprised of a constriction resistance and a film resistance. When present, the latter of these is usually much greater in value and dominates the contact resistance. For a given contact spot,

when the film resistance is zero or negligible the contact resistance for that spot is nearly the same as the constriction resistance and therefore, as a practical matter, has a minimum value which represents a clean metal-to-metal contact spot. As real contact surfaces exhibit varying degrees of roughness, real contacts are necessarily composed of many contact spots which are electrically parallel. In practical cases the clean metal-to-metal contact spots will carry most of the current and the total contact resistance is primarily dependent on the size and number of metallic contact spots present (see Note 1). In addition, acceptably low values of contact resistance are often obtained with true areas of contact being significantly less than the apparent contact area. This is the result of having a large number of small contact spots spread out over a relatively large apparent contact area.

NOTE 1—The term metallic contact as used here is intended to include the so called quasi-metallic contact spots as well. The latter case was discussed in *Electric Contacts* by Holm.

5.2 The practical evaluation and comparison of electrical connections depend in large part on their contact resistance characteristics. On the one hand, the absolute value of contact resistance is greatly dependent on the amount of metallic contact established and indicates initially how efficient the system is in producing areas of metallic contact. On the other hand, a comparison of the initial resistance to the resistance after aging indicates how stable the system is in maintaining the initial contact area. Both of these characteristics should be considered when evaluating contact systems. The criteria employed in evaluating contact resistance and stability are not a part of these test methods as they depend on specific applications and therefore, will not be quantitatively stated. However, an estimate of contact resistance³ resulting from good metallic contact can be made for a given physical situation and used as a comparison to actual measurements to determine how effective the system is in establishing stable metallic contact.

6. Interferences

6.1 Measurement of Low Resistance:

6.1.1 Contact resistances are normally very small, ranging from microohms to a few milliohms in cases of practical interest. The measurement of resistance in this range requires special techniques to eliminate effects of thermal potentials, external interference, and resistance of connections and wires leading to the test sample.

6.1.2 The resistance-measuring procedures in these test methods are four-terminal techniques. Test current in the sample is measured and controlled, and made independent of the sample resistance. Voltage-measuring probes are attached to the sample so as to eliminate the effects of connections of the sample into the test circuit, and so as to include as little of the bulk resistance of the sample as possible in the measurement of the contact resistance.

6.1.3 The Wheatstone bridge is not a suitable instrument for contact resistance measurements. Connections to the

³ Calculations and formulae for contact resistance of various types of contacts are covered very thoroughly in Holm's *Electric Contacts*, 4th Edition, Springer-Verlag, New York.

sample contribute part of the measured resistance, and these may be large, unknown, and variable and can completely mask the desired contact resistance of the sample.

6.1.4 The Kelvin double bridge is an extension of the Wheatstone bridge and includes circuitry to eliminate the resistance of connections to the sample from the measurement. The Kelvin bridge is not recommended by these methods, however, for the following reasons:

6.1.4.1 It is difficult to balance properly, and false readings can easily be obtained.

6.1.4.2 Most Kelvin bridge instruments do not measure or control the test current applied to the sample. In contact resistance measurements a knowledge and control of test current is important.

6.2 A-C Versus D-C Measurements:

6.2.1 Either method described herein can be used with a-c or d-c test currents, with appropriate changes in instrumentation to correspond with the power supply. The methods are described as using d-c test currents, and the following comments apply when a-c is used.

6.2.2 Sixty-hertz ac has the advantage that the power supply, which can be a step-down transformer operating from ordinary power lines, is cheap, simple, and readily available in a wide range of output voltages and currents. It is also an easily variable current supply with the use of variable transformers. A-C measurements are of special interest when the test sample is to be used in a-c circuits. A-C measurements eliminate the necessity of reversing current in the sample when taking readings.

6.2.3 The main disadvantage of a-c current is associated with electro-magnetic coupling that can exist between the power-supply circuit and sensitive voltage-measuring instruments. This coupling can lead to false readings, since measurements depend on the physical placement of meters and test leads as well as the current level and the sample resistance. Further, sensitive meters are affected by stray fields in the vicinity due to power-distribution lines, motors, and transformers. It is therefore essential to constantly check the test setup and frequently restandardize the equipment.

6.2.4 Some of this disadvantage is overcome if an a-c supply frequency different from 60 Hz is used. This requires more complicated power-supply equipment. The frequency cannot be too high, as the higher frequency enhances electromagnetic coupling between supply and measuring circuits. If the frequency is too low the measuring equipments (voltmeters) become complicated, and proper linear response with narrow bandpass is difficult to obtain. Frequencies of 20, 40, and 1000 Hz have been used.

6.2.5 A-C measurements of contact resistance sometimes do not agree with d-c measurements, even when adequate precaution has been taken to eliminate coupling and stray fields. There are two main reasons for this: first, the a-c measurement normally measures impedance, not resistance, and includes inductive or capacitive reactance, or both, of the sample. Second, the a-c current can heat the sample and the temperature of the contact spots will follow to some degree the alternations in current magnitude. The average resistance of the sample under such conditions is not the same as the rms meter readings indicate. This effect is especially important when the a-c current and contact resistance are high.

6.2.6 In general, when these methods are used with a-c test currents, more skill is required to make the measurement and interpret the results at the accuracy, reliability, and reproducibility of comparable d-c measurements.

7. Apparatus and Test Circuits

7.1 Figure 1 shows the basic arrangement of contact resistance measuring equipment. The equipment consists of the following elements:

7.1.1 *Power Supply*—For many years the best primary d-c supply was a bank of automotive storage batteries. Batteries provide a stable source for d-c current up to about 30 A which is free of ripple, transients, and other variations normally observed in power-line voltage. Several a-c line-operated d-c power supplies have recently become available which have the desired properties of good voltage regulation and stability, freedom from ripple and line transients, and ability to provide the moderately heavy currents required for contact resistance measurements. These methods recommend either storage batteries or an a-c-operated d-c supply, with the following comments applying to the choice of the latter.

7.1.2 When test currents less than 25 A are used, a filtered power supply is recommended; otherwise ripple voltages may affect the accuracy of ammeter and voltmeter readings. Filtering of rectifier power supplies at heavy currents is impractical or expensive, or both. If a high current (>25 A) is required, three-phase full-wave rectification is recommended.

7.1.3 Good regulation of d-c voltage output is desirable, to avoid drift readings.

7.1.4 Voltmeters and ammeters built into power supplies may or may not meet the requirements of these methods with respect to accuracy or precision. External metering should be used when necessary.

7.1.5 Both output terminals of the d-c supply must be isolated from the power line, the case of the supply, and the building ground. This prevents "ground loops" or undesired connections through ground, between the power supply and other measuring instruments (such as an electronic voltmeter) attached to the sample.

7.1.6 The maximum current required in the power supply can be estimated from Table 1, which gives rated currents for various wire-size terminations according to Military specifications.

7.1.7 The output current of the power supply should be variable and readily and accurately adjustable. Rheostats can be used to control battery supplies, and variable transformers can control the a-c input to rectifier-type supplies. The output voltage of the supply may be low. Six-volt or twelve-volt batteries are suitable, and rectifier supply voltages seldom need to exceed 40 V.

7.2 *D-C Ammeter*—A good d'Arsonval-type ammeter is adequate. It should be a multirange instrument and in each test a range should be selected such that the meter reads in the upper half of its scale. For measuring high test currents (up to 100 A or more) a calibrated shunt and millivolt-meter combination is used.

7.3 *Reversing Switch*—Since millivolt-drop readings across the sample are to be taken with both forward and reverse d-c current, a double-throw switch of