Journal of Electrostatics 88 (2017) 127–133

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

A practical comparison of surface resistance test electrodes

Jeremy Smallwood

Electrostatic Solutions Ltd, 13 Redhill Crescent, Bassett, Southampton, SO16 7BQ, UK

ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form
22 December 2016
Accepted 27 December 2016
Available online 19 January 2017

Keywords:
Surface resistance
Standard measurement electrodes

ABSTRACT

Four surface resistance test electrodes are compared using a selection of materials under similar test conditions. The results vary considerably with some materials due to variation in surface resistivity. Using a relatively uniform material two concentric ring electrodes compliant with the same standard differed in results by a factor of 1.8. Silver stripe and copper tape electrodes gave results a factor 0.4 and 0.7 compared to the reference electrode. A 2-pin electrode gave results a factor 4.7 greater. The 2 pin probe cannot be expected to give similar results to the other electrodes for materials that have variable resistivity.

1. Introduction

Surface resistance test methods are used for a variety of purposes in industry including evaluation of resistive materials for electrostatic ignition risk, qualification of equipment intended for use in potentially explosive atmospheres under European Directive 2014/34/EU (ATEX) [1] and characterization of packaging materials for use in Electrostatic Discharge (ESD) protection in the electronics industry. Several standard test methods exist for these purposes. The general objective of the measurement in each case is to evaluate the electrostatic charge dissipative ability of the material surface, for avoidance of charge build up and subsequent electrostatic discharges. When the resistance between the electrodes is measured, it is typically reported without compensation for the electrode form, as "surface resistance" rather than surface resistivity. This greatly increases convenience, especially for routine and frequent measurements. Related standards (e.g. IEC 61340-5-3 [9] or IEC 60079-0 [8]) then specify materials in terms of surface resistance for material classification and evaluation purposes.

Conductive rubber faced concentric ring electrodes (IEC 61340-2-3 [5,6] and ESD STM 11.11 [2,3]) were developed for compliance verification evaluation of electrostatic discharge (ESD) control materials used in packaging for the electronics industry. IEC 61340-2-3 [5,6] is also specified for general measurements of properties of materials with resistance or resistivity in the range 10^4–10^{12} Ω use in electrostatic control. The concentric ring electrodes typically have an outer ring outer diameter of 63 mm and mass of 2.5 kg. They are suitable for moderate sized flat samples of material, but are unsuited for measurement of small, curved or other non-planar surfaces.

With the development of miniature ESD control packaging products there evolved a need for a miniature surface resistance test method that could also be used on non-planar surfaces or within depressions in moulded products. A miniature point-to-point 2-pin probe electrode (IEC 61340-2-3 [5,6] and ESD STM 11.13 [4]) was developed for this purpose. This consists of two sprung loaded and conductive rubber faced pins 3.2 mm in diameter and separated by 3.2 mm.

In evaluation of materials for electrostatic hazard control materials in processes and ATEX in Europe, a different electrode system has historically been used for many years, e.g. in IEC 60079-0 [8]. This consists of two stripes of conductive paint (e.g. silver paint) 1 mm wide and 10 mm long, separated by a gap of 10 mm. This electrode system has recently been published again in IEC 60079-32-2 [7]. This standard also allows the electrodes to be made from conductive rubber or foam strips mounted on insulating supports.

The standards that refer to these test methods typically specify classifications or requirements in terms of surface resistance measured according to these methods. It is typically the high resistance limits that are of most interest. For example, in IEC 61340-5-3 [9] a material is classified as insulative if the surface resistance measured according to IEC 61340-2-3 [2,3] (2 pin or CR probe) is $\geq 10^{11}$ Ω. An insulative material would, where possible, be excluded from use in an ESD Protected Area. In contrast in IEC 60079-0 [8] requires the surface resistance of enclosures for equipment used within a flammable atmosphere area to be $\leq 10^9$ Ω

E-mail address: jeremys@static-sol.com.

http://dx.doi.org/10.1016/j.elstat.2016.12.019

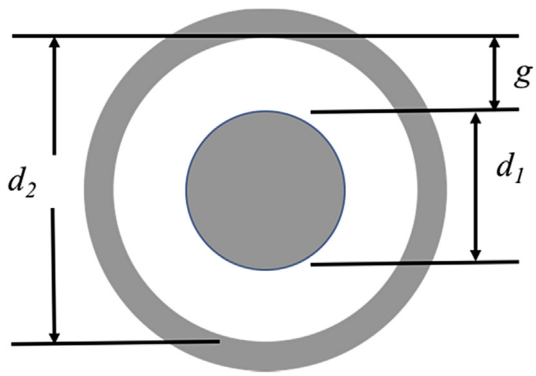

Fig. 1. Concentric ring (CR) electrode.

(@ 50 ± 5% r.h.) or 10^{11} Ω (@ 30 ± 5%r.h.) measured according to the conductive paint stripe electrode method given in the standard. So, it is particularly important that the measurement results are repeatable and reproducible in these resistance ranges.

In theory the surface resistance R_s measured by an electrode system across a surface of uniform surface resistivity ρ_s is of the form

$$R_s = K\rho_s$$

where K is a constant dependent on the electrode surface contact geometry. Any electrode systems having the same K might be expected to give the same results when measuring a material of uniform surface resistivity. For the concentric ring electrode system the value of K is defined differently in different standards. In STM 11.11–2015 [3] surface resistivity is simply quoted as a factor of 10 times the surface resistance, making $K_{CR} = 0.1$.

In IEC 61340-2-3:2000 [5], the relationship between surface resistivity and surface resistance was given as

$$\rho_s = \frac{R_s(d_1 + g)\pi}{g}$$

which leads to

$$K_{CR} = \frac{g}{\pi(d_1 + g)}$$

where d_1 is the diameter of the inner contact electrode and g is the gap between the inner electrode and inside of the outer electrode (IEC 61340-2-3 [5,6]). In practice it is the inner diameter of the outer electrode that is specified instead of the electrode gap. All dimensions are specified in the standards with a tolerance (see Fig. 1).

In STM 11.11–2006 [2] and 61340-2-3:2016 [6] the formula relating R_s and ρ_s is defined as

$$\rho_s = \frac{2\pi R_s}{\log_e \frac{d_2}{d_1}}$$

This leads to

$$K_{CR} = \frac{\log_e\left(d_2/d_1\right)}{2\pi}$$

As the objective of this paper is to directly compare surface resistance measured using different electrodes, conversion to surface resistivity is not required. Clearly, different conversion factors defined in different standards could lead to different values calculated for surface resistivity given the same surface resistance measurement result. In order to avoid this problem in calculating K_{CR}, the formula given in IEC 61340-2-3:2000 [5] is used to compare electrode systems in Table 1. Calculation of K_{CR} according to IEC 61340-2-3:2016 [6] gives only a small difference compared to the IEC 61340-2-3:2000 [5] formula (0.100 compared to 0.096). As the surface resistance values measured with each electrode are compared directly by experiment, differences in results due to different formulae for conversion to surface resistivity are avoided.

For a parallel stripe electrode such as IEC 60079-0 [8] (which is the same as IEC 60079-32-2 [7]) the electrode constant is

$$K_{st} = \frac{g}{l}$$

where l is the length of the stripe and g is the gap between the electrodes, and any fringe effects at the electrode ends are neglected. The dimensions may be in meters or mm (see Fig. 2).

When the electrode tolerances are taken into account, each electrode system gives a range for K that would be expected for electrodes built according to the standards. For the CR electrodes, the minimum K is given for minimum gap, and vice versa. For the stripe electrode the minimum K is given for minimum gap and maximum length, and vice versa. The calculated minimum, nominal and maximum values are given in Table 1. It can be seen that the range of constants for the various standard cells is very similar, ranging from about 0.091 to about 0.106. The approximate variation in measurement result due to this, for a uniform resistivity sample, should be about ±5% for the CR electrode and ±6% for the stripe electrode system.

The electrode configuration for the 2 pin electrode system is shown in Fig. 3. So far the author has not found an equation deriving a constant K for this configuration.

Typical materials and products under test can have variable resistance characteristics across the surface that can lead to differences in results according to the type and scale of the electrode and direction or location of measurement. The concentric ring electrode has infinite rotational symmetry and can be expected to give the same result with all orientations even on an anisotropic material. In contrast a parallel stripe electrode can be expected to give results variable with orientation on an anisotropic material. The concentric ring electrodes are designed for flat surfaces, and typical products measured may have curved or textured surfaces. Some products may have features that are too small to apply large electrode systems. The 2 pin electrode structure allows measurements on small areas or curved surfaces. Conductive rubber faced electrodes are easy to apply, do not affect the surface material and are easily removed leaving no trace after measurement. The IEC 60079-0 [8] painted stripe electrode can conform to a surface curvature or profile but may affect the surface material and could be difficult or impossible to remove after measurement. For this reason, IEC 60079-32-2 [7] allows alternative electrodes of the same geometry. The standard electrode systems therefore have advantages and disadvantages according to the form of the sample under test.

This paper gives a comparison of results and experience of using standard test electrodes on a variety of materials with resistance in the range GΩ to TΩ. In addition, the use of self-adhesive conductive (Cu) tape electrodes is explored. These electrodes have been used in practice by the author for many years. These can conform to moderate surface contours or textures and are often conveniently applied. They normally do not physically affect the surface and can be removed, leaving only a residue of adhesive that can be easily cleaned off if necessary (see Fig. 4).

The objective is to directly compare the electrodes and surface