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A method of charge measurement for contact electrification

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ABSTRACT

A method for studying contact electrification charge between different materials was developed. Physical models for the contact electrification measurement system of metal/metal, metal/insulator and insulator/insulator were proposed, where the relationships between charge and measuring potential were developed. According to the models, an electrification charge measurement system was built. As an example of using the method, contact electrification experiment between polytetrafluoroethylene (PTFE) and carbon steel plates was conducted. Comparison of the charge results by this method and Faraday cup method was made, which suggested that the current method reduced the error resulted from the charge dissipation.

1. Introduction

Contact electrification is a common phenomenon in nature. Although having a long history, research work is still insufficient for fully understanding the mechanisms of electrification. One of the main reasons is the difficulty in accurate measurement of transferred charge due to the tiny amount of the charge and its easy dissipation to environment [1–3].

Faraday cup is one of the commonly used devices for charge measurement, especially in particle electrification [4–7]. The charged samples are put into the cup, and the same magnitude of charge is induced on the cup shields, by measuring the potential difference and the capacitance of the cups, the charge is calculated by their production. However, the error resulted from the charge dissipation during the movement of the samples is unavoidable and the measurement is discontinuous.

Field mills and metallic probes [8,9] could be used to measure the electric fields and the potentials induced by electrification charge. Because of the contact electrification charge, the surface potential of the sample changes and an electric field is generated surrounding the surface. By shifting the position of the probe, surface potential and electric field distribution could be obtained.

Electrometer could also be used to measure the induced charge. An electrode connected to the electrometer is placed above the charged sample. The induced charge on the electrode is supposed to be equal to the charge on the sample. This method is widely used in current electrification charge study. Lowell, Akende and Whitesides [10,11] directly measured the induced charge by putting metallic electrodes above the charged polymer. In Burkett's work [12], electrification charge was calculated based on the measurement of the current which was resulted from the induced charge flow from the electrode to the ground. However, it is doubtful if the induced charge is equal to the contact charge, because the earth capacitance and capacitances between the probe and other materials are unavoidable in the measurement system, which will share the induced charge and introduce the error of measurement.

In this paper, a measurement method of contact electrification charge was developed. The relationship between the total electrification charge and the measured potential was established. Experiment for the contact electrification of PTFE and GCr15 steel was conducted, and the results were compared to that of the Faraday cup method.

2. Physical models of electrification charge measurement

2.1. Contact electrification between a metal and an insulator

A model of electrification charge measurement of a metallic plate and an insulator plate was built. The sketch of the measurement system is shown as in Fig. 1. It is assumed that in the process of contact electrification, electrons transfer from the insulator to the metal, hence the former is positively charged and the latter

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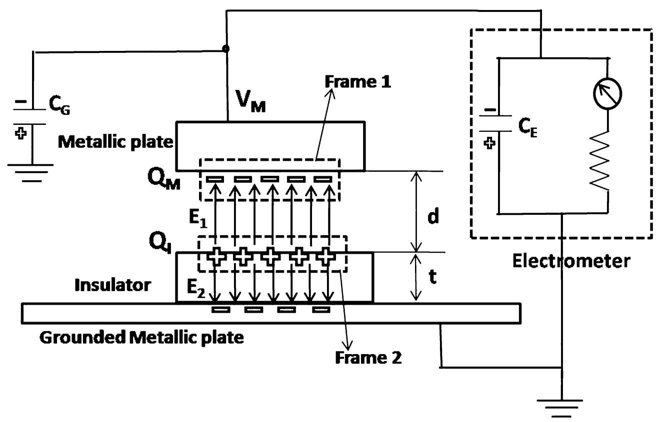

Fig. 1. Sketch of the measurement system for the contact between a metal and an insulator.

negatively. Q_I is the charge on the insulator whose magnitude is equal to the electrification charge. The metallic plate is connected to the electrometer and its electric potential V_M is recorded. A grounded metallic plate is placed beneath an insulator as the zero potential reference.

If the metallic and the insulator plates are put in contact, transferred charge with opposite polarities and equal magnitude will form an electrical double layer whose effect is neutralized. There is no induced charge on the metallic plate and V_M is zero.

When the metallic plate is separated from the insulator, negative electrification charge on metallic plate spreads to the electrometer and the earth capacitance. At the same time, negative charge is induced on the upper surface of the grounded metallic plate. As a consequence, the potential of the metallic plate is changed. By measuring this potential V_M, electrification charge Q_I could be calculated according to the relationship between V_M and Q_I which is described as follows.

In this model, the size of the plane surface of the specimens is supposed to be much larger than the maximum separation distance and the thickness of the insulator plate. So the electric field in the separation gap and within the insulator could be assumed as uniform.

According to the Gauss theory, in frame 1, the charge on the metallic plate Q_M is calculated by:

$$Q_M = \oint \varepsilon E \cdot ds = -\varepsilon_0 E_1 S \tag{1}$$

where E is the intensity of electric field, E_1 is the intensity of the electric field between the metal and the insulator in vacuum, S is the contact area, ε_0 is the vacuum dielectric constant.

In frame 2, the charge on the insulator plate Q_I is calculated by:

$$Q_I = \oint \varepsilon E \cdot ds = \varepsilon_0 E_1 S + \varepsilon_0 \varepsilon_r E_2 S \tag{2}$$

where E_2 is the intensity of electric field in the insulator, and ε_r is the relative dielectric constant of the insulator.

The charge on the electrometer Q_E and the charge on the earth capacitance Q_G are given by:

$$Q_G + Q_E = V_M (C_G + C_E) \tag{3}$$

where C_E is the capacitance of the electrometer and C_G is the earth capacitance.

According to the charge conservation theory, the overall charge in this system is zero, so we have:

$$Q_G + Q_E + Q_I + Q_M = 0 \tag{4}$$

The potential of the metallic plate measured by the electrometer is expressed by:

$$V_M = E_2 t - E_1 d \tag{5}$$

where d is the distance between the bottom surface of the metallic plate and the upper surface of the insulator plate, t is the thickness of the insulator plate.

Combining Eqs. (1)–(5), the contact electrification charge is calculated as follow:

$$Q_I = -V_M \frac{(C_E + C_G)\varepsilon_r d + (C_E + C_G)t + \varepsilon_0 \varepsilon_r S}{\varepsilon_r d} \tag{6}$$

Eq. (6) describes the relationship between the contact electrification charge Q_I and the potential V_M measured by the electrometer. In order to calculate the electrification charge by using Eq. (6), the value of the systematic capacitance $C_E + C_G$ must be firstly determined. By measuring the potential of the metallic specimen, the V_M vs. d curve could be obtained. A series of (V_i, d_i) data are fitted into Eq. (6), and by solving these equations, the constant $C_E + C_G$ could be obtained by the least square method.

2.2. Contact electrification between metals

The sketch of the measurement system for the contact between metals is shown as in Fig. 2. Electrification occurred between two metallic plates M_1 and M_2. An insulator plate is placed beneath M_2 for insulation, and a grounded metallic plate M_3 is placed beneath the insulator plate as the zero potential reference. M_1 is connected to the electrometer and its electric potential V_M is measured.

It is assumed that electrons transfer from M_2 to M_1, so M_1 is charged negatively, and M_2 is charged positively.

According to the Gauss theory, in frame 3, the charge Q_1 on M_1 is given by:

$$Q_1 = \oint \varepsilon_0 E \cdot ds = -\varepsilon_0 E_1 S \tag{7}$$

where E_1 is the electric field intensity between M_1 and M_2 in vacuum, S is the contact area of the metals.

In frame 4, we have:

$$\oint \varepsilon E \cdot ds = Q_1 + Q_{2a} = 0 \tag{8}$$

where Q_{2a} is the charge on the upper surface of M_2.

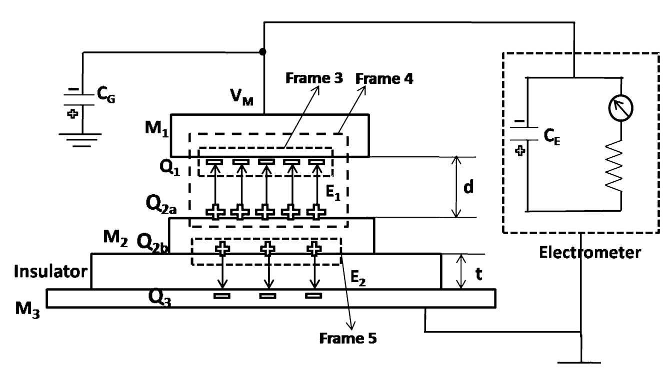

Fig. 2. Sketch of the measurement system for the contact between metals.