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Measurement of electric charge transferred by brush discharge from electrified dielectric or conducting surface – differences and potential source of error

***Abstract**. The paper presents results of computation of electrostatic field distribution on the surface of the metallic ball electrode for measurements of electric charge transferred during provoked electrostatic brush discharges between electrode and electrified dielectric. The electrode consisted from the shielding ball of 30 mm diameter and insulated thin central electrode for charge collecting. It was proved that in the case of distance between electrode and dielectric less than 50 mm, discharge current can obey the central electrode.*

Streszczenie.** W artykule przedstawiono wyniki obliczeń numerycznych rozkładu natężenia pola elektrycznego na kulistej powierzchni ekranowanej sondy do pomiaru ładunku przenoszonego w czasie prowokowanego wyładowania snopiastego między powierzchnią naelektryzowanego dielektryka i sondą. Wykazano, że w przypadku małych odległości (poniżej 50 mm) między typową sondą o średnicy 30 mm i powierzchnią dielektryka, prąd wyładowania może omijać centralnie umieszczoną w sondzie elektrodę pomiarową.* (Pomiar ładunku elektrycznego przenoszonego przez elektrostatyczne wyładowanie snopiaste z naelektryzowanej powierzchni dielektryka lub przewodnika – różnice i potencjalne źródło błędu***).

Keywords: electrostatic charge transfer**,** electrostatic brush discharge, electrified dielectric, electrostatic field distribution
Słowa kluczowe: elektrostatyczne wyładowanie snopiaste, naelektryzowany dielektryk, rozkład natężenia pola elektrostatycznego, przenoszeni ładunku elektrostatycznego.

Introduction

Electrostatic discharges (ESD) create serious hazard of ignition of the explosive atmospheres. About eight to ten percent of all industrial explosions are caused by ESDs. Crucial point of explosion prevention is a comparison of the available discharge energy and the minimum ignition energy (MIE) of the explosive atmosphere. In case of capacitive spark discharges which appear between conducting objects, risk evaluation is based on non-contact measurements of potential difference U and measurement of the electric capacitance C between the objects, and then calculation of the energy stored in the electric field $W = CU^2/2$. Prevention of capacitive spark ESD is achieved by bonding and earthing of conducting objects in the protective zones.

The risk evaluation for the case of brush discharges is more complex. In practice, this kind of ESDs appear between the electrified dielectric surfaces and conducting objects like human body, metallic tools, parts of devices etc. Brush discharges are one electrode and not complete and their energy does not exceed 4 mJ. Therefore they can ignite only the gas explosive atmospheres (mixture of flammable gases and vapours of flammable liquids with air). The process of evaluation of their incendivity is difficult because there are no practical methods of measurement of the stored energy. Additionally, as it is not complete discharge, only a small and unknown part of energy is released during discharge. Therefore, currently more popular becomes the method based on the measurement of the electric charge transferred to the earth during the brush disharge which is provoked by a special kind of electrode [1].

The basic obstacle at such measurements is appearing of two parts of measured current during approaching the electrified surface by the probe: real part (electron and ion current in the air), and imaginary part (current induced in the probe moving towards the electrified surface by electrostatic induction). It causes usually significant measurement errors [2, 3, 4, and 5]. Only the real part can be incendive, so both parts of current should be separated. For that the shielding of discharge electrode is applied, as was shown in Fig. 1. The electrode connected to charge meter (Q in Fig. 1) is shielded by the metallic earthed ball. The imaginary part of the current is almost whole directed to the ground and real discharge current part is directed from discharge electrode to the charge meter. The metallic ball has the other function also; it forces the electric field distribution necessary to provoke only brush discharge during approaching the electrified dielectric. For this reason the diameter of the ball cannot be smaller than 5 mm and greater than 50 mm [e.g. 5]. The typical value which is used in practice is about 30 mm.

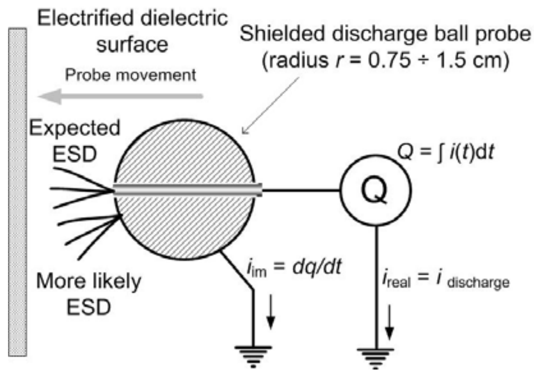

Fig. 1. Circuit with shielded measurement electrode for provoking brush discharges. Brush discharge is achieved by the appropriate choice of diameter of the shielding ball.

The idea of such shielded probes is based on assumption that during approaching electrified surface a brush discharge begin at the central measurement electrode insulated from shielding ball and connected to the coulomb meter (see Fig. 1). The ESD which begins from the surface of the ball cannot be measure. In the paper, on the basis of computational simulation, there was proved that the last case is more likely for electrified dielectric objects, and first case is typical for electrified conducting objects.

Methods

There was put the basic assumption that the brush ESD begins on the surface of metallic ball surface at the point where the electric field intensity is the highest. The source of the field was the dielectric disc (diameter – 250 mm, thickness – 2 mm, relative permittivity – 2) or the metallic disc of the same size, both placed horizontally. The applied software did not allow introducing surface charge density parameter, so there was necessary to distribute the charge in the whole dielectric volume homogenously. The metallic ball of diameter 30 mm (imitating electrode) was fixed above the centre of electrified disc, on the height H. The electric potential of the ball was zero (earthed electrode). To complete the boundary conditions, the analysed space was bounded by the cube 1.2x1.2x1.2 m with the electric potential of the walls equals to zero.

The computations of the electric field intensity on the surface of the ball were made with Finite Element Method with the software OPERA/TOSCA ver. 8.70 of Vector Fields Co. The maximum element size at the ball surface was 2 mm and at the boundary surface – 0.1 m. The analysed geometry was shown in Fig. 2. Due to cylindrical symmetry of the system, there was enough to compute the field intensity along the half-circle line (thicker part of the circle in Fig. 2). The results of computation in the form of function $E(\alpha)$ was shown in the next chapter.

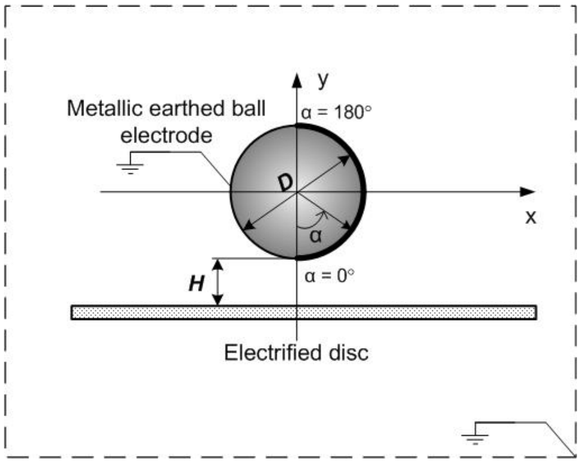

Fig. 2. Geometry of the system to be computed

Results

The computation were made for two general cases – for electrified dielectric disc and electrified (forced steady electric potential) metallic disc, for different values of distance H between disc and ball (see Fig. 2).

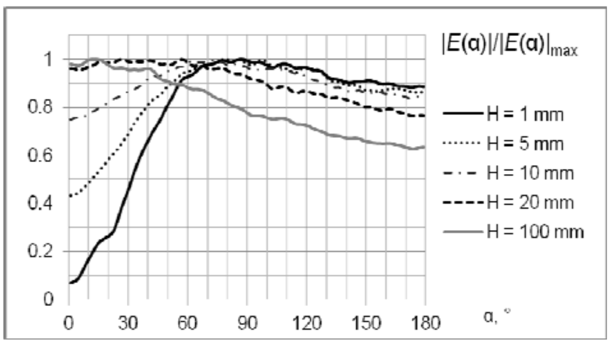

Fig. 3. Electric field intensity distribution on the surface of the conducting earthed ball, placed over the electrified dielectric. The angle zero corresponds to the bottom point of the ball, the nearest to the disc

The results were presented (Fig. 3, Fig 4) in the form of relative functions:

(1) $|E(H, \alpha)|/ |E(H, \alpha)|_{max}$

Discussion and conclusions

Conducted simulation proved that the maximum value of the field intensity on the surface of the conducting ball can be far aside the point nearest to the electrified dielectric. In 3-D space the maximum field intensity is located on the circle on the surface of the shielding ball, as it was shown in Fig. 5. The angle between the distance o any point on that circle to the ball centre and the vertical axis y is equal to α_c (Fig. 5). This is a critical value of angle because for the values smaller then α_c discharge cannot appear. The critical value of the angle α corresponds to the value $|E(H, \alpha)|/ |E(H, \alpha)|_{max} = 1$ (Fig. 3) directly. In case of conducting electrified disc, as it was expected, the point of the maximum file intensity is identical with point nearest to the plate.

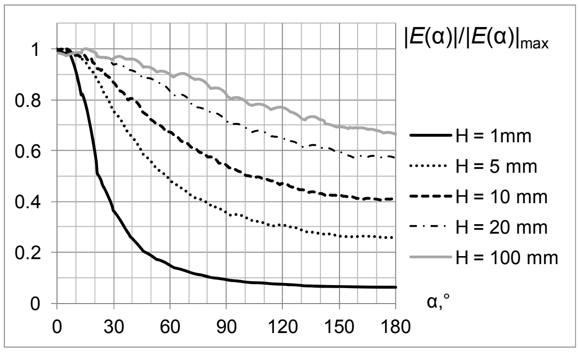

Fig. 4. Electric field intensity distribution on the surface of the conducting earthed ball, placed over the electrified metallic disc. The angle zero corresponds to the bottom point of the ball, the nearest to the disc

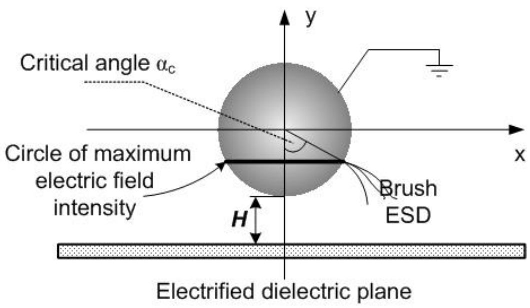

Fig. 5. Definition of critical angle α_c

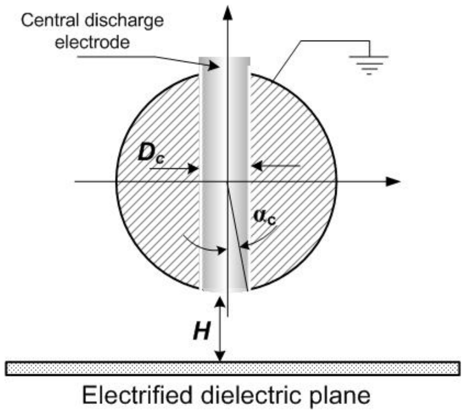

Fig. 6. The dependance of the minimal criticla vdiamer of the central dischrge electrod on the criticla value of angle α_c

From that it results the demanded minimum diameter D_c of the central discharge electrode (Fig. 6). If this diameter is smaller than D_c the discharge current flows directly to the shielding ball but not to the coulomb-meter.

The relation between the minimum (critical) electrode diameter D_c and diameter of the shielding ball D is:

$$D_c = D \sin(\alpha_c) \tag{2}$$

The dependence of the critical angle and minimum electrode diameter for diameter of the shielding ball D = 30 mm on the distance between the ball and electrified dielectric was shown in Fig. 7. From the Figs. 3. and 4. results conclusion that if the distance H is graeter, the critical angle is smaller and the situation is more similar to the case of electrified metalic disc.

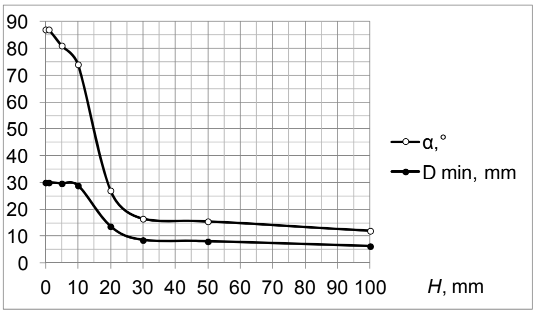

Fig. 7. Relation between the critical angle and minimum electrode diameter D_{min} and the distance between the ball electrode and electrified dielectric flat object

In practice the distance H is the distance at which the electrode approaching the electrified object provokes the brush discharge. Therefore the value of distance H depends directly on the surface charge density on the dielectric object. So for high charge density the distance H can be enough to force ESD to form on the surface of the central measurement electrode and to direct whole real part of discharge current to the coulomb-meter. The smaller is the surface charge density, the smaller has to be the distance H to provoke the brush discharge but also increases the probability that the discharge current flows to the shielding ball but not to the coulomb-meter. It can be the reason of neglecting the hazardous risk of ignition (e.g. problems noticed in [7]). To avoid such errors the central electrode should to protrude over the ball surface. The further detailed computations should be aimed at the answer how much the central electrode could protrude.

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