Zygmunt GRABARCZYK

Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy

Electrostatic potential of surface charge – error of the measurements made with electrostatic field mill voltmeter

Streszczenie. *W artykule przedstawiono numeryczną analizę błędu pomiaru potencjału ładunku elektrostatycznego na powierzchni płaskiego, cienkiego dielektryka, wykonywanego bezkontaktowym, młynkowym miernikiem strumienia indukcji elektrycznej, przeskalowanego przy użyciu rozległej, płaskiej elektrody metalowej o zadanym potencjale elektrycznym względem uziemionego miernika. Wykazano, że taki pomiar, stosowany w przeciwwybuchowej ochronie antystatycznej, może być obarczony błędem ujemnym rzędu 45 – 55 %. (**Błąd pomiaru potencjału ładunku powierzchniowego, wykonanego bezkontaktowym woltomierzem młynkowym).***

Abstract. *This paper presents numerical analysis of the error of the measurement of the electric potential of electrostatic surface charge distributed on the thin dielectric plane. The virtual measurement was made with the field mill voltmeter, calibrated with metallic plate which electric potential was established in respect to the earthed filed mill voltmeter.*

Słowa kluczowe: błąd pomiaru, elektryczność statyczna, potencjał elektrostatyczny, miernik młynkowy natężenia pola.
Keywords: measurement error, static electricity, electrostatics potential, field mill meter.

Introduction

Electrostatic discharges (ESD) in the hazardous area were assumed to cause about 8.5 – 10% accidents of explosions/fires of explosive atmospheres (EX) [1,2,3]. Currently, on the territory of EU, the risk assessment of the EX ignition, was obligatory, also by ESDs.

The EX ignition risk assessment is a process of comparison the measured values of some physical quantities to their critical values, established by technical standards (e.g. [4]), or by the state regulations. There can be distinguished two groups of analysed physical quantities – related to the environmental and material properties and to the accumulated energy of electric field around the electrostatic (ES) charge. The first group covers resistance parameters as leakage to the ground, volume or surface resistance or resistivity materials and objects. The values of those parameters are crucial if the object dissipates or accumulates the ES charge. The second group covers ES charge, ES field intensity, ES potential, energy stored in the ES field. The values of those parameters are used for evaluation the probability of the ESD appearance and, if so, the probability of ignition of the EX being analysed. One of those quantities is ES potential of the ES charge. As the value of the ES charge is always limited (the lack of continuous supplying, opposite to DC suppliers), the properly carried on measurement of the charge or potential shouldn't cause the significant decrease of the charge. In practice, that condition follow only the non-contact meters, which applied the phenomenon of electrostatic induction. The most commonly used is a field mill, based on measuring of the ES field intensity and usually calibrated in ES potential values. In field mill there are two sets of electrodes. The first set is the grounded and rotating, the second is motionless, of which every second electrode is connected to the AC amplifier, and others are grounded. Rotating electrodes, periodically cut off the ES filed at sensing electrodes, and generating the AC current flow through the AC amplifier input. This principle and example of mill were shown at Fig. 1.

The risk assessment of the ignition of explosive atmospheres (EX) by electrostatic discharges (ESD) needs including brush discharges from the electrified dielectric or insulated metallic surfaces. Usually the measurement of surface charge potential or electrostatic field intensity at that surface is the basic tool. To avoid any contact of the meter with charged object (to prevent fast discharge the object through the meter), non-contact methods are used.

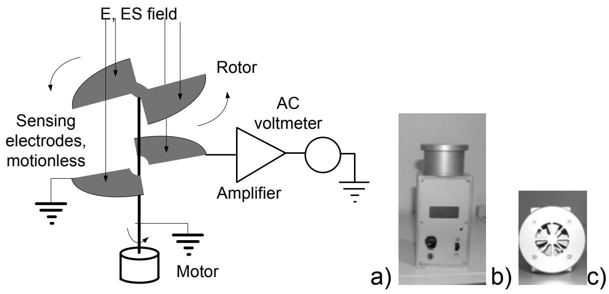

Fig. 1. The principle of the work of field mill a), mill meter by Central Institute for Labour Protection – National Research Institute (Poland) b), and c)

To measure the ES potential of the charge distributed on the flat metallic or dielectric plane, the mill is placed over the plane, with aperture directed to the plane and parallel to it (see Fig. 2). The indication of the meter is proportional to the electric flux through the aperture. The meter can be calibrated for electric field intensity, or (more often) for electric potential. To calibrate or measure the ES potential, the distance between the aperture and plane always has to be the same. Usually, that distance is fixed at 10 cm (e.g. Static Monitor, product of John Chubb Instrumentation, GB).

Typical method of calibration of the mill voltmeter was shown at Fig. 2.

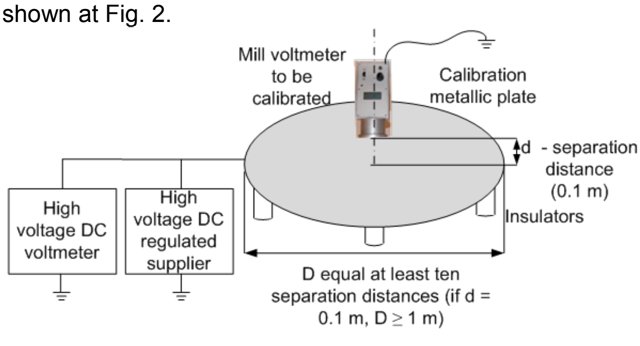

Fig. 2. Arrangement of the setup for calibration of a proximity field mill voltmeter, with accordance to BS 7506:Part 2: 1996 – Methods for measurements in Electrostatics.

The mill was earthed and the metallic plane was supplied with DC voltage from regulated supplier. While applying such method, the question appears, if this meter can indicate properly the potential of the surface charge distributed on the dielectric plane, as it is usually used. In the case of dielectric, surface charge distribution is constant during the measurement of potential, because of the extremely low charge carriers mobility. The approaching meter does not influence the charge distribution on dielectric surface. In case of the metallic plate, also during calibration procedure, approaching the plate by the meter causes significant change of charge distribution. To evaluate that potential source of measurement error, the numerical simulation of the measurement and calibration processes were carried out.

Numerical simulation

The solver Tosca of software OPERA v. 8.7 (product of Vector Fields, GB) was used to solve Laplace's and Poisson's problems. There was no possibility to force surface charge density, but only the volume one, so to simulate the surface charge the author applied thin (g = 2 mm) dielectric (relative permittivity ε_r = 2, typical for polymers) plane with homogenous net charge distribution. The geometry of the meter model is cylindrical, 150 mm long and 50 mm diameter. The applied aperture was a circle of diameter 30 mm (like at static monitor of JCI).
The results of measurement and computation could be significantly influence by all the nearby placed object, especially conducting. For that, the measured material and meter were placed inside the room model of cylindrical shape (see Fig. 3). The height of the room was fixed 4 m, and the diameter - 4 m. The floor, ceiling and walls of the room were earthed.

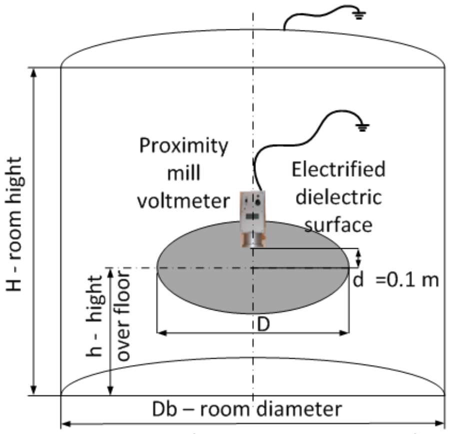

Fig. 3. Model arrangement of the measurements of electrostatic potential of the electrified dielectric surface. Grounded voltmeter and the dielectric sample are tightly surrounded by grounded conducting cylinder which imitates the room.

Simulation of the calibration of the field mill voltmeter
The computations were made for geometry shown at Fig. 3. The potential of the meter was equal to zero, and potential of the metallic plate was U = 1000 V. The distance between the aperture and metallic plate was d = 0.10 m. At such initial conditions the field and potential distribution were computed, and next, the electric flux F, through the aperture was calculated, as follows:

(1) $$F(U)=\iint_{S_a}\varepsilon_0 E_n(U)ds_a$$

where $F(U)$ was the value of the flux at the plate voltage U, E_n was the component of electrostatic field, normal to the aperture of the mill, S_a was the area of the aperture, ε_0 was a permittivity of the air.
From that formula, the calibration constant K_c was derived as follows:

(2) $$U_V(U)=K_cF(U)$$

where U was a fixed voltage of the metallic plane (here U = 1000 V), $U_V(U)$ was the indication of the mill voltmeter at a voltage of the metallic plane U = 1000 V.

Measurements simulation
The metallic plane was replaced by dielectric plate of thickness d = 2 mm, and with homogenous net volume charge density, as shown in Fig. 3. The series of computations of the electric potential of the surface charge on the plane were made, where the dielectric plane diameter and height above the floor were changed. The potential was computed for the virtual voltmeter moved out of the room. Next the virtual mill voltmeter was positioned at d = 0.10 m above the centre of the dielectric plane and the electric flux through its aperture was computed. Then the relative error of the virtual measurement was calculated as follows:

(3) $$\delta(x)=\frac{U_V(\phi(x))-\phi(x)}{\phi(x)}=\frac{K_cF(\phi(x))-\phi(x)}{\phi(x)}$$

where $\varphi(x)$ was the ES potential of the charge, at the surface of dielectric, averaged over the area equal to the area of the voltmeter aperture, x was the function of the size and position of the dielectric plane.

Results

The calculated relative error of the virtual measurement of the electric potential of the charged dielectric plane, as a function of the dielectric plane diameter and height above the floor was shown at Fig. 4.
The error of virtual voltmeter calibration was assumed to be zero. The applied space resolution at the voltmeter aperture was 1x1 mm.

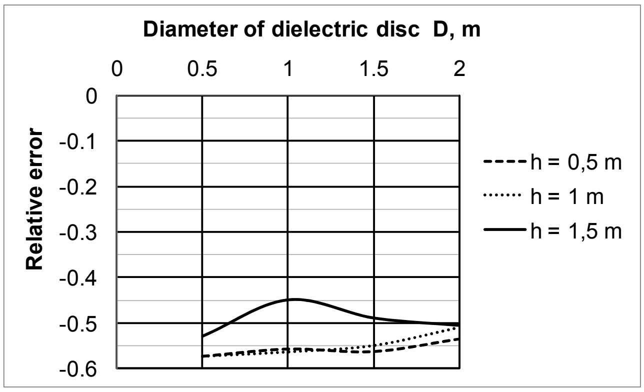

Fig. 4. The error δ of measurement electrostatic potential of electrified dielectric disc with non-contact electrostatic mill voltmeter. D – disc diameter, h – height of the upper disc surface over the floor. Disc thickness – 2 mm, surface charge density – 88.5 μC/m^2, room diameter Db = 4 m, room height H = 4 m

Discussion and Conclusions

In the paper there were not analysed the another more complex geometries of the industrial space, where the influence of the nearby conducting objects might cause the increase of the measurement error. The obtained results confirmed that the use of the field mill voltmeter for the measurement of electrostatic charge potential of spread dielectric materials would not be reliable for ESD risk assessment. That instrument could be used only in the case of insulated conducting objects.

Acknowledgments *This paper has been based on the results of a research task carried out within the scope of the second stage of the National Programme "Improvement of safety and working conditions" partly supported in 2011–2013 — within the scope of research and development — by the Ministry of Science and Higher Education/National Centre for Research and Development. The Central Institute for Labour Protection – National Research Institute is the Programme's main co-ordinator.*

REFERENCES

[1] BIA-Report: „*Dokumentation Staubexplosionen. Analyse und Einzelfalldarstellung*", HVBG, Sankt Augustin, 11/97, 1997
[2] Jones, T., B., King, J., L., *Powder handling and electrostatics*. Chelsea, Michigan, Lewis Publishers, 1991
[3] Kondej, D., Gawęda, E. 2006, Wybuchowość pyłów metali na przykładzie pyłów aluminium. *Bezpieczeństwo Pracy. Teoria Praktyka*. 10 (421), CIOP-PIB, 12-15 (in Polish)
[4] DIRECTIVE 1999/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (15th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)
[5] PN-92/E-05201: Elektryczność statyczna w procesach i operacjach technologicznych. Identyfikacja, ocena i likwidacja zagrożeń. (Polish Standard, Static electricity In technological processes and operations. Identification, assessment and liquidation of hazards)

***Author**: dr eng. Zygmunt Grabarczyk, Central Institute for Labour Protection – National Research Institute, Czerniakowska 16 str. 00-701 Warszawa, zygra@ciop.pl*