Zygmunt GRABARCZYK

Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy

doi:10.15199/48.2016.12.11

Electrostatic discharges at working posts – evaluation of possibility of their investigating with photographic methods

Streszczenie. *W artykule przedstawiono rodzaje wyładowań elektrostatycznych spotykanych na stanowiskach pracy oraz powodowane przez nie zagrożenia. Autor zaproponował zastosowanie do badania właściwości wyładowań metody fotograficzne z użyciem cyfrowych aparatów fotograficznych i ultraszybkich kamer CMOS. Na przykładzie badania wyładowania snopiastego rozprzestrzeniającego się i wyładowania snopiastego omówiono podstawowe zalety i ograniczenia tej metody*

Abstract*. In the paper there were listed kinds of electrostatic discharges met at the working posts and the hazards caused by those discharges. Author proposed the use for investigating the characteristics of discharges the photographic methods, applying classic digital cameras and ultra fast CMOS cameras. On the basis of the example of investigating of propagating brush discharge and brush discharge the advantages and limits of the method were discussed.* (***Wyładowania elektrostatyczne na stanowiskach pracy – ocena możliwości ich badania metodami fotograficznymi***).

Słowa kluczowe: wyładowania elektrostatyczne, zagrożenia elektrostatyczne, wyładowania snopiaste, ultraszybka kamera, fotografia.
Keywords: electrostatic discharges, electrostatic hazards, brush discharges, ultrafast shutter camera, photography.

Introduction

The electrostatic discharge (ESD) is a pulse of electrical current in the air, between two objects at high enough difference of potentials and the source of which is the electrostatic charge. ESD duration is short (several nanoseconds up to few hundred microseconds) because of the limited value of locally available electrostatic charge. In the area of occupational safety, there were distinguished a few kinds of ESDs:

1) corona – between conducting sharp point or edge (surface curvature diameter less than 5 mm) and the other conducting object or electrified dielectric (solid or liquid) if the potentials difference is at least a few kilovolts. Its energy is less than 0.1 mJ. Probably positive streamers are able to ignite very sensitive atmospheres (e.g. with hydrogen or carbon disulphide) [1].

2) brush discharge – exist two variants – between two conducting objects of different potential or conducting object and electrified dielectric (solid or liquid) at the potential difference at least several kilovolts. The diameter of the curvature of the surface of the smaller electrode should range from 5 up to 50 mm. It can ignite explosive atmospheres containing flammable gases or vapours of flammable liquids. Its energy doesn't exceed 3.5 mJ.

3) cone discharge – along the surface of the cone of bulk material in silo or in big container. Energy of it can be up to 20 mJ. It ignites flammable gases and vapours and only some powders.

4) capacitive spark discharge – only between conducting objects (including human body), difference of potentials is higher than 330 V [2]. Its energy can achieve a few joules. It is able to ignite almost all explosive atmospheres. This discharge is complete one.

5) propagating brush discharges (PBD) – from the surface of electrified dielectric sheet covering the conducting object to the other conducting object approaching the sheet or breaking across the bilaterally charged sheet. It could happen if dielectric sheet is not thicker than 10 mm and surface charge density [3] extend 0.25 mC/m^2. This is the most powerful ESD, up to several joules, able to ignite all explosive atmospheres, including powders. It couldn't appear if the dielectric sheet strength is lowest than 4 kV.

Electrostatic hazards

There are two kinds of recognized most serious electrostatic hazards, which would be caused by ESDs. There ignition of explosive atmospheres (EX) and electrostatic shocks. Risk of ignition depends on ESD energy and minimum ignition energy (MIE) of the explosive atmosphere. There is luck of the substantial global statistics of the accidents caused by ESDs. According to report [4], based on the analysis of about 600 explosions of powders, about 8.5 % of them were initiated ESDs. In the case of gaseous atmospheres, probably about 10% of explosion originated from ESDs. To ignite EX there should be cumulated so amount of electrostatic charge, to raise at least locally the ES field intensity up to about 2.7 MV/m.

The strongly electrified dielectrics could cause almost all listed above kind of ESD with exception of sparks. But the field generated by the dielectrics can electrify by induction the insulated from the earth conducting objects (e.g. human body) and indirectly cause sparks ESD also. There was a popular opinion that corona discharges are rather safe and their energies are too small to cause an explosion. But in the author opinion the positive corona streamers [1] could ignite the mixture of hydrogen (MIE=0,017 mJ) or carbon disulphide (MIE=0,006 mJ) with the air. As mentioned earlier, charged dielectric objects can generate electrostatic brush discharges. In their nature they are somewhat different than sparks. As spark is the one plasma channel connecting both electrode, usually well visible, but brushes start at the conductive electrode surface and usually finish in the space between dielectric and the electrode. What more, there are possible multiple plasma streamers, during approaching movement of the electrode towards the dielectric.

Electrostatic shocks could be defined as perceptible electrostatic discharges current pulse through the body. Theirs perception threshold is about 0.1 – 2 mJ, and above 10 mJ they could cause pain and uncontrolled body movements, sometimes resulting in accidents also.

The most of researches of the ESD characteristic were made by use of the electrical methods, especially oscilloscope. The direct measurement of the energy of ESDs is possible only by integrating the product of voltage and current at the output of the object capacitance or square of discharge current, with oscilloscope registration. The accuracy is limited as the oscilloscope real resolution is only one to ten bits. More exact can be measurement of the electric charge transferred during discharge to the earth. At the every way of the ESD measurements, but especially from the dielectric, one have to consider the separation of real and imaginary part of the current. Imaginary part is of an induction origin and doesn't take part in ignition process, but as the real part (igniting part) of the discharge current could flow through the same measurement circuit, generating the significant error. Those methods didn't answer the questions about the important problems of discharge geometry. The most of researches of the ESD characteristics were made by use of the electrical methods, especially oscilloscope. The direct measurement of the energy of ESDs is possible only by integrating the product of voltage and current at the output of the object capacitance or square of discharge current, with oscilloscope registration. The accuracy is limited as the oscilloscope real resolution is only one to ten bits. More exact can be measurement of the electric charge transferred during discharge to the earth. At the every way of the ESD measurements, but especially from the dielectric, one have to consider the separation of real and imaginary part of the current. Imaginary part is of an induction origin and doesn't take part in ignition process, but as the real part (igniting part) of the discharge current could flow through the same measurement circuit, generating the significant error. Those methods didn't answer the questions about the important problems of discharge geometry. Oscilloscope method does not answer about the size of the plasma stream, which would be useful to evaluate the space power and energy density of ESD. Also doesn't answer about the spreading size of PBDs. One of the methods of assessment of the initiation risk by brush ESDs is the measurement of the charge transfer during provoked discharge. The coulomb-meters were equipped for that with complex probe consisting from the shielding (against induction effect) and central collecting electrode (see Fig. 1). The size of the probe (diameter about 20 – 30 mm) should be chosen to stimulate brush discharge.

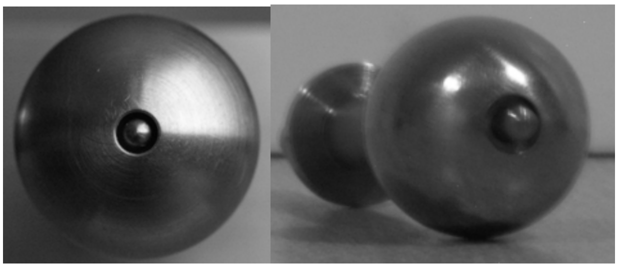

Fig.1. the view of the typical probe used with coulomb-meters for collecting the charge during provoked ESD

That solution is correct if discharge from electrified conducting object is forced, but if electrified dielectric is investigated, it could be possible to get discharge to the shielding but not to collecting electrode. Therefore it would be necessary to see the brush ESD on probe surface. This is possible with photographic methods. For the reasons mentioned above, there were checked the possibilities of the photography to be used for ESD investigations.

Problems of photographic recording of ESDs

There are two possibilities of photographic registration: with classical camera or ultra fast shutter camera. The main advantage of the first one, if long time open shutter used, is integration the light signal of all duration of the ESD. To avoid disturbances from external lights it should be used in a dark room only. The second kind realizes the differentiation function and main advantage could be observation registered phenomena step-by-step. In case of recording ESDs, it could be done at the daylight conditions but to decrease the noise level, the dark room is convenient also.

Ultra fast camera needs much more light than classic one. If the moving objects are recorded, the need additional strong light exposure, the faster the movement and faster shutter, more intense light had to be applied.

There are specific aspects to consider if record so fast phenomena as ESDs:

1) maximum shutter speed – it should be take under consideration the time of duration of ESDs. Oscilloscope recordings show that they last a few tenth of nanosecond up to a few microseconds. To record such short pulses the camera should have shuttered speed at least 100 mln frames per second (FPS). Available at the market professional camera with Complementary Metal Oxide Semiconductor (CMOS) matrixes at the moment could have the shutter speed up to the order of 1 mln FPS. It means that the exposure time window would be about 1 μs. In fact, the camera electronics needs some time to process the picture and to record it in memory, so there should be expected some death time gap in the frame. There are available at market cameras with exposure time of the order of few tenth of nanosecond, but the total speed is of the order of 1 mln FPS still. To make use of such narrow exposure band, the recorded phenomenon should be periodic and the shutter should synchronize with ESD. In practice it is not possible, as EDS are random and irregular. In the past there were used film camera with very complex optics (mirrors) and their speed could be much higher than mentioned above. But that method was very difficult and expensive.

2) amount of available light stream – the shorter the exposure time is the smaller amount of light energy could be absorbed by matrix pixels. It should be considered that colour camera have to divide the light stream to three sensors (RGB), so every sensor get 3-4 folds energy less. So for ESDs recording monochrome camera should be used. To absorb higher amount of light the cameras with larger matrixes should be used. Also the higher camera resolution, the smaller size of the pixel has to be and pixel sensitivity is lower. That's why such ultrafast cameras resolution is of order of HD. Those cameras do not record the sound also.

The distance between camera lens and ESD should be as short as possible. The author used the distance about several centimetres. Camera in metallic housing is preferable to avoid high potentials and currents induction in electronics. To record ESDs the large depth of the field is not necessary, so the lens of Macro kinds would be convenient as the usually are very light. Brightness of the lens should be as high as possible (f/3 less than 3).

3) memory speed and capacity – ultrafast cameras have the electronic speed enough to record the frames in inner RAM.

Online recording frames to mass storage devices (HDD, SSD) are difficult to achieve so the local onboard storages are applied. If the ESD appearing moment is not known and not synchronised with camera, the continuous recording in loop have to be applied and on board flash storage should have capacity about 100 GB or higher.

Experimental recording of ESDs

To assess the real possibility and potential benefices of recording of ESDs the experimental efforts with use of ultrafast CMOS camera were undertaken. The pictures with classic mirror camera were made also.

Basic parameters of applied devices:

1) ultra fast camera – Phantom V1610 manufactured by Vision Research:

- maximum speed 16 000 FPS at resolution 1280x800 up to 1 000 000 FPS at reduced resolution 128x16,
- throughput to RAM – 16 Gpx/s,

- sensor matrix - size 35.8x22.4 mm, pixel size 28 µm, monochrome, sensitivity ISO 43,700T, pixel depth 12-bit,
- internal RAM – 96 GB
- lens – constant focal MACRO 100 mm f/2.0, 25 mm f/2.8,
2) digital camera - Olympus 300,
- lens – 14-45 mm 1:3,5-5.6
3) source of ESDs – HV DC (-1 to -150 kV) supplier PS/LT150N product of Glassman HV Inc.

The examples of different ESDs pictures were shown below. The PBD was achieved by electrifying 0.2 mm polyethylene film lying on the earthed metallic disk of diameter 300 mm, with negative corona – 50 kV and then approaching the earthed metallic 50 mm in diameter ball to film. Forced PBD was shown in Fig. 2.

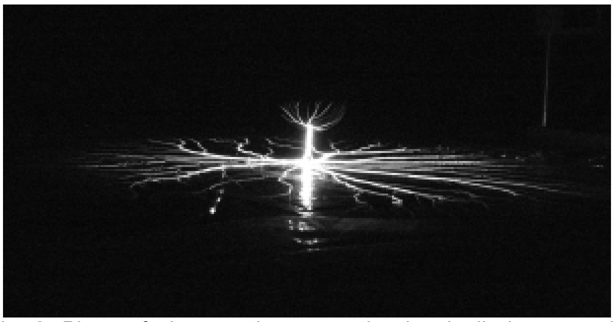

Fig. 2. Photo of electrostatic propagating brush discharge made with camera Olympus 3. Exposure time 10 s, the diameter of discharge area – 300 mm, distance between the Ball electrode and charge film – 25 mm.

The photos step-by-stem appearing and disappearing of PBD was shown in Fig. 3.

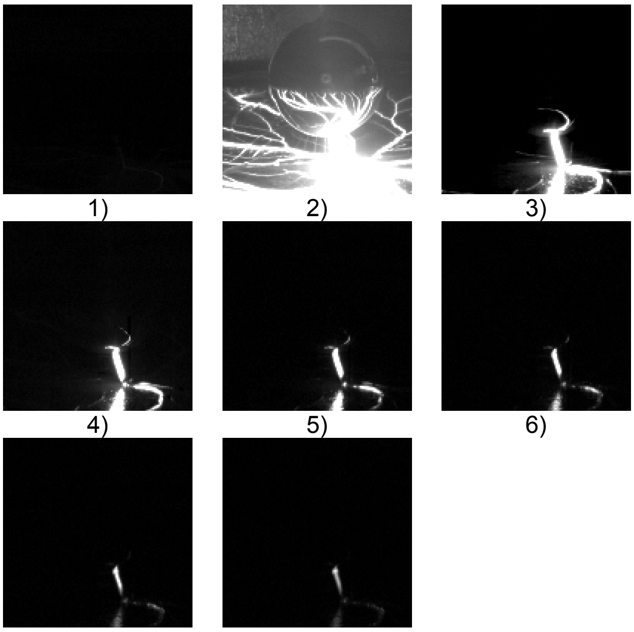

Fig. 3. Sequence of phases of electrostatic PBD recorded by ultrafast camera. Duration of each frame – 19 µs, resolution 512x512 pxs. Distance of the electrode and film – 24 mm. The basic discharge is visible in the second picture, pictures 3-8 show the plasma disappearing

Brush discharges were forced approaching earthed steel 10 mm diameter ball towards the electrified to – 40 kV, 51 mm diameter, insulated steel ball. The electrodes arrangement was shown in Fig. 4.

During approaching the electrodes there were recorded multiple discharges, in presented result there were four. It confirmed that brush discharges were not complete. During comparison the brush energy with MIE of EX atmosphere, the number of those discharges has to be consider. In each picture the Brush discharges was recorded by digital camera “Olympus 300”. The results were shown in sequence at Fig. 5.

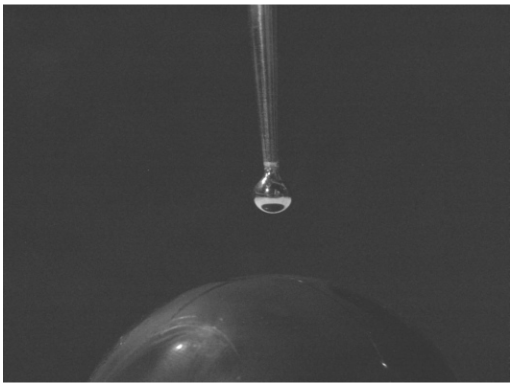

Fig. 3. Arrangement of the electrodes for electrostatic brush discharges. Lower ball electrode was insulated from earth and electrified up to -40 kV. Upper electrode was moved down toward the lower ball

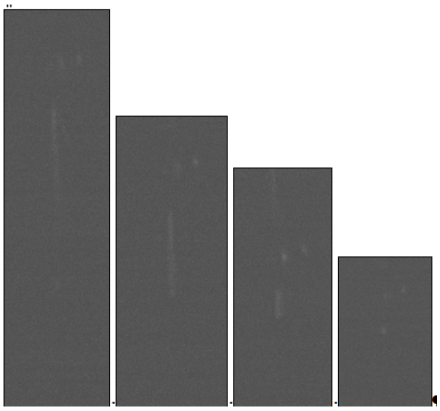

Fig. 5. Sequence of brush discharges During approaching the earthed electrode to the charged object, four discharges were recorded, one after one.

The recording of those electrostatic brushes with ultrafast camera didn’t achieve.

Discussion and conclusions

The primary experiments with ESDs recording with ultra fast and with classic digital cameras showed the limits and advantages of that method. The amount of the energy of light stream emitted by ESDs is very small. As the known maximum brush discharge energy is less than 4 mJ, probably the low energetic ESDs (below 1 mJ) couldn’t be recorded with fast and classic cameras. It occurred possible to get satisfying quality of the records of propagating brush discharges with both kinds of cameras. Both methods are convenient for recording of discharges with energy order of a few hundred millijoules or higher. The most important advantages of the photographic methods found during described research were the possibilities:
1) to assess the number of single discharges during brush discharge, and
2) to assess the time period of the duration of PBD. The hot plasma disappeared after about 1.4 ms. It means that the time period in which the risk of ignition of EX atmospheres by PBDs could be of the order of at least 1 ms, which is

probably 10-folds longer than basic time of charge transfer. It was proved that probably the time of cooling down the plasma should be considered if ignition risk would be evaluated. The oscilloscope registered duration of discharge is probably not adequate for those analyses.

Acknowledgements

This paper has been based on the results of a research task carried out within the scope of the third stage of the National Programme "Improvement of safety and working conditions" partly supported in 2014–2016 — within the scope of state services — by the Ministry of Labour and Social Policy. The Central Institute for Labour Protection – National Research Institute is the Programme's main co-ordinator.

***Author**: Dr Eng. Zygmunt Grabarczyk, Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy, ul. Czerniakowska 16, 00-701 Warszawa, E-mail: zygra@ciop.pl.*

REFERENCES

[1] Grabarczyk Z.J., Laboratory ignition of hydrogen and carbon disulphide in atmospheric air by positive corona discharge, *Journal of Electrostatics,* 71 (2013), n.6, 1041-1045
[2] Kaiser K.L., (2006) Electrostatic Discharge, CRC Taylor&Francis, Boca Raton
[3] Glor M., (1988) Electrostatic Hazards in Powder Handling, Research Studies Press, Letchworth
[4] BIA-Report, *Dokumentation Staubexplosionen. Analyse und Einzelfalldarstellung*, 11 (1997), HVBG, Sankt Augustin