Zygmunt DUDZICZ
Department of Electrical, Automatics and Computer Engineering, Technical University of Opole

Pomiary eksperymentalne napięcia przeskoku dla układów elektrod z małą szczeliną używanych do projektowania modeli laboratoryjnych odpylaczy elektrostatycznych i separatorów

***Streszczenie**: Badano eksperymentalnie napięcie przeskoku U_p dla układów ostrze-płyta i szpilka-płyta. Mierzono doświadczalnie w jaki sposób zmienia się U_p ze wzrostem odstępu miedzy elektrodami dla różnych kształtów ostrza. Celem była ocena możliwości zwiększenia U_p w układach niejednostajnych. Były określane wzrost napięcia przeskoku oraz jego powtarzalność. Kształt elektrod był symulowany za pomocą elektrod stożkowych, kulowych lub szpilkowych, które są użyteczne do dalszych symulacji numerycznych. Pomiary prowadzono w celu zdefiniowania zakresu wartości szczytowych charakterystyk napięciowo-prądowych. Wyniki wykorzystano do projektowania modeli laboratoryjnych odpylaczy elektrostatycznych, separatorów jak również aparatury pomiarowej. W wąskim zakresie można sterować U_p przy zmianie krzywizny elektrody.*

***Abstract.** The sparking voltage U_p of a wire-plate and pin-plate systems has been investigated experimentally. How a U_p changed with increasing distance between electrodes for different shape of edges was measured experimentally. The objective was to evaluate potential increase in the U_p in non-uniform systems. Potential increase in the Up and repeatability were determined. The shape of electrode was simulated by conical, spherical or pin electrodes, which proved useful for further numerical simulations. The measurements were taken to define the peak range for current-voltage characteristics tests. The results were used to design prototype laboratory scale models of electrostatic precipitators and separators as well as measurement apparatus.In the small range can be control U_p by changing curvature electrode. (**Experimental measurement of sparking voltage for electrode systems with small air gap for use in designing laboratory precipitators and electrostatic separators**)*

Słowa kluczowe: Napięcie przeskoku ,układ szpilka-płyta, układ drut-płaszczyzna, Charakterystyki napięciowo-prądowe
Keywords: Sparking voltage, Pin-plate system, Wire-plate system,Voltage-current characteristics

Introduction

The sparking voltage of a sphere-sphere, cone-cone, and cone-plate systems has been investigated as standard apparatus. These models of the discharge zone simulated real internal electrode systems, such as those that exist in the electrostatic precipitator or electrostatic separator. The literature lacks in experimental results of sparking voltage measurements or U-I characteristics of laboratory scale systems. Sparking voltage values quoted in Polish and EU standards refer only to the industrial systems. These sparking voltage values are measured as a peak voltage and are placed in the standard E-04050 [1]. In this paper, the author compared his own experimental measurements of sphere gaps that were carried out for DC voltage with negative polarity with those given in standard E-04050 for AC voltage.

The purpose of the measurement was to define the influence of the pin curve upon sparking voltage and U-I characteristics, while considering possible increase in the sparking voltage and the possibilities of controlling the discharge. Test results are assumed to appear as a comparative model, i.e. as a reference for testing other pin-plate systems and to design new types of laboratory scale models of electrostatic precipitators, electrostatic separators, electric curtain, and measurement devices.

Corona discharge in a pin-plate system is a major element of any electrostatic precipitator. It may be analysed theoretically through numerical calculation of the electric field distribution and of the space charge density [2].

Sparking voltage measurements performed for pin–plate system may prove as a reference for testing such systems supplied with alternating voltage and controlled pulse voltage. These measurements are of great importance to recognise the phenomena occurring during corona discharge. The conventional method of particle charging is based on the use of DC corona discharge. New types of charging devices use both DC and AC voltage simultaneously. Masuda developed a bi-directional mono-polar charging system named “boxer charger”. A boxer charger makes use of corona discharge along with alternating voltage pulse supply, to efficiently charge the dust particles of very high resistivity [3]. This device was later developed by Zevenhoven et al. [4]. The evaluation of such charging devices, employing alternating voltage supply, was developed by Jaworek et al. A new resolution made to design this type of device resulted in a prototype 4-electrode system to charge flowing aerosol particles [5].

The sparking voltage in the wire-plate system was analysed by the author. The experimental analysis was made for discharge electrodes with diameters in the range 0.2-3.0 mm. The intensity of the corona discharge increased together with the decrease in the size of the wire diameter of the discharge electrode. With very thin wires, the value of the intensity of the strength was so high, that it disturbed the corona discharge. In such cases only experimental measurements could verify the value of sparking voltage system of the wire-plate [6].

These results can also be useful in researching nonuniform systems of pin-plate type, series of pins-plate, wire-plate, and in the field of electrostatic precipitators, separators or other measurement devices using corona discharge. Given characteristics are used as standard measurements of systems pin-plate and series pins–plate. The sparking voltage and U-I characteristic inside the electric curtain plane was also measured. The stability of corona discharge influenced the stability of the oscillation path of the charged particle inside the curtain. The systems presented in this paper are used to charging dust particles, introduced to the electric curtain or as supporting devices useful in the research of electric curtains [7,8].

The corona discharge is applied to many technological processes that include, electrostatic precipitation, electro-static separation or electrostatic painting. Electrical corona discharge can exist, when the electric field is strongly non-uniform. These conditions take place in systems, such as, pin-plate, series pins–plate, ball-plate, cone-plate, wire-plate, and series wires-plate. Such elementary systems were experimentally measured and analysed. Measurements of the sparking voltage and the voltage-current characteristics, were used to describe the electrical properties, for the small air gap systems.

The main goal of these measurements was to develop a new method, to increase sparking voltage and the value of the emission current. Increasing sparking voltage allows improvement of the efficiency of the corona discharge, and increasing the maximum value of the working supplied voltage. Such possibilities results as well from Levitow at al. experimental reserches [9, 10]. This goal can be accomplished by controlling the sparking voltage and emission current. By changing the distance and the value of the supplied voltage, measurements were taken on how the shape of the pin, influences the sparking voltage. The pin shape was simulated by a pin, cone or a small ball, specially designed and polished. The space charge cloud created in front of the pin, caused the electrical field to weaken and increased the sparking voltage. These experiments were carried out with supplied DC voltage, with negative polarity, at AC 50 Hz, and results for both cases were compared.

A sphere-sphere system

The experimental investigations of a sparking voltage in differently arranged apparatus were used to research an electrical strength of small air gap. The sparking voltage for systems with low current is like a bias voltage. In this case, a continual electrical corona breakdown does not exist. The pin-plate systems were used as a measuring instrument to compare the sparking high voltage with results obtained using another technological electrostatic apparatus.

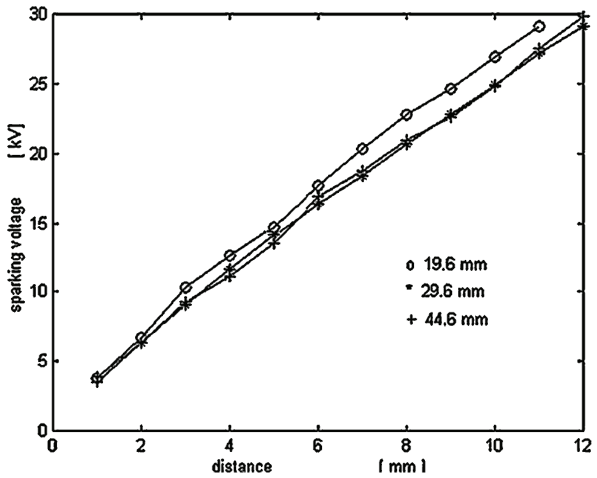

Fig. 1. Experimentally measured sparking voltage for a sphere-sphere system

The sparking voltage of a sphere-sphere system was measured for balls of diameters 19.6, 29.3, and 44.6 mm. Each value placed in the point on the graph is a middle value of five experimental measurements. All measurements were done or recalculated under normal conditions of 760 mm Hg and 20^{o}C. The sphere-sphere system was used as a measurement voltage probe and to research electrical conditions of air gap. The sphere-sphere system was supplied with a high DC voltage with negative polarity by apparatus ABK-70 used to research cables.

The experimentally measured sparking voltage in a distance gap is seen on Figure 1. This figure shows that differences between the three curves are insignificant. The values of sparking voltage well agree for two curves with diameters 29.6 mm and 44.6 mm. These two curves had very similar routes. All these curves could be approximated to a straight line. The maximum difference between each two curves did exceed the value 2.6 kV, i.e., about 9% of measured voltage value. These measured differences were small and did not provide a definite reason to draw an important conclusion. The random course of electrical breakdown in air plays a significant role in this phenomenon. The value of the voltage was measured by electrostatic kilovoltmeter C-196. By analysing the results from the measurements obtained, this relationship was shown to be similar to a straight line. These curves can be simulated using a line equation in the form of y=2.8x+1 and y=2.5x+1. It is strange that the curve for a sphere-sphere system of a ball with diameter 19.6 mm lies above the other two.

The sphere-sphere system can be used to test a maximum available high voltage value. Very interestingly, it can be compared with a measured sparking voltage of the sphere-sphere system with DC voltage with negative polarity with sparking AC voltage from the given standard E-04050 (PN-64). There are two cases here. In the first case, the sparking voltage is measured for alternating current with a frequency 50 Hz. The maximum sparking voltage for a known gap can be read from published standard "high voltage measurements" PN-64/E-04050.

This is a given standard value of sparking voltage for small balls with diameters 2, 5, 6.25, 10 cm. Figure 2 shows the comparison between a sparking voltage with supplied AC voltage taken from standard E-04050 with this experimental study measurements for the balls with similar diameters supplied with DC voltage of negative polarity. The two higher curves on Figure 2 shows peak values of sparking voltage with an increase in the distance of balls. As shown, for distances up to 8 mm, the maximum sparking voltage had the same value for diameters Φ=20 mm and Φ=50 mm.

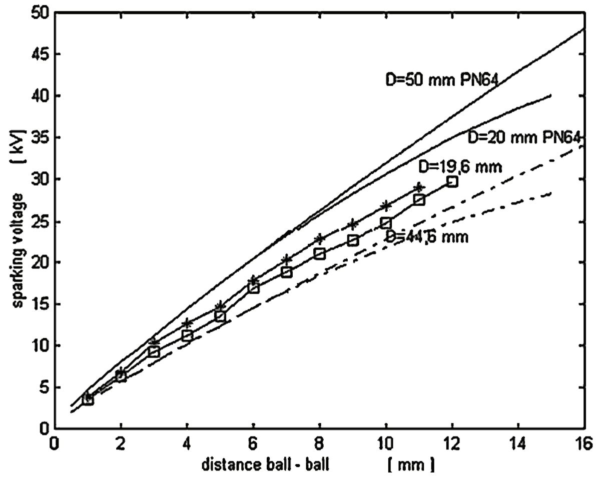

Fig 2. Comparison between experimental measurements of sparking voltage in sphere-sphere system at DC negative polarity with standard E-04060 at AC

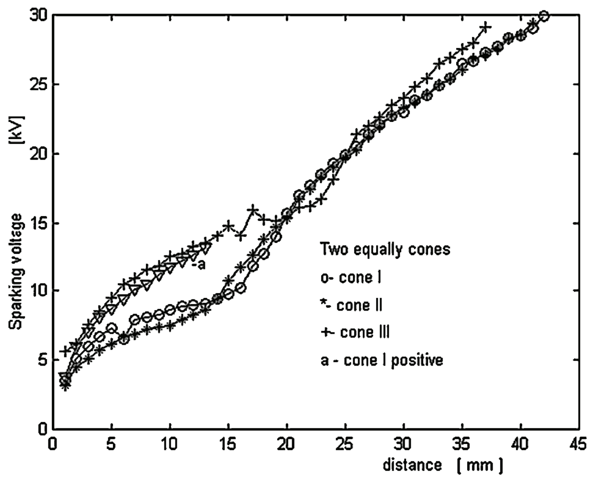

Fig.3. The sparking voltage in the function distance for a cone-cone system

For this range, the relationship can be seen exactly as a straight line. A sparking voltage from the standard can be used only as an estimate reading of the sparking voltage. Because Figure 2 shows a peak value, these values have to be divided by $\sqrt{2}$ and these curves are shown as dotted lines.

A cone-cone system

The next experimentally researched spark gap was created by using two equal cones. The cones had a height (h) of 60 mm and different diameters of the base; cone I – 30 mm, cone II – 40 mm, and cone III – 50 mm: thus, angles at the apex were adequately 28^o, 34^o, and 45^o. The exact measurements of the distance of a sparking voltage in function were taken while the apparatus was supplied with DC voltage with negative polarity. Figure 3 shows the experimental results. Each measurement point is shown in the figure. Each value of the voltage is the average value from five experimental measurements. When the angle of the cone increased, the sparking voltage increased as well. Each curve for higher angle of cone lies above the previous one. Each single curve has a similar shape, but has different routes and has two ranges. All curves have characteristic inflexion point that exists in the vicinity of a distance of 20 mm.

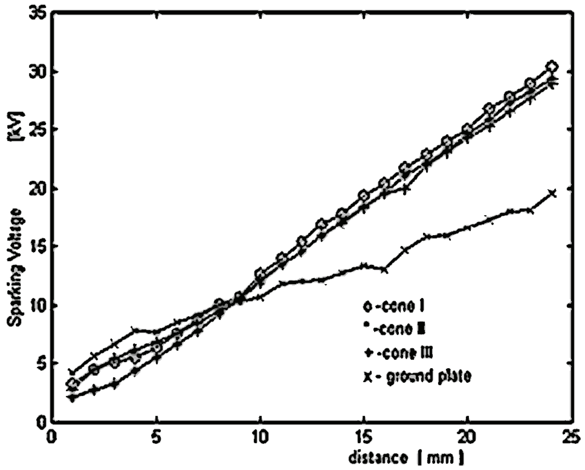

Fig.4. The sparking voltage in the function distance for a cone-plate system

In the first range, the increase of sparking voltage is higher than in the second. This may be caused that in the vicinity of point to crates a space charge of ions which increased the electrical strength of air gap. In this region, the differences of sparking voltage value for two curves reach the value of 5 kV.

In the second range, curves have very similar routes and the differences of sparking voltage are not large. It follows that the electrical strength of air gaps mostly increased at positive polarity. The results obtained are compatible with the theory that for higher angle of cones, the electrical strength increases.

A cone-plate system

The next researched electrode system consisted of a plate made from brass of diameter 147 mm and three types of cones made from aluminium. In this case, cones with the same parameters were used as described in the previous section.

When the one from electrodes was a plate and another a cone, the sparking voltage characteristics presented are shown in Figure 4. High voltage negative polarity was connected to the cone. Two ranges were observed as in the previous section. However, the route of the curves, shape, and order are not similar as in the previous section. The characteristic inflexion point took place at a distance of 9 mm. In the first region, the differences in values for two curves were very minimal because only one of the electrodes is a cone. The second part of the curves are similar and can be approximated by a straight line with the equation $y=1.3x-1$. Figure 4 distinguishes between the two curve areas, which cross each other at the inflexion point. The bottom area features a lower effect of the spatial cloud in the pin-plate system. This also influences insignificant differences in the course of the curves. Upon earthing of a plate electrode, the inclination angle of the sparking voltage curve significantly tends to reduce. For the whole range of electrode gaps, the range of changes in the sparking voltage equals as little as 15 kV. For this measurement, the pin–plate system was loaded with a current for a period of 15-30 minutes. The course of both curves were similar, yet one of the U-I characteristics is found below. Differences in the course tended to grow along with the increasing electrode spacing.

A sparking voltage in cone-plate system measured under various conditions

Very interesting results were obtained, when we compared sparking voltage values obtained under different conditions in which measurements were taken. For the system cone I – plate, different results on the electrical strength of a spark gap for two cases were obtained as follows:

1. The sparking voltage was measured according to standard E-4060 when the value of the voltage was increased with velocity 1 kV/s. In this case, only the sparking voltage of system electrodes was specially measured.
2. The sparking voltage was obtained from measuring U-I characteristics for a cone-plate system, when the gap in air took place during an electrical breakdown.

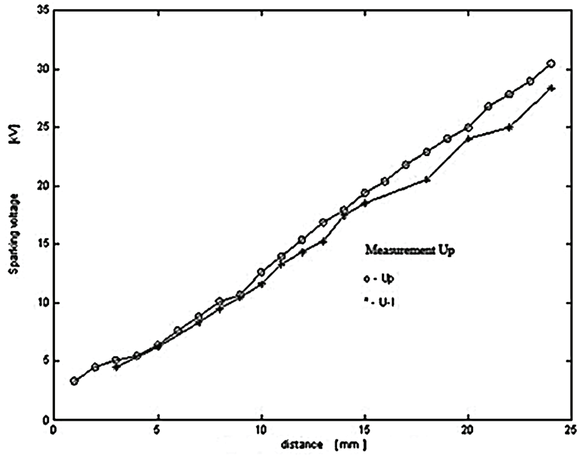

Fig.5. A comparative measurement of two different cases measuring of Up for the system a cone I – plane

These two cases presenting different measurements are shown in Figure 5. In the second case, the time of measurement was longer as in the previous one. In both cases, similar results were obtained. Characteristics presented in this paper can be used as a pattern to compare with other measurements of similar type of spark gaps.

For each use of the new spark gap, calibrations using electrostatic voltmeters must be done. The results presented above create the basis for analysing systems, such as pin-plate, a series pin–plate, and wire-plate that are useful in research on electrostatic precipitators, electrostatic separators, and electric curtains.

Conclusions

From the discussions described above, the following conclusions were obtained:

1. For sphere-sphere system, a sparking voltage can be used from standard E-04050 to get a peak value with an accuracy of about 10 %.
2. For a sphere-sphere spark gap for distances below 15 mm, the sparking voltage is linear in function from the distance and can be approximated by means of a straight line.
3. The sparking voltage 'Up' in function distance for a cone-cone system is not linear and can be approximated only for the upper parts of the curves.
4. For a cone-plate, this function Up=f(d) is linear and may be approximated with a linear equation in all ranges. The angle of inclination is about 40^o.
5. For a cone-ground plate spark gap, this function is less linear and has an angle of inclination of about 20^o.
6. In the identical system and at identical distances, similar values of sparking voltage can be obtained.
7. These measurements of sparking voltage can be used to develop new methods to increase the value of sparking voltage. Increasing sparking voltage allows improvement of the efficiency of the corona discharge.

The received results can be used to compare to another measurements as standards.

REFERENCES

[1] European Standard Norm. IEC 60-1, PN-64/E-04050, PN-92/E-04060, 1989

[2] Adamiak K. Atten P.: Simulation of corona discharge in point –plane configuration. *J.Electrostatics* 61 (2004) 85-98

[3] Masuda S.:Boxer-Charger –A Novel charging for high resistivity powders. Proc IEEE/IAS 1978 Annual Meeting, p.119-125

[4] Zevenhoven C.A.P. et al. An evaluation of the Masuda "boxer charger*". J.Electrostatics*, Vol. 32, Issue 2, 1994 pp.133-155

[5] Jaworek A. et al. Current-voltage characteristic of alternating electric field charger. *J. Electrostatics* 58 (2003) 77-89

[6] Dudzicz Z., Comparative analysis of computer-simulated and experimental sparking voltage of the wire-plate system. *Electrostatics 2003*. Inst. of Phys.Conf. Series Nr 178**,** 361-366

[7] Dudzicz Z., Electrodynamics of charged dust particles and repulsion force within plane-type electric curtain. *J. Electrostatics*, 51-52 (2001) 111-116

[8] Maźniewski J. Dudzicz Z.,Zasady działania i możliwości aplikacyjne kurtyn elektrycznych płaszczyznowych. *Przegląd Elektrotechniczny*(1998) nr.3, 66-69

[9] Levitow W.I. at al. Dymowyje elektrofiltry. Moskva, *Energja, 1980*

[10] Levitow W. I. at al. Osnowy elektrogazodinamiki dispersnych sistem. *Energja*, Moskva, 1974

Autor: *dr Zygmunt Dudzicz, Department of Electrical, Automatics and Computer Engineering, Technical University of Opole,ul. Sosnkowskiego 31. 45-233 Opole, E-mail: z.dudzicz@o2.pl*