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ELECTRICAL BREAKDOWN AND FLASHOVER OF SHORT SPARK GAPS IN ATMOSPHERIC AIR AT TRANSIENT VOLTAGES

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ABSTRACT

This paper deals with the investigation of flashover behaviour of several materials as well as electrical breakdown of short spark gaps with short length in atmospheric air at transient voltages.

The advancing miniaturisation of electrical devices for example in the field of power electronics requires the knowledge of the electrical strength of short insulating gaps. For those explorations mainly surface flashover voltages but also electrical breakdown voltages are measured for sparking distances less then 1 mm in atmospheric air. The investigations are accomplished for ramp voltages with a high steepness. The dielectric strength of air gaps and primarily the flashover resistance for several materials are presented and discussed.

1. INTRODUCTION

The flashover behaviour of several materials is mostly investigated for spark length longer than 1 cm. It is well known that, for example, the surface-conductance or rather partly conductive coatings on insulator surface e.g. by moisture or by polluted surface cause a decrease of flashover voltage [1], [2], [3], [4], [5], [6]. Especially an inhomogeneous allocation of surface conductivity causes a field distortion which reduces the flashover voltage [3], [6].

Surface pollution diminishes the flashover voltage to:

DC:	15%
AC:	20%
switching surge:	50%
lightning voltage:	90 %

of the original values [1], [4], [7].

From high voltage researches it is also known, that beveled and diagonally interfaces of insulating materials with atmospheric air cause a decrease of flashover voltage [1], [2], [3], [4], [8]. Beveled and diagonally interfaces entail a field displacement to the weak dielectric medium. The more the relative permittivities of the materials (air and insulator) differ the more change the field strength and the electric field vector. Also the roughness of the insulator surface affects the flashover voltage. For example the flashover voltage of ceramics with high porosity is less than that at low porosity [9]. In [10] it is shown, that the flashover voltage is low for ceramics with small grit size.

From [11] and [12] is known that the flashover voltage also decreases with increasing the relative permittivity of the material.

This paper wants to have a share to the review of flashover behaviour of several materials with several attributes at short gap length. Therefore measurement investigations with different materials took place with a flashover length less than 1.0 mm.

2. MEASURING ARRANGEMENT AND VOLTAGE SOURCE

In [5] and [6] an electrode shape was chosen which guarantees a homogeneous electric field. So only the insulator affects the electrical field and the flashover characteristics. But in [5] and [6], flashover lengths up to 40 mm were investigated.

Because of the short flashover length and the multitude of materials we have here, a very easy electrode shape is selected. The circular shaped insulating material is placed between to discoidal carbon electrodes which are braced with 15 N, see Figure 1. The electric field is homogeneous in the flashover area with this electrode configuration.

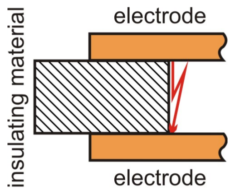

Figure 1: electrode configuration for flashover investigations

The insulating material is circular shaped to accomplish a positive fitting between electrodes and insulator and to avoid air gaps between insulator and electrode.

The electrode configuration which is schematically shown in Figure 2 was used to measure the electrical breakdown of short sparking distances.

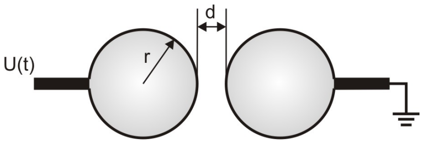

Figure 2: electrode configuration for electrical breakdown investigation

The electrical breakdown and surface flashover voltages of the different gaps and materials are investigated with a ramp voltage with an approximated steepness of 10 kV/µs. All flashovers and breakdowns took place within the first 0.4 µs of the voltage curve witch is shown in Figure 3.

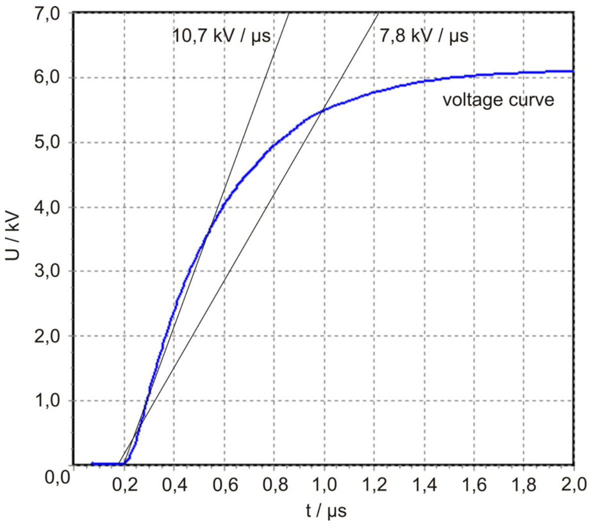

Figure 3: voltage curve

The ramp voltage is generated by an electric circuit according to Figure 4.

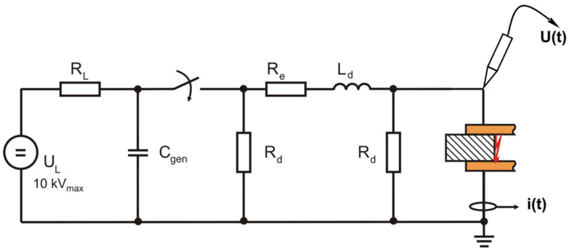

Figure 4: voltage generator

All measurements took place at θ = 20°C and an atmospheric pressure of p ≈ 1000 hPa.

3. ELECTRICAL BREAKDOWN OF SHORT SPARK GAPS IN NEARLY HOMOGENOUS FIELD

To estimate the flashover voltages of different materials it is important to get an idea of the electrical breakdown values at very short distances. Therefore the electrical breakdown voltages for gaps with a sparking distance less than 1.0 mm with different electrode materials have been measured.

Sphere gaps (Figure 2) with different electrode materials have been used for the measuring of the electrical breakdown voltage in nearly homogenous electric field. The sphere electrodes have a diameter of 20 mm. Measurements for $r = 0.4878 \cdot d$ and $r = 0.4838 \cdot d$ took place.

According to equation

$$p = \frac{r + x/2}{r} \qquad (1)$$

the geometric factors [2] result in p = 1.0025 or rather p = 1.00125 for the considered sparking distance. So it is shown, that the electric field is nearly homogenous.

Corresponding to Paschen´s law

$$U_d = \frac{B \cdot p \cdot d}{\ln \dfrac{A \cdot p \cdot d}{\ln\left(1 + 1/\gamma\right)}} \qquad (2)$$

for the values $p \cdot d = 500$ bar µm and $p \cdot d = 250$ bar µm respectively (p equates the air pressure and d the sparking distance) it is a discharge on the right range of Paschen minimum without any space charges.

According to equation (2) and with the values for the coefficient of ionization and electron emission γ as well as the gas constants A and B for copper electrodes in air [2] the calculated breakdown voltages are presented in the following Table 1.

E_d / kV/mm	U_d / kV	p·d / bar µm
10.44	5.22	500
14.2	3.55	250

Table 1: calculated breakdown voltages for copper electrodes in air

With the described sphere gaps the breakdown values have been measured. The results are shown in Figure 5.

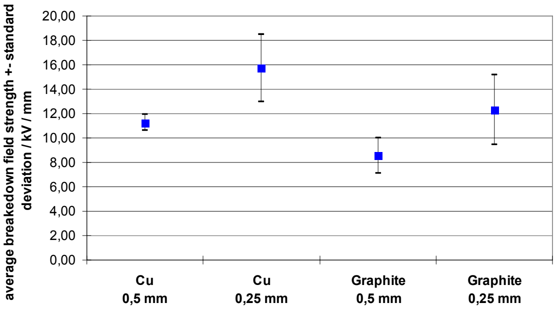

Figure 5: measured breakdown voltages

From Figure 5 three facts become apparent. First, the breakdown voltages for copper electrodes, calculated with equation (2), nearly equate the measured values from Figure 5. This shows that Paschen´s law is useable to evaluate the breakdown voltages for these short sparking distances even for the used transient voltage.

Second, for these short sparking distances the common value of 30 kV/cm for the breakdown voltage in homogenous field configuration is not useable. The actual values are much higher.

And thirdly it demonstrates that the breakdown voltages for the graphite electrodes are approximately 30% less than those of the copper electrodes. This shows that the coefficient of ionization and electron emission γ and the constants A and B for graphite in air (which cannot be found in literature) must be less than those for copper.

4. SURFACE FLASHOVER OF DIFFERENT MATERIALS

4.1. Beveled interfaces between air and insulating material

PTFE was used for the investigation of the influence of beveled interfaces between air and insulating material. The relative permittivity of PTFE is 2.1. Figure 6 shows two examples of the beveled interfaces. To accomplish these interfaces with the small flashover length the PTFE electrode arrangement (Figure 1) was heated so that the insulating material became deformed thermoplastically. The disadvantage of the used procedure is that the interface angle is not adjustable rather it is at random. But the used arrangement is good enough to get a feeling of the influence of beveled interfaces at this small sparking distance less than 1.0 mm.

Figure 7 shows the measured flashover values for PTFE insulators with and without beveled interface. It is obvious that the flashover behaviour of the beveled interfaces is worse than of the regular PTFE insulator. The flashover values are 15% to 25% less. So it falls into place that there is an important influence of the shape of the insulator surface at short sparking distances less than 1.0 mm.

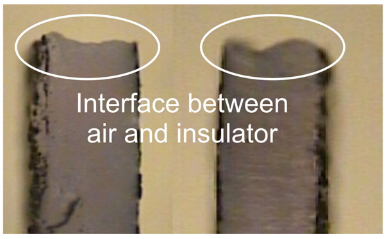

Figure 6: PTFE insulator with beveled interface

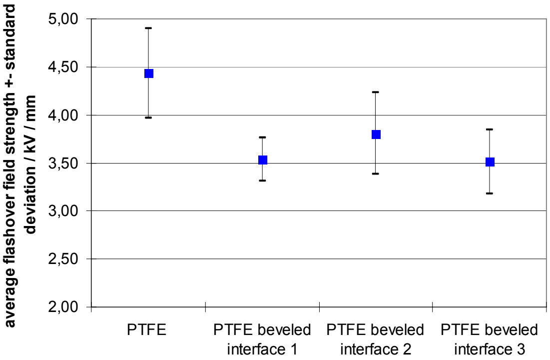

Figure 7: measured flashover values / PTFE insulators with and without beveled interface

4.2. Insulators with conductive boundary layer

Also PTFE insulators have been used to investigate the flashover behaviour of insulators with surface conductivity at short sparking distances. Some of these insulators were covered with graphite powder and some were covered with a thin surface layer of gold by sputtering. The conductive coating is only provided on the insulator area where the flashovers take place (Figure 8). Table 2 shows the measured insulator conductance of the coated insulators. The high insulator resistances result from the not homogeneously closed conductive surface layer.

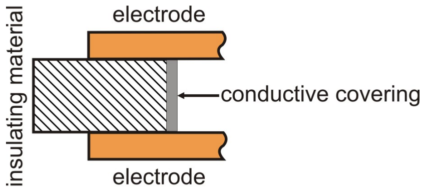

Figure 8: conductive covering

	PTFE graphite coated	PTFE gold coated
insulator resistance/ M Ω / mm	42	25

Table 2: measured insulator conductance

It is known ([1], [4], [7]) that for sparking distances longer than 10 mm and transient voltages a decrease of the flashover voltage of approximately 10 % is expectable. The actual decrement of the flashover strength is considerably above. From Figure 9 it becomes apparent that for sparking distances less than 1.0 mm the graphite coating decreases the flashover strength to 64 % of the initial value. The gold covered insulator only has 41 % of the flashover strength of a normal PTFE insulator.

So the short sparking distances combined with conductive covering of the insulator surface cause a big decrease of the flashover behaviour of the insulators.

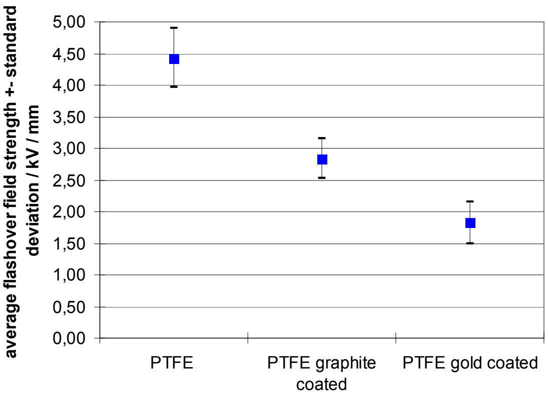

Figure 9: measured flashover values / PTFE insulators with different coatings

The flashover values of the coated insulators increase with each surface flashover during the experiments. This is shown in Figure 10 for the first ten flashovers. This is reasonable by the burn down of the conductive coating from the boundary layer.

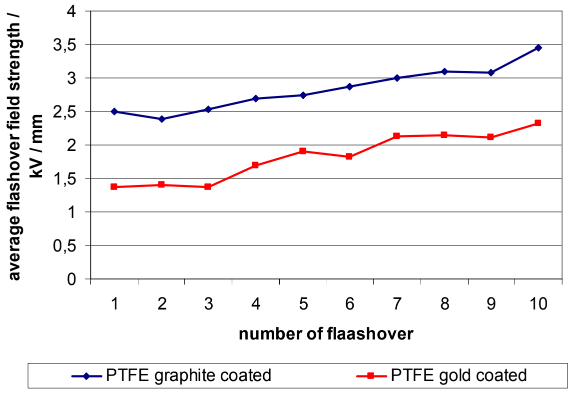

Figure 10: rising of flashover values

4.3. Insulators with high permittivity

It is shown, for example in [11] and [12], that the flashover strength is decreasing with increasing relative permittivity of the insulating material. Different plastics are used as well as different ceramic materials to investigate the influence of the relative permittivity of the insulator material on the flashover behaviour. So the relative permittivity of the insulator material variegates between 2.1 and 600.

From Figure 11 some things become apparent. The well known fact that the flashover strength is decreasing with increasing relative permittivity of the insulating material cannot be considered applicable in general for short sparking distances less than 1.0 mm which are investigated here. Some of the flashover voltages of materials with high permittivity are in fact much lower than the values of materials with lower permittivity. But for example the flashover strength of the ceramic material with $\varepsilon_r = 600$ is three times higher than that of the ceramic material with $\varepsilon_r = 100$ but much less than PTFE with a lower permittivity of 2.1. The fact that some materials with high permittivity do not generally follow this “physical law“ shows, that also other physical effects have an important influence. It is known and it also seems to be important for short sparking distances, that for example the flashover voltage of ceramics with high porosity is less than that for low porosity [9], and the flashover voltage is low for ceramics with small grain size [10]. The ceramic material with $\varepsilon_r = 100$, which is TiO_2 ceramics, has a big porosity and also a big grain size. That is why this material has this worse flashover strength.

Also at these short flashover distances which are used here always the sum of influences (the roughness of the insulator surface, the grain size of ceramics, the conductance of the insulator surface, to advice only some) affect the flashover behaviour. The investigation of these factors of influence should be continued.

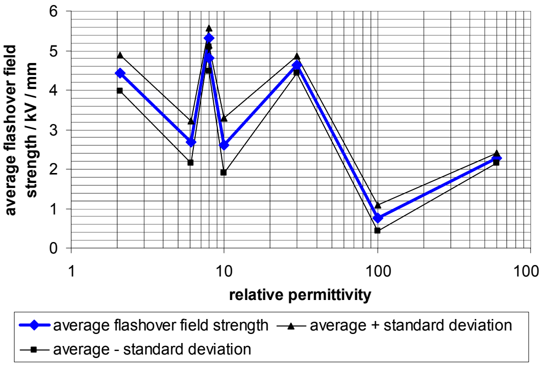

Figure 11: measured flashover values of insulators with different relative permittivity

5. CONCLUSION

Several factors of influence on the breakdown and especially flashover behaviour with sparking distances longer than 10 mm are known from literature. Measurement investigations of breakdown and flashover behaviour with different materials took place with a sparking length less than 1.0 mm and a ramp voltage with an approximated steepness of 10 kV/µs.

From the investigation of the electrical breakdown behaviour of short spark gaps in nearly homogenous field configurations three facts become apparent. First, the calculated values with Paschen´s law for the breakdown voltage for copper electrodes nearly equate the measured values. This shows that Paschen´s law is useable to evaluate the breakdown voltages for these short sparking distances even for the used transient voltage.

Second, for the investigated sparking distances less than 1.0 mm the common value of 30 kV/cm for the breakdown voltage in homogenous field is not usable. The actual values are much higher.

And thirdly it demonstrates that the breakdown voltages for the graphite electrodes are approximately 30% less than those of the copper electrodes. This shows that the coefficient of ionization and electron emission γ and the gas constants A and B for graphite electrodes in air (which cannot be found in literature) must be less than those for copper.

The investigation of surface flashover behaviour of different materials shows that the flashover strength of the beveled interfaces between PTFE insulator and atmospheric air is worse than that for the regular PTFE insulator. The flashover values are 15% to 25% lower. So it falls into place that there is a big influence of the shape of the insulator surface at short sparking distances less than 1.0 mm.

Short sparking distances combined with a conductive boundary layer of insulator surface cause a big degradation of the flashover strength of the insulators. The values which are expected in literature for longer sparking distances do not apply for short sparking distances. The flashover strength decreases down to 41 % of the initial value.

The well known fact that the flashover strength is decreasing with increasing relative permittivity of the insulating material can not be considered applicable in general for the short sparking distances less than 1.0 mm. The fact that some materials with high permittivity do not follow this “physical law“ shows that also other physical effects have an important influence.

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