NASA TECHNICAL MEMORANDUM NASA TM-77936

SURFACE DISCHARGE THROUGH AN INSULATOR IN A VACUUM

H. Boersch, H. Hamisch, and W. Ehrlich

Translation of "Oberflaechenentladung ueber Isolatoren im Vakuum, Zeitschrift fuer angewandte Physik (Journal of Applied Physics), Vol. 15, 1963, pp. 518-525.

(NASA-TM-77936) SURFACE DISCHARGE THROUGH AN INSULATOR IN A VACUUM (National Aeronautics and Space Administration) 26 p HC A03/MF A01 CSCL 09C
N86-21756
Unclas
G3/33 05796

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 OCTOBER 1985

STANDARD TITLE PAGE

1. Report No. NASA TM-77936	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SURFACE DISCHARGE THROUGH AN INSULATOR IN A VACUUM		5. Report Date October 1985
		6. Performing Organization Code
7. Author(s) H. Boersch, H. Hamisch, W. Ehrlich		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address The Corporate Word, Inc. 1102 Arrott BIdg. Pittsburgh, PA 15222		11. Contract or Grant No. NASW-4006
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes Translation of "Oberflaechenentladung ueber Isolatoren im Vakuum," Zeitschrift fuer angewandte Physik (Journal of Applied Physics), Vol. 15, 1963, pp. 518-525.

16. Abstract This study develops a model for the mechanism of stationary discharges over insulators in a vacuum: upon introduction of this discharge, the insulator charges as a result of secondary emissions, in such a way that electrons coming from the cathode strike with an average secondary electron yield of 1, and so that the secondary electrons return again to the insulator through the electric field near the insulator. When the secondary electrons strike, electrons with an average yield of 1 are released again, and so forth. The electrons move in short faults toward the anode, which they strike with lesser energy.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unlimited.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

NASA-HQ

SURFACE DISCHARGE THROUGH AN INSULATOR IN A VACUUM

H. Boersch, H. Hamisch, and W. Erhlich[1]
Physikalisches Institut der Technischen Universitaet, Berlin

Introduction /518*

If an insulator like that shown in Figure 1 is located between two electrodes, between which the voltage U_0 exists, surface discharges occur during voltage increases before another disruptive discharge follows through the insulator itself. Very little is known about these surface discharges in a vacuum, while numerous studies have appeared on surface discharges in air.

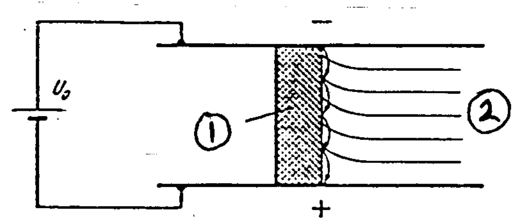

Figure 1: Stationary discharge over an insulator in plate condensor. 1. Insulator 2. Potential surfaces

Current strength surface discharges in a vacuum--ie., breakdowns of surface conduction--which cause voltage on electrodes to break down, were investigated by Gleichauf [1] and Kofoid [2].

Weak current discharges connected with flashes occur among breakdowns of surface conduction voltage. They lead only to short-lived and small voltage decreases[2] on the

---

[1] This study was delivered in part at the 5th International Electromicroscopy Conference, Philadelphia, 1962.

*Numbers in the margin indicate pagination in foreign text.

[2] 100 to 300 V at 30 kV total voltage, preresistance 10 MΩ

electrodes. Flashes can be recognized only in complete darkness and by a well-trained eye. During steady voltage, the frequency of flash occurrences decreases with time. These discharges can be designated as microflashovers /519 analogous to the microflashovers between metal electrodes.

In addition to microflashovers, there are also slowly oscillating or sometimes completely still current components below microflashover voltage. Both predischarge components --stationary components and microflashovers--are considered by Gleichauf [1], too. Investigation of the stationary predischarging mechanism forms the essential content of this study and of an earlier memo [3]. It shows that the same mechanism can be valid, as well, for microflashovers. The discharge mechanism does not change until flashovers form.

Discharge Model

Electrons were released by field emission on the cathode near the insulator. This occurs even with relatively small macrofield powers by means of microfrictions, impurities, and field increases.

It is important for continuation of the discharge that the insulator's surface display a uniform, weak glow. The simplest explanation for this fact is the assumption that flashes are caused by electrons striking the insulator's surface.[1] The field emission electrons partially reach the insulator and release secondary electrons there. If the yield is greater than 1--with insulators this already occurs with primary energies larger than 30 eV--the striking

---

[1] The assumption that electron movement in the insulator's surface causes flashes does not hold because of the low field strength ($E \approx 10$ kV/cm).

position takes on a positive charge. This strengthens the field components normally directed at the insulator in the environment, so that subsequent secondary electrons are drawn back to the insulator in increasing numbers during their flow toward the anode and consequently release further secondary electrons upon striking. The electrons take the energy needed for this process from field components which are parallel to the insulator. Thus, the positive charge continues to propagate up to the anode. A positive charge sets up so rapidly that the secondary electron yield has an average of one at all positions on the insulator.

The charge is constant in this stationary condition. Electrons occuring at the insulator's cathode-side end move in short leaps without increase or loss in direction toward the anode, which they reach with lower energy (related to overall voltage) on the final jump (see Figure 1). The size of the electron current is unimportant. The insulator's surface flashing is a side effect, which may not occur in every case.[2]

---

[2] Fryszman, Strzys, and Wasinski [4] also base their investigations of flashover mechanisms in a high vacuum on a flash phenomenon which precedes flashovers. They also find that the mechanism is determined essentially by the secondary emission characteristic. According to them, the insulator takes on anode potential as the result of postive charging. We thank Mr. R. Hawley for the reference to this study.

Discharge Model Theory[1]

a) Calculating Electron Courses

The insulator surface should be inclined toward the condensor normal at the angle α (Figure 2). The field component E_x, which is normal to the insulator and is a part of the stationary condition, is determined in this general case in part by positive charge and in part by the incline of the insulator. The field near the insulator's surface is assumed to be homogenous. This will be true to a satisfying

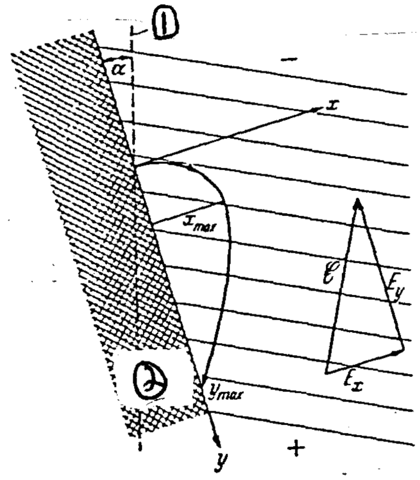

Figure 2: Lay of coordinate system for path calculation of secondary electrons. Key: 1. Condensor normal 2. Insulator

degree for the greatest part of the charge path. One electron should overflow in the coordinate origin perpendicular to the insulator with energy A_0: It is

$$\mathfrak{r}_0 = \{r_0, 0, 0\}, \quad \frac{m v_0^2}{2} = A_0, \quad \mathfrak{E} = \{E_x, -E_y, 0\} \qquad (1)$$

(m = electron mass, = overflow speed).

---

[1] Although the process here is combined with an insulator charge, we have used the commonly accepted term "discharge" for the entire process.

From the movement equations it follows for

Flight height $$x_{max} = \frac{A_0}{eE_x},$$ (2)
(e = electron charge)

Flight width $$y_{max} = \frac{4A_0E_y}{eE_x^2},$$ (3)

Striking energy $$A = A_0\left(1 + 4\left(\frac{E_y}{E_x}\right)^2\right).$$ (4)

The statistical distribution of energy and overflow direction of the released electrons are considered in the following manner. Energy distribution of the secondary electrons is independent of overflow angle. A cos-distribution is assumed for angle distribution. Then we arrive at the following for the average striking energy:

$$\bar{A} = \bar{A}_0\left(1 + 2\left(\frac{E_y}{E_x}\right)^2\right).$$ (4a)

In the stationary condition $\bar{A} = A_I$, similar to the lower energy in Figure 3, for which the secondary electron yield equals 1.

A numerical example: For an average overflow energy of $\bar{A}_0$ = 5 eV and A_I = 30 eV we obtain E_x = 6330 V/cm for the field component perpendicular to the insulator using equation (4a) in which E_y = 10 kV/cm. At the same time we obtain a flight height of 8 μm and flight width of 50 μm for an electron overflowing at a perpendicular with 5 eV using equation (2) and (3). 520

This value's dimensions confirm the assumption of a homogenous field in the range of these paths. On the other hand, it becomes clear that the mechanism can be affected by surface roughness.

Substantially larger flight widths occur in smaller quantities along with small flight widths, when an electron is reflected a number of times in a row. A portion of the electrons jumping from the insulator at a greater distance in front of the anode and strike the anode with greater energy.

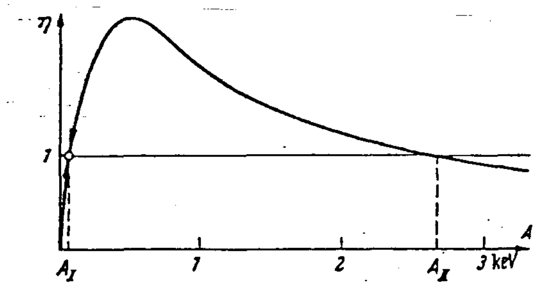

Figure 3: Secondary electron yield in relation to striking energy (schematic)

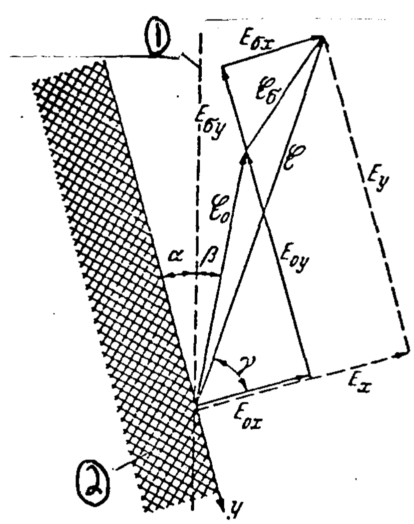

Figure 4: Dissection of the field strengths in two portions: Field strength without insulator charge; Field strength determined by charge. 1. Condensor normal 2. Insulator

The average overflow energy A_0 used in equation (4a) depends on the amount of primary energy maintaining the process. Since the average primary energy constant = A_I,

A_0 changes very little along the insulator's surface. Further calculations are made with a constant A_0.

b) Discharging mechanism stability

If the working point A_I is to be stable for the secondary electron yield, a return to this point must occur when small deviations in yield take place through charge variations. If the secondary electron yield is somewhat larger than 1, the striking point takes on a positive charge. This causes E_x to become larger and, according to equation (4a), striking energy to decrease until a yield of 1 is reached again. The negative charge which occurs below a yield of 1 also causes a return to a yield of 1.

If the electrons come from the insulator itself, then the working point A_I is indeed stable. In this case, according to equation (4a), a positive charge variation of the insulator's surface causes a decrease of energy in the striking electrons. If, however, the electrons reach the insulator from the environment, a positive charge variation generally causes an increase of energy in the striking electrons. Accordingly, A_{II} occurs as a stable working point when the striking energy was originally $> A_I$, and the anode potential was $\geq A_{II}/e$. If the striking energy was originally $< A_I$, then $A = 0$ will become the stable working point.

Equation (4a), which governs stability, depends only on the field components' ratio, not on the set voltage. This discharging mechanism is possible, as well, on condensors at low voltages. It is of no consequence where the starting electrons near the cathode originate on the way to the insulator. For this reason, electrons are shot at the insulator through a crack in the cathode to counteract the accidental nature of field emissions.

The potential of this shooting position occurs in such a way that electrons strike with energy A_{II}. Adaptation of both conditions of working point A_{II} at the shooting position and working point A_I to other discharge paths is largely possible and happens automatically through charge distribution on the insulator's surface.

c) **Surface charge dimensions**

Equation (4a) says that field lines must intersect the insulator at a very definite angle γ to obtain the stationary condition. This angle is given by the following:

$$\mathrm{tg}\,\gamma = \frac{E_y}{E_x} = -\sqrt{\frac{A_I - \bar{A}_0}{2\bar{A}_0}} \tag{4b}$$

To obtain charge densities from this, the field strength is dissected in two portions: (Figure 4) the field strength occurring without charge and including angle β with the condensor normal, and the field strength determined by surface charge with the components $E_{\sigma x}$ and $E_{\sigma y}$. According to Figure 4, the following is true:

$$E_x = E_0 \sin(\alpha + \beta) + E_{\sigma x}$$
$$E_y = -E_0 \cos(\alpha + \beta) - E_{\sigma y}.$$

$E_{\sigma x}$ can be expressed through the surface charge density σ.

$$E_{\sigma x} = \frac{\sigma}{2\varepsilon_0}$$

(ε_0 = influence constant)

The y-component $E_{\sigma y}$ is proportional to the x-component. The proportionality factor is, however, a function of the y coordinate of the insulator location.

$$E_{\sigma y} = K \cdot \frac{\sigma}{2\varepsilon_0}.$$

Inserting this into equation (4b) results in the following for charge density:

$$\left.\begin{aligned} \sigma &= \frac{2\varepsilon_0}{P-K} \cdot E_0 [\cos(\alpha+\beta) - P \sin(\alpha+\beta)] \\ P &= \sqrt{\frac{1}{2}\left(\frac{A_I}{A_0}-1\right)}. \end{aligned}\right\} \quad (5)$$

with

Angle β, determined by the field line intersection is a function of α. /521

From this it follows for the insulator charge:

The charge is proportional to field strength E_0 and with it to the voltage on the condensor, independent of surface position. The charge is positive for the perpendicular position ($\alpha = \beta = 0$). The charge decreases as angle α increases. The charge equals 0 at a definite angle α_0, independent of the set voltage:

$$\operatorname{ctg}(\alpha_0 + \beta_0) = \sqrt{\frac{1}{2}\left(\frac{A_I}{A_0} - 1\right)}. \quad (6)$$

The charge is negative for $\alpha > \alpha_0$.

Experimental Investigations to Determine Discharge Model

a) Current density and energy distribution on the anode

Electrons reaching the anode primarily leave the insulator directly beneath the anode. Accordingly, they should attain this mode at low energies in the immediate vicinity of the insulator. For this reason, electron energy distribution--related to the anode potential--is measured with an opposing field composition at different distances x from the insulator.

Experiment set-up (Figure 5). The glass plate insulator stands in a crack of the cathode. Directly above it is the electron source, consisting of a tungsten wire stretched across the slit-shaped opening of the Wehnelt cylinder

(parallel to the insulator). The insulator is shot with electrons using this device at a width of 7 mm.

The anode contains the measuring aperture (diameter 0.1 mm) and can be slid across from the insulator together with the Faraday cage located behind the aperture. The weak opposing field exerts only a slight disturbance through the measuring aperture onto the field in front of the anode and vice versa. The opposing voltage U_g is set at the cage. Cage current i_k, proportional to current density, is registered with a direct-current amplifier independent of the opposing voltage U_g. The RC-component was required in front of the amplifier to go through the opposing voltage and to filter out potential jumps which occur from coil to coil on the petentiometer.

Secondary electrons are released at the anode measuring aperture. Some of these electrons arrive in the measuring cage and thereby disturb the clarity of the measurements, since they cannot be immediately differentiated from slow electrons coming from the insulator end. Secondary emission was strongly, but not sufficiently, reduced using a smoked measuring aperture. To recognize electrons coming from the insulator, the insulator was made shorter than the electrode interspaces. The space between insulator end and anode determines the potential of the electron's jumping point on the insulator. It can be recognized in the opposing voltage curves (Figure 7) at the starting point of the cage current's decline. The distance was 1.3 mm in the recorded measurements, and springing place potential (-26 V)[1] is

---

[1] The fact that jumping place potential occurs at only 26 V less than the anode potential does, is a result of the positively charged insulator, which greatly weakens the field in front of the anode.

sufficiently large enough at an anode voltage of 2.5 kV to be able to differentiate the secondary electrons released on the anode from those electrons coming from the insulator. To identify the springing place potential with that of the insulator end, the insulator end was equipped with a conductive silver strip on the front side and charged with a potential U_L. This allows the starting point for the decrease of the opposing voltage curve to be influenced. Agreement between the two potentials results, however only for a certain U_L, which depends on the interspacing. This value can be introduced for measuring.

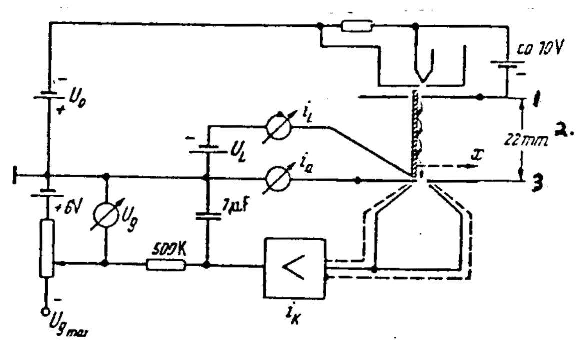

Figure 5: Test set-up to measure energy distribution of electrons. 1. Cathode 2. Insulator 3. Anode with measuring aperture and opposing field set-up, movable in x-direction

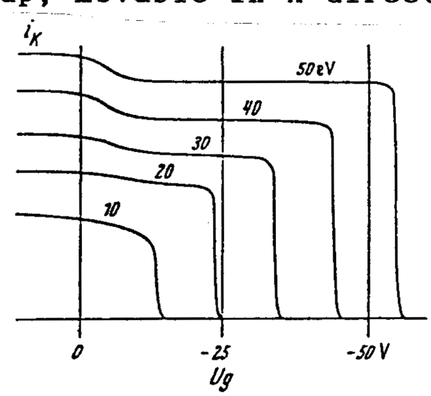

Figure 6: Opposing voltage curves of thermic electrons at a pitch angle of 12° for five different electron energies.

The work at this relatively large distance has two further advantages: current flowing over conductive silver strips i_L at smaller U_L values--secondary electrons coming from the anode--nearly disappears, and the electron path pitch angles to the measuring aperture become sufficiently small because of minimum energy amounting to 26 eV. An estimation showed that only a small portion of the insulator electrons enter into the measuring aperture at a pitch angle greater than 12°. One disadvantage of the large distance is the spraying of the current distribution.

The opposing field arrangement's work was controlled by thermic electrons. At an injection angle of 0° the opposing voltage curves' path was as expected. At 12° injection angle, disrupting deviations resulted only for electron energies < 25 eV (Figure 6). The first cage current decrease at $U_g = 0$ rests on secondary electrons released at the anode. The continued path for energies > 40 eV is horizontal. The decrease which then follows corresponds approximately to a Maxwell distribution. The curve branch, expected to be horizontal, is somewhat sloped at energies < 40 eV. The decrease for 25 eV-electrons amounts /522 to 5% at most. Since the electrons coming from the insulator in the experiment possess an energy of at least 26 eV, no substantial errors result for their energy determination.

Results. Figure 7 shows the opposing voltage curves, recorded at different distances x from the insulator's surface. All curves show a horizontal path after the decrease at $U_g = 0$, which can be traced back to secondary electrons released at the anode opening. The opposing voltage curves recorded in the vicinity of x = 0 decline rapidly after exceeding the potential of the insulator end ($U_L = -26$ V). These are numbers 6 - 9. This means that slow electrons come from the insulator end. The onset of the decrease is postponed to a certain extent for the somewhat greater distance x. Only the somewhat more rapid electrons reach this point. The current distributions in Figure 8 come from the opposing voltage curves and correspond to the different opposing

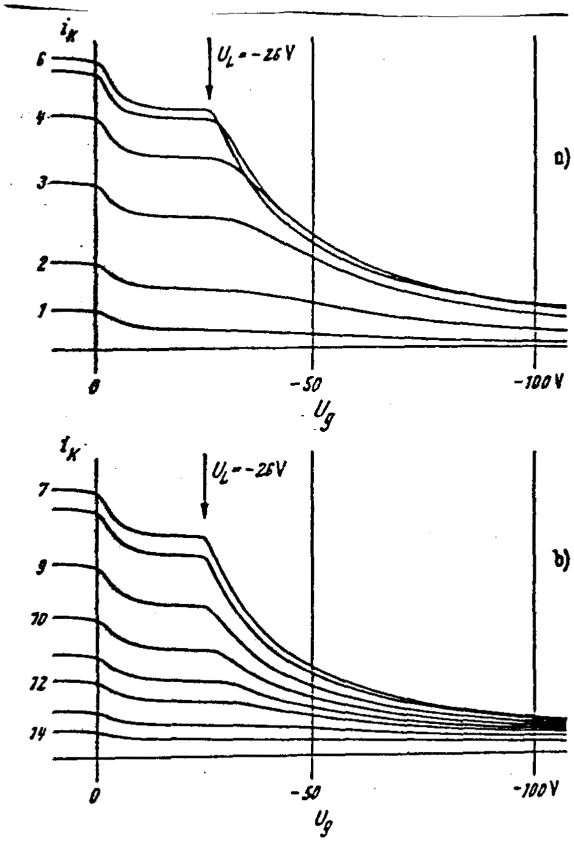

Figure 7: Opposing voltage curves recorded during discharge at different distances x. Curve numbers correspond to x-values in Figure 8. U_0 = 2.5 kV, i_a = const ≈ 1 μA, distance between insulator end and anode = 1.3 mm, U_L = −26 V.

voltages. The overall current--the −26 V-curve--coming from the insulator has its maximum directly next to the insulator. The largest portion of this current consists of slow electrons: 0 to 9 V-electrons between the curves for U_g = −26 and −35 V; 9 to 24 V-electrons between the curves for U_g = −35 and −50 V. At greater distances from the insulator, the more rapid electrons predominate, as expected.

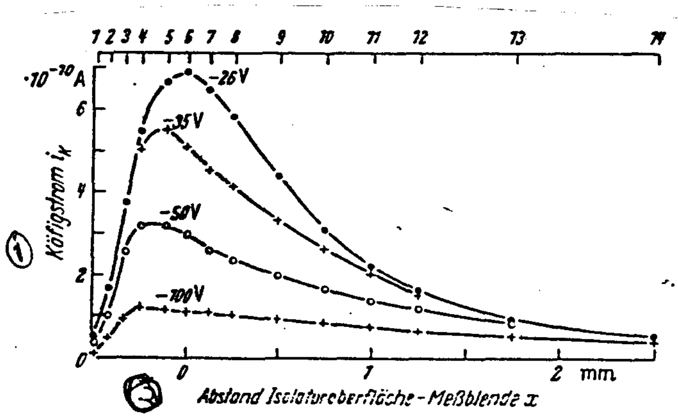

Figure 8: Current distribution at the anode for different opposing voltages. 1. Cage current i_K 2. Distance between insulator surface and measuring aperture x

The electrons move in opposite directions in the area between the insulator end and the anode because of the weak field. This leads to a broadening of the distribution curve. The distribution's half-value width with a 3 mm distance between insulator end and anode was about half that in Figure 8.

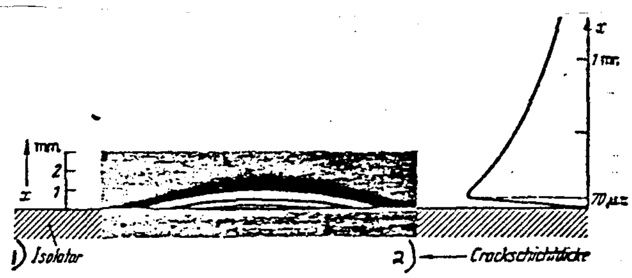

Figure 9: Crack layer formed during discharge at the anode photographed with overhead illumination, wave length λ = 480 mμ. Enlarged to the right of it is the resulting crack layer density in its relation to the distance x for the middle of the discharge range. 1. Insulator 2. Crack layer density

A picture of current distribution (Figure 9) for a distance of approximately 0.1 mm could be obtained from the crack layer formation on an anode of the conducting glass. The crack layer's cross section is shown in the enlargement on the right in Figure 9. Density is approximately proportional to current density.[1] The maximum occurring at x = 70 μm corresponds approximately to the average flight height calculated using equation (2). Because of field weakening, this position is substantially larger in front of the anode as a result of positive charging than is the case in the insulator's midsection.

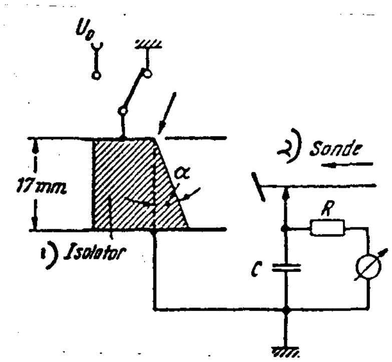

Figure 10: Test set-up to measure insulator charge.
1. Insulator 2. Probe

b) Determining average surface charge density

Test set-up (Figure 10). The charge is measured in the range of the probe surface using a probe inserted against the insulator surface after shutting off the discharge. Electrons were shot onto the insulator during the previous discharge, similar /523
to Figure 5. The insulator is massive in this case, to avoid disturbances during charge measurements otherwise caused by random charges on the insulator's back side. The probe is situated on a ball joint of the injector apparatus so that it fastens tightly to the insulator's surface. Plate distance amounts to 17 mm, diameter probe 12 mm, making it necessary to deal with a greater area.

---

[1]Deviations result from the dependence of crack layer formation on energy.

Influence and charge balance on the contact points between probe and insulator assure that the condensor C and the insulator surface lying opposite the probe have an equally large charge Q just after the rapid advancing of the probe. This flows away exponentially evanescent over the resistance R:

$$i(t) = i_0 e^{-t/RC}.$$

Integration up to $t = \infty$ gives the overall charge

$$Q = i_0 RC,$$

which was determined by measuring i_0 with a direct current amplifier. The time constant amounted to 12 sec, so that it was possible to read i_0 with sufficient accuracy. Further, this makes it possible to reduce the charge flowing away to a negligible size already while advancing the probe ($\approx$0.3 sec).

Insulator areas neighboring on the probe influence charges on the probe in the presence of their particle capacity and corresponding to the probe. This is not taken into consideration for the given average charge density q; it is set at q = Q/probe surface.

Measurements were made with plexiglas to avoid disturbances caused by surface conductivity. With glass, for example, the surface charge's mobility expresses itself through a dependency of the i_0 value on the length of the pause between shut off of the discharge and advancing of the probe. Furthermore, the current rose just after the advancement because the surface charges from the probe's environment were attracted to it.

Results. Figure 11 shows average charge density as a function of condensor voltage U_0 at four different pitch angles α with the linear path expected according to equation (5). Data from three different measuring series are recorded. The charge for $\alpha = 45°$ is negative. Deviations from the linear path at larger voltages U_0 may be traced back to increasing mobility of negative surface charge with the voltage. The deviations at smaller voltages were not completely explained.

The angle function resulting from Figure 11 is depicted in Figure 12. The charge which is positive at angle $\alpha = 0$ decreases almost linearly with increasing α and, independent of the previously laid voltage U_0 reaches a 0 value at 31.5° and beyond that point becomes negative. The constants in equation (5) are determined from the σ-values for $\alpha = 0°$ and 15°, $\beta = 0$, $U_0 = 10$ kV:

$$K = 1.37; \quad P = 1.64; \quad A_I/\bar{A}_0 = 6.37.$$

Exact values for the comparison are not known for plexiglas. With $A_I = 30$ eV we get $\bar{A}_0 = 4.7$ eV, not to be confused with the most likely outlet energy at ≈1-2 eV for insulators. The angle distribution calculated with these constants is almost identical with the one in Figure 12, from which fact we may conclude that the angle β still has no substantial influence on the investigated range.

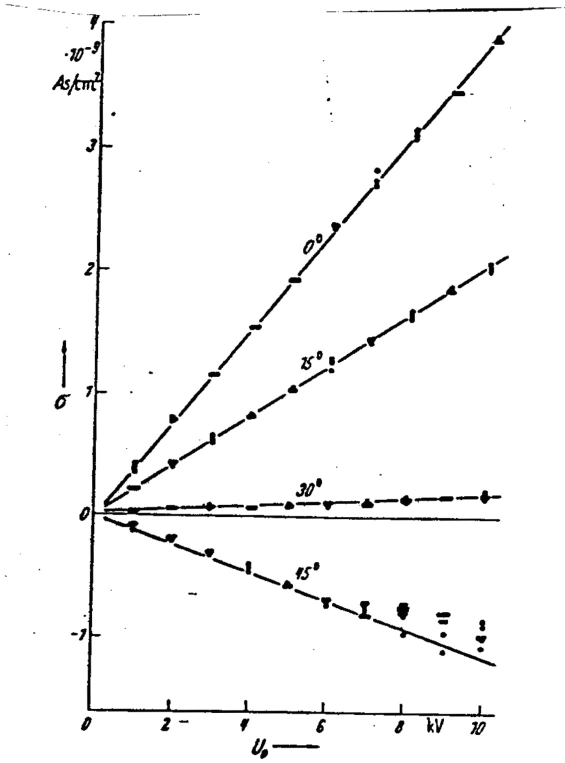

Figure 11: Charge density as a function of condensor voltage U_0 at different insulator pitch angles α.

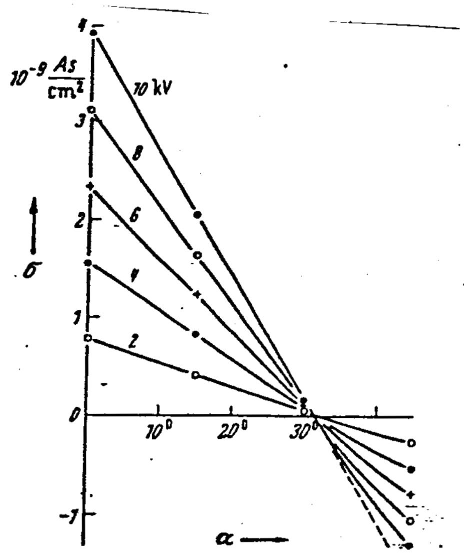

Figure 12: Charge density as a function of insulator pitch angle at different voltages on the condensor.

Potential Path along the Insulator

The positive charge of the insulator (with perpendicular surface) decreases field strength in front of the anode and increases field strength in front of the cathode. Instead of a straight potential path--curve 1 in Figure 13--the potential path indicated by curve 2 generally results. The onset of overflow potential $U_{II} = A_{II}/e$ leads to a distortion of the potential path, whereby the field strength in front of the cathode increases and subsequently becomes very weak at the overflow point, so that a large shift of the fault results there.[1] This first fault can be recognized from the crack layer formation (Figure 14).

The crack layers also permit the average shift of the fault to close in those areas where an individual fault can no longer be recognized. Crack layer density is proportional to the electron's average striking density, and this is inversely proportional to the average shift of the fault. From the average shift of the fault it is possible to move again to the field strength component E_y which is parallel to the insulator.

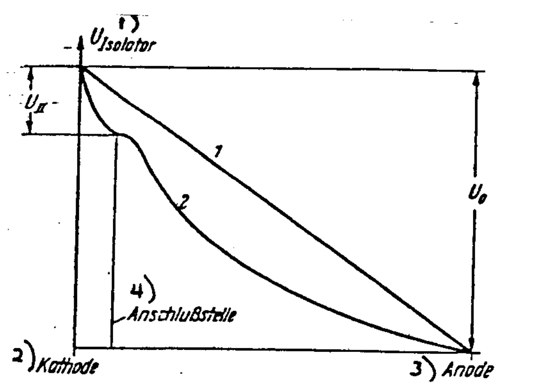

Figure 13: Potential path along the insulator without charge (curve 1) and with stationary surface discharge (curve 2). 1. Insulator 2. Cathode 3. Anode 4. Connection

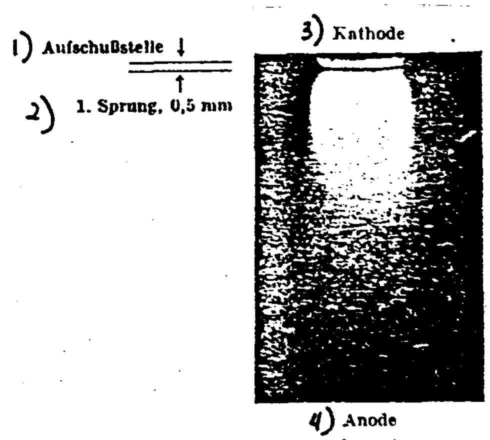

Figure 14: Crack layer formation on the insulator resulting from surface discharge. (The brightest points correspond to the greatest crack layer density.) 1. Overflow point 2. First fault, 0.5 mm 3. Cathode 4. Anode

Conclusions on Flashovers

The described discharge mechanism is important for the development of flashovers because its onset is often combined with a positive charge. Several conclusions from this fact will be discussed, although we do not investigate the flashovers themselves.

If the voltage on an originally uncharged insulator is increased so high that field emission begins at one point on the cathode, then the positive charge moves toward the stationary condition. Field strength increase at the cathode coupled with this causes a strong increase of the field emission current. When the positive balance charge of the insulator is reached, the current could also assume a constant value since the field strength is constant then, and the discharge model receives any and all currents. This stationary situation does not always occur, however. Changes on the emission center or on the insulator connected to discharge current cause microflashovers or flashovers to form.

In the case of microflashovers on the insulator, the discharge breaks up after a small charge transfer. The reason for this can lie only in the emission center, which self-destructs with increasing emission current before the insulator has reached the positive balance charge. This concurs with the observation that the amount of charge transferred by a microflashover is smaller than the insulator's positive charge needed for the stationary condition!

The emission center must be more resistant for the less frequent flashover so that current can assume greater values. The following is assumed for the transfer to flashovers: If electrons reach the insulator with an energy smaller than A_I (Figure 3) during field emission, then the onset of overflow energy A_{II} causes a field strength increase of at most A_{II}/A_I. This ratio has a magnitude of 100. Before reaching the stationary condition, the power iU_{II}, transferred at the overflow point, can become so large that insulator material vaporizes, and the flashover is started. The field strength increase at the cathode is not sharply limited to location. For this reason, it can cause emissions, as well, in previously non-emission areas.

Relations during charge formation become more complicated when the insulator possesses weak surface conductivity. This allows field strength increases to form at relatively low voltages in front of the cathode <u>and</u> anode. These lead to field emission, thus causing premature "ignition" of discharges.[1] After igniting, secondary emission characteristics of the insulator surface become decisive for potential distribution.

---

[1] Field emission in front of the anode leads to limited discharge in front of the anode, as they were occasionally observed along with the microflashovers moving from cathode to anode.

The previously mentioned possibilities exist again for continuing this development. Even the positive charge remaining after a microflashover can lead to renewed ignition of the charge caused by a certain mobility in the surface.

In spite of the numerous and individually unexplained possibilities for the formation of discharge forms, the stationary discharge model developed in this study indicates how insulator voltage stability can be improved in the presence of flashovers: Field strength increases in front of the cathode can be prevented by a predischarge, that is by a positive charge on the overflow point and in the rest of the insulator area. This can happen along the discharge course by sloping the insulator surface, leading, according to Figure 12 to a negative or no charge ($\alpha \geqq /\alpha_0$). The easiest means to suppress a positive charge of the overflow point, is, in principle, to remove the "air cracks" at the cathode. This, however, is experimentally difficult to carry out. A deployable air crack ought to be so large that striking energy is equal to or greater than A_{II} from the start, or ought to be screened so that the secondary electrons cannot overflow there, and so that $\eta > 1$ does not /525
take affect.

Summary

This study develops a model for the mechanism of stationary discharges[1] over insulators in a vacuum: Upon introduction of this discharge the insulator charges as a result of secondary emissions in such a way that electrons coming from the cathode strike with an average secondary electron yield of 1 and so that the secondary electrons return again to the insulator through the electric field near the insulator. When the secondary elecrons strike, electrons with an average yield of 1

---

[1] See footnote to page 521.

are released again, and so forth. The electrons move in short faults toward the anode which they basically strike with lesser energy.

The insulator is located in a plate condenser during measurements to check the discharging model. Electrons are shot onto the insulator through a slit in the cathode. The energy distribution of the electrons arriving on the anode is measured with an opposing field arrangement at different distances. Afterwards the current density maximum with basically slow electrons lies directly next to the insulator. The relative portion of more rapid electrons increases at greater distance. The insulator's charge resulting from a previous discharge iw measured with an inserted probe. The charge is proportional to the voltage laid during discharge. The charge is positive when the insulator surface is perpendicular to the electrodes. It decreased at increased sloping of the surface and finally changes the pattern.

The discharge mechanism described is significant for the development of flashovers because the beginning of the stationary mechanism is often connected with a positively charged insulator. As the result of the field strength increase generated by this in front of the cathode, the charge does not reach the stationary condition, but rather converts immediately into a flashover.

We should like to thank the Senator for Economics and Credit for making ERP-research funds available.

REFERENCES

1 Gleichauf, P. H., Appl. Phys. 22, 535, 766 (1951).

2 Kofoid, M. J., AIEE 79, 991, 999 (1960).

3 Boersch, H., Hamisch, H., and Erlich, W., Physik. Verhandl. 11, 185 (1960).

4 Fryszman, A., et Strzyz, T., and Wasinski, M., Bull. acad. polon. sci., Ser. d. sci. techn. VIII, No. 7, 379 (1960)