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EFFECTS OF BOUNDING SURFACES OF THE SMALL GASEOUS GAP ON THE STATISTICAL TIME LAG OF A DISCHARGE

1. Introduction

Presence of free electrons is a necessary condition for a discharge to occur. Low probability of appearance of an incepting electron in a gaseous gap is responsible for a delay of a discharge. A statistical character of the liberation process of free electrons results in statistical character of the discharge time lag. It has been shown in [2] that the statistical time lag of a discharge in a small gaseous gap is given by Weibull's distribution of a shape parameter, determined by the rate of appearance of the electrons, capable of initiating a discharge.

The problem of the source of a discharge inceptive electrons has been studied by a great number of research workers, without however satisfactory results [1,3,4,5,8].

A gaseous space is a well known source of the electrons, which initiate a discharge. A gaseous space contains, apart from neutral particles, also carriers of electric charges. Radioactivity of the Earth, cosmic radiation and other incidental sources of "hard" radiation are the sources of the electric charges. Concentration of the atmospheric air ions is low the average figure being 1000 pair of positive and negative ions per 1 cu.cm. Still much lower is the concentration of free electrons - 10 per 1 cu.cm, as their life in air is very short. The above figures are approximate only - the measurements show, for instance, that subject to the atmospheric conditions, the number of ions could vary considerably, from 40 to 1500 per 1 cu.cm [9].

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The phenomenon of "detachement liberation" of electrons from the negative oxygen ions has been so far regarded as a main source of a discharge inceptive electrons. However, latest tests on a discharge time lag in an arrangement of a non-uniform field (pointed electrode-plate electrode) and subsequent calculations of the rate of emission of free electrons, submitted in [10] have shown, that the time lag of a discharge at negative polarity of a pointed electrode is considerably shorter that at the positive polarity, although for the negative polarity:

1. calculated critical volumes are much smaller, and

2. due to "escape" of ions from that space with a drift velocity, the number of negative ions is evidently lower.

The author of this Paper suggeststhat other sources of free electrons must in this case exist. As the electrode surface is part of surface closing the critical volume for negative polarity, only that source could be the extra source of free electrons. The field emission (also called "cold" emission) is the best known kind of the emission of free electrons. However, in the case of gaps, bounded by metal electrodes, it is applicable only to high intensity fields ($E > 10$ kV/mm). It is interesting to know, that the field emission can occur at the field intensities as low as 4 to 6 kV, but then it would be present at points of reduced work function or increased local intensities, such as irregularities of the cathode surface, cracks of oxygen layers, impurities, etc. However, all those phenomena are pretty well known, so with adequate control of the electrode surfaces, they could be completely eliminated.

"Exoemission" is other, less known, kind of the electron emission from a surface. Facts, that certain substances, when radiated and then treated mechanically or thermocally, become a source of low energy negative charge carriers, known as exoelectrons, have been cited in the literature. That phenomenon, generally, referred to as exoemission of electrons, is associated with the relatively low power electron traps on a metal surface. Undoubtedly for instance gases absorbed on a surface or changes of a surface, due to various chemical reactions, would affect this phenomenon. According to [3] liberation of electrons from negative ions, absorbed on a surface, is responsible for the emission of approx. 10^2 to 10^3 electrons from 1 sq.cm in one second.

A completely different model of the emission has been proposed in [7]. The author is of the opinion that on a surface of an insulating material, "dwarf" avalanches come into being, to increase the field local intensity (the avalanches are due to microfields, resulting from charges of an earlier discharge). Emission of the electrons from a dielectric deeper layers, which partly neutralize that charge and partly contribute in initiating a new discharge in a gaseous space, takes than place. Please refer to [2] for more details about different kinds of the surface electron emission.

To sum up, it is certain, that none of the presented mechanisms of the surface electron emission is sufficiently supported. Nor there are reliable experimental data to promote any of the described models.

Usually authors propose interpretations quite satisfactory for the effects they have noticed, but useless for the phenomena, observed by others. The situation is further complicated by the fact, that as shown by Waters [11], not only the material of the cathode but also material of the anode considerably affects the discharge time lag.

2. Scope

The problem of examining the phenomena associated with an initiation of a discharge (and in consequence the problem of sources of the electrons, initiating a discharge) seems to be particularly interesting in the case of gaseous gaps of small size. Such gaps are found in practical insulating arrangements, as a result of technological process inaccuracies. The size of such gaps is $V \leqslant 1\ mm^3$. It seems true, considering all that we have said before about the sources of a discharge inceptive electrons, that the surface closing the gap is in this case, the only source of the electrons. However, the mechanism of the emission has not been fully recognized yet.

Hence the parameters of the surface, which effect this phenomenon, are also unknown and therefore hard to control, when performing the tests. For those reasons we have decided to vary them deliberately in our tests and then, by measuring the time lag, to find out the difference, if any, in the intensity of the emission of electrons, capable of initiating a discharge.

Our studies have covered the effect of polarity of a charge artificially imposed on a dielectric on a discharge time lag.

3. Tests

3.1. Fig. 1. illustrates the arrangement for the measurement of a discharge time lag. A programmed circuit-breaker LSP is used for applying the required polarity voltage when the voltage sine wave passes through zero.

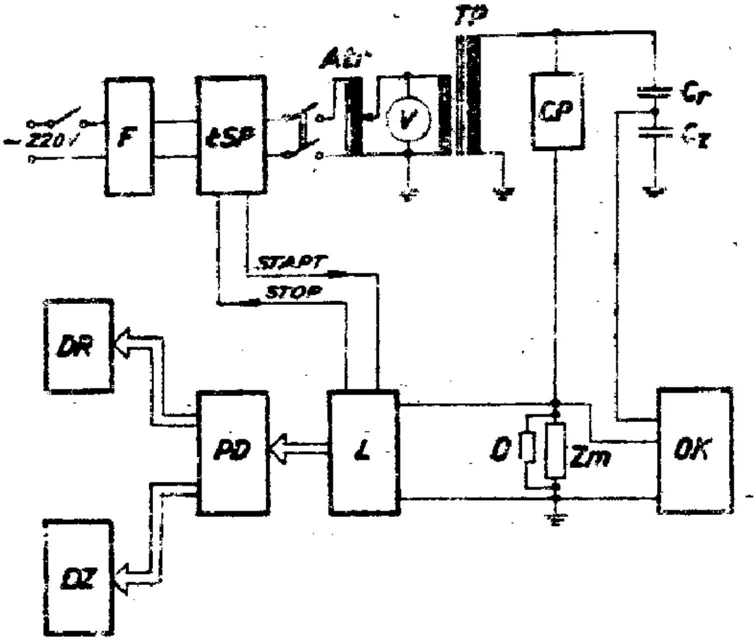

Fig.1. Test circuit for measurement of discharge delay time
F - interference eliminator, LSP - Programmed synchronizing switch, V - moving-iron voltometer, Atr - autotransformer of laboratory type, CP - measuring cell, TP - testing transformer - voltage transformer, Zm - test impedance, 0 - lightning arrester, Cr/Cz - capacitor divider, OK - oscilloscope, PD - control unit for printer and card punch, L - time counter - digital frequency meter PFL-20 type, DR - card punch, DZ - tape punch.

At the same instant a start pulse is being directed to a time counter L, which starts to operate. A voltage pulse which appears at the instant of a discharge on the impedance Z_m is sent to stop the time counter L. The same pulse, suitably shaped, is directed to the breaker [illegible] the voltage and also to energize a timer which controls the [illegible] voltage interval between the cycles i.e. the salled "rest time" - T_{od}. The logic output is coupled with a printer and a cord punch to record the test results.

3.2. Electrode arrangement

The tests have been carried out on a model consisting of a spherical electrode of 8 mm dia and a flat plate electrode, placed at a distance of $d = 0,4$ mm from the sphere. A dielectric has been placed on the plate electrode.

Samples of polyethyleneterephtalate (known under a tradename of Estrofol EK), 20 μm thick and of $\varepsilon = 3,2$ permittivity were used.

The electrodes have been placed in a measuring cell CP, which has allowed easy replacement and setting of the electrodes.

3.3. Arrangement for placing a charge on dielectric

Fig. 2 is a schematic of an arrangement for placing a charge on a dielectric.

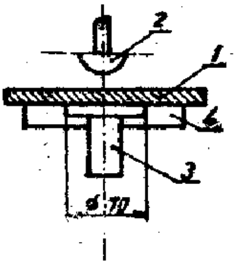

Fig. 2. Electrode arrangement
1 - sample, 2 - H.V. electrode, 3 - detection electrode, 4 - insulating shield

Application of a suitable voltage to a pointed electrode has resulted in the appearance of a corona on the electrode end and in consequence a flow of a corona current to an earthed electrode, with a dielectric on it. As a final result a charge of polarity identical to that on the pointed electrode end has been placed on the dielectric. The charge value has depended on the duration of the corona. In our test a charge of a surface density of 20 pC/cm^2 has been placed on the dielectric.

A grid electrode has been used to make the field within the area limited by the grid and the dielectric as uniform as possible

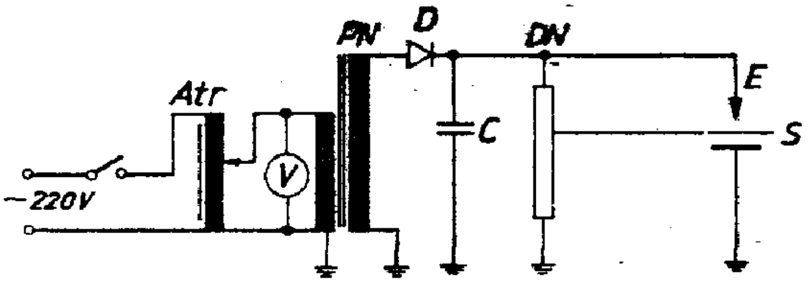

Fig.3. Schematic of arrangement for placing charges
Atr - autotransformer of laboratory type, PN - voltage transformer, D - rectifier diode, C - filtering capacitance, DN - voltage divider, E - H.V. electrode, S - control grid

3.4. Test conditions

It has been shown, during the preliminary testing, that the method and way of preparing the samples have had a marked effect on the test course. Hence, great attention has been given to strict observance of the technological requirements:

- prior to testing all samples have been thoroughly washed with water and wiped dry with a fine cotton cloth,
- then the samples have been washed with ethyl alcohol and stored in an air-tight container with a suitable, moisture absorbing, substance,
- the so prepared samples have been placed on the lower electrode, covered with a thin layer of silicon oil, by means of specially designed stretching rings,
- the surface condition was being controlled continuously and in the case of any irregularities, the samples were repolished and rewashed,
- finally a.c. test voltage has been applied and the measurement performed. Then a charge of required polarity was imposed on that sample and the discharge time lag measured.

4. Test results

The test results have been statistically processed to determine the empirical Weibull's distribution. A program, prepared by the programmers of Łódź Technical University, High-voltage Equipment Testing Division, has been processed on a mini-computer, model MERA-400.

The following have been computed:

1. Parameters of the Weibull's distribution
   - shape parameter - k
   - scale parameter - T_1
   - displacement parameter - T_o
2. Conformity of the empirical distribution function with a theoretical one

   $$\left(H = \frac{\chi^2}{\chi^2_{=0,05}}\right)$$

   by means of an χ^2 standard test.
3. Average value - E(T)
4. Standard deviation - σ

One full cycle (20 ms) of the power frequency (50 Hz) voltage has been used as a time unit in our computations. The results have been listed in the Tables below.

5. Interpretation of the test results

The test results, listed in the accompanying Tabels, indicate that the polarity of a charge, placed on a dielectric, affects a discharge time lag. Positive polarity considerably reduces the discharge time lag and also reduces scatter of the results, while the effect of the negative polarity is negligible. With either polarity charge no tendency to initiate discharges in a specified sine-wave half has been noticed.

The above mentioned observation can be explained by the fact, that when a positive polarity charge is placed on a dielectric, the resultant layer of that charge causes the field intensity to increase.

The higher intensity field "is extracting" the electrons onto the surface. In consequence, such electrons increase the number of a discharge inceptive electrons. In the case of samples with a negative charge, there is no such layer and the surface negative charge repels the free electrons into the dielectric deeper layers. The presented hypothesis requires further confirmation.

Table 1

The test results of discharge delay time
– the charge didn't place on dielectric

t_{odp}	Number of sample	T_0 Number of period (50Hz)	T_1 Number of period (50Hz)	k —	E Number of period (50Hz)	σ Number of period (50Hz)	H —
100	1	0,73	4099,5	0,35	3993,3	241,0	0,35
	2	0,9	833,36	0,31	811,8	48,95	0,3708
	3	0	1030,85	1,0	224,89	12,67	0,3584
	4	0	4737,7	0,54	4615	278,6	0,3511
	5	0	9452,9	0,48	9208,1	555,8	0,4875
	6	0	6335,3	0,56	6171,3	372,5	0,3313
	7	0	9745,8	0,6553	9493,4	573,0	0,7137
	8	0	2208,5	1,0	2021,4	122,0	1,0102
10	1	0	719	1,0	371,8	22,4	1,0171
	2	0,9	10,9	0,345	10,7	0,6	0,485
	3	11,6	41,9	0,361	41,1	1,8	0,592
	4	0	517,1	0,51	312,1	20,1	0,421
	5	0,6	1613,8	0,3894	1572,0	94,9	0,5728
	6	0	812,2	0,72	615,4	38,5	0,313
	7	0	1115,2	0,41	918,2	24,4	0,517
	8	0	213,1	1,0	210,1	15,1	0,102

There were about 30 measurements in each series.

Table 2

The test results of discharge dealy time the positive charge placed on dielectric (There were the same sample in Table 1 and Table 2)

t_{odp}	Number of sample	T_e Number of period (50Hz)	T_1 Number of period (50Hz)	k —	E Number of period (50Hz)	σ Number of period (50Hz)	H —
100	1	0,94	21,8	0,194	21,3	1,2	2,2057
	2	0	30,3	0,4001	29,5	1,8	0,7875
	3	0	212,0	0,38	182,0	15,7	1,21
	4	0	815,0	0,46	762,0	14,2	0,[illegible]4
	5	0	610,0	0,42	600,0	17,9	1,7
	6	0	3875,3	1,0	5275,8	318,5	1,5101
	7	0,88	217,5	0,514	211,9	12,7	1,4839
	8	0	1456,6	1	989,7	59,7	1,5114
10	1	0	5,5	0,4313	5,3	0,3	0,7432
	2	0	12,0	0,5243	11,[illegible]	0,7	0,3527
	3	0	5,1	0,57	[illegible],1	1,2	0,785
	4	0	4,2	0,38	4,[illegible]	1,3	0,834
	5	0	8,3	0,62	8,0	1,3	0,477
	6	0,5	85,5	0,5817	83,3	4,99	0,6201
	7	0	71,1	0,42	52,1	2,8	0,672
	8	0	218,0	1,0	59,4	3,6	0,3017

There were about 30 measurements in each series

Table 3

The test results of discharge delay time - the charge didn't place on dielectric

t_{odp}	Number of sample	T_o Number of period (50Hz)	T_1 Number of period (50Hz)	k	E Number of period (50Hz)	σ Number of period (50Hz)	H
100	1	0	7273,8	0,9051	7085,4	427,7	0,788
	2	0	12141,5	0,9079	9999,0	713,9	0,4853
	3	0	1874,0	0,3412	1825,5	110,2	0,1589
	4	0	11890,5	0,5971	9999,0	704,5	0,373
	5	0	12134,6	0,4583	8141,3	713,5	0,2623
	6	0	1238,8	1,0	789,2	47,6	1,1045
	7	0	2977,6	0,3599	2900,5	175,1	0,6756
	8	0	21357,4	1,0371	9999,0	20743,4	0,4099
10	1	0	230,8	1,0	210,1	12,7	0,2014
	2	0	150,6	0,6547	146,7	8,9	0,6015
	3	0,7	305,2	0,3044	297,3	17,9	0,3002
	4	0	8970,1	0,437	5486,6	331,2	0,376
	5	0,09	2271,3	0,3372	2212,5	133,5	0,6236
	6	0	17759,1	1,0	9492,3	573,0	2,8418
	7	0	907,1	0,371	817,1	27,9	0,637
	8	0	13543,1	1,0	9992,1	684,0	0,763

There were about 30 measurements in each ries

Table 4

The test results of discharge delay - the negative charge plased on dielectric (There were the same sample in Table 3 and Table 4)

t_{odp}	Number of sample	T_o Number of period (50Hz)	T_1 Number of period (50Hz)	k	E Number of period (50Hz)	σ Number of period (50Hz)	H
100	2	0	24,5	0,5349	25223,9	1,4	0,165
	3	0,76	4363,6	0,2576	4250,7	256,5	0,3229
	4	0,72	2700,5	0,3211	2630,6	158,7	0,5091
	5	0	3481,0	0,625	3390,8	204,7	0,2864
	6	0	3022,6	1,0	1677,1	101,2	1,4596
	7	0	14746,8	1,12	9999,9	847,7	1,7261
	8	0	14559,6	1,0	9999,9	764,8	0,9802
	9	0	9690,2	0,5066	9439,2	569,8	0,5739
	10	0	12339,7	0,7385	9999,9	725,6	0,2433
10	2	0	51,5	0,5632	50,2	3,02	0,068
	3	0	2291,8	0,3612	2232,5	134,8	0,8439
	4	0,66	3301,5	0,2866	3216,0	194,0	0,8274
	5	0	7113,2	0,4275	6929,0	418,2	0,337
	6	0	7739,2	0,6281	7538,7	455,1	0,3032
	7	0	4475,9	1,07	4308,9	260,1	0,9682
	8	0	4069,5	0,7101	3964,0	239,3	0,4038
	9	0,69	5663,5	0,1686	5516,8	332,9	0,6103
	10	0	9909,8	0,5025	9653,0	582,7	0,3894

There were about 30 measurements in each series.

6. Summary

As has been already mentioned, our studies have been essentially, an attempt to explain the causes of the inceptions of discharges in very small gaseous spaces, present in practical arrangements. The studies have been carried out as a part of a general program, under the heading "Electrical discharges in gases and vacuum", sponsored by the Polish Ministry of Education (Program No. R.1.13). It has been already known [2], that a gaseous space (void), due to its very limited size, is not the only and main source of a discharge inceptive electrons.

It has been therefore suggested that the surface closing such a gaseous void, might be the main source of the electrons. It has been shown in [2] that the statistical time lag of a discharges, should satisfy the Weibull's distribution of a shape parameter, determined by the rate of appearance of the discharge inceptive electrons.

Our studies have concentrated on the measurement and analysis of a discharge time lag, for small size gaseous woids, versus parameters describing the surface, closing (bounding) the void and also as a function of the kind and pressure of the gas filling it. The test results have shown that:

1. Kind of a dielectric covering one of the surfaces enclosing a gaseous void, considerably affects a discharge time lag, expressed as a function of the rest time. Use of a dielectric of higher surface resistivity as a covering of a flat plate electrode, has resulted, for a given rest time, in certain increase of the time lag.

2. Kind of the gas used has no visible effect, neither on the discharge time lag itself, nor on the doscharge time lag, expressed as a function of the rest time.

3. Effect of the dielectric used is inversly proportional to the pre-voltage interval (varying from 1 to 100 s).

4. Effect of the dielectric used is more pronounced for a sample tested for the first time than for a sample already subjected to discharges for a prolonged time.

5. Positive polarity charge on a dielectric surface considerably reduces a discharge time lag.

It seems that the test results support the presented hypothesis i.e. that in the case of small volume gaseous voids the effect of the surface of a dielectric on the discharge inception mechanism is decisive, when compared with the effect of the gaseous void itself. It is further evident that the tests so far performed are still not fully representative, to present a model of such effects. The problem is being further investigated. At present, it seems that the simplest explanation of the relationship between the time lag and kind of the dielectric, covering one of the surface enclosing a gaseous void, is to assume that the surface resistivity is primarily responsible for the emission intensity of the electrons for the rest time range from 1 to 100 s. Greatest effect would have a charge settling on the walls enclosing a gaseous void and more precisely, variations, of the charge concentration on the cathode, with time.

We can further say that the tests on a discharge time lag as a function of the rest time for various dielectrics may be one of the methods to determine the ability of a dielectric to maintain the partial discharges, initiated by the voltages (e.g. internal overvoltages). The greater the slope of the curve $T_{op} = f(T_{odp})$ the more difficult to maintain a discharge in a given arrangement.

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