STREAMER PROGRESS IN DIELECTRIC LIQUIDS

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Abstract: A breakdown criterion in liquids has been deduced to reach a value of 25. The streamer has been divided into three stages bush like structure one with values equal or greater than breakdown index, with critical field 3 MV/cm. And the second stage consist of two modes. The first one with breakdown index less than 25 and inception field of 21.5 MV/cm. The second mode streamer with breakdown index greater or equal 25 under the same inception field. The streamer may stop or complete its progress toward breakdown. According to available published data the bush streamer must advance not than fifth to fourth the gap distance. In this paper the streamer must advance ahead of the bush zone in the gap toward the breakdown when the prospective electric field achieve a breakdown index of 25 at 66% of the gap distance. This result can be considered as a new criterion for streamer progress. This finding has been applied to many experimental data and yield a good result.

1 INTRODUCTION

The streamer inception electric field in dielectric liquids has not yet identified clearly as in gases and solid dielectrics. Thus the authors start an effort for clearing the streamer mechanism in dielectric liquids under an energy balance concepts [1], which gives a breakdown index of 25 and three streamer stages. First one as bush like structure, with inception field 3 MV/cm and velocity of tens of m/s. The second one is tree like structure with electric inception field of 21.5 MV/cm and two modes, first modes with velocities from sound speed in air till1.4 km/s (sound speed in liquids). The second mode with velocities of tens of km/s and more.

2 STREAMER MECHANISMS

2.1 Bush-like streamer

The equation relating electric field and injected energy W in this stage, can be given by [1]

$$\frac{W}{W_c} = \left(\frac{E}{E_c}\right)^2 \geq 25 \qquad (1)$$

Where
W : actual applied energy
W_C : critical energy required for formation of one fine branch in bush structure.
E : actual applied electric field.
E_C : critical electric field required for one air branch formation.
The breakdown index given from energy balance analysis is 25. The critical electric field E_C equal 3 MV/cm and maximum electric field in zone is less than 21.5 MV/cm.

2.2 First mode of streamer structure

This mode is given by the following equation [1]

$$\frac{W}{W_{st}} = \left(\frac{E}{E_{st}}\right)^2 = \left(\frac{v}{v_{st}}\right)^2 < 25 \qquad (2)$$

Where E_{st} is the streamer inception field 21.5 MV/cm, v is the the streamer velocity and v_{st} =1.4 km/s and E_{st} is sufficient to generate energy equal to the dissociation one.

2.3 Second mode of streamer structure

This mode is given by the following equation [1]

$$\frac{W}{W_{st}} = \left(\frac{E}{E_{st}}\right)^2 = \left(\frac{v}{v_{st}}\right)^2 \geq 25 \qquad (3)$$

The streamer velocity in this mode is more than 7km/s.

3 STREAMER ADVANCE IN DIELCTRIC LIQUIDS

The streamer start as bush-like structure and then further advance as a tree structure. The streamer may stop or complete its progress till breakdown. The streamer progress can be divided into three stages. The first one is bush-like structure and advance with low velocities from tens of m/s till less than 331 m/s (speed of sound in air) and critical electric field E_C for one branch imitation is 3.15 MV/cm, but to what extent this stage, with huge number of branches, will continue in the gap?. According to [2], it mush be advance not more than fifth to forth gap distance. But with further increase of electric field till 21.5 MV/cm the streamer becomes tree like structure as given before, *i.e.* One streamer stem with low number of branches emanate from the bush like zone. The question now is to what extent this streamer will advance in the gap?. And what are factors affecting its progress.

3.1 Factors affecting streamer progress in dielectric liquids

After bush zone when the electric field exceeds 21.5 MV/cm the following new criterion must be checked:

i. The prospective electric field (E) at 66% of the required test gap is estimated.
ii. The ratio (E/E_{st}) must be equal to the breakdown index 25.
iii. When the prospective ratio $(E/E_{st})^2 = 25$, the streamer will complete its advance till complete breakdown, if not, the streamer will stop.

4 STREAMER LENGTH DETERMINATION

The streamer start as bush-like structure firstly and then further advance as a tree structure. The streamer may stop or complete its progress till breakdown, see Figure 1.

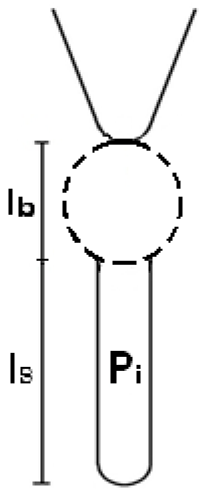

Figure 1: Streamer length determination

Under balance condition concerning the streamer, the energy delivered to the critical volume at the bush-like streamer zone tip (5 µm), under electric field equal or greater than 21.5 MV/cm will be consumed to extend the streamer channel into the dielectric liquids, see Figure 1. The following equation can be given

$$\frac{1}{2}\,\varepsilon E^2\, v_o = P_i\,(\pi r_o^2 l_s) \qquad (4)$$

Where v_o is the critical volume with radius r_o, which is the same radius of streamer channel, P_i internal pressure inside the channel $P_i = \frac{2\sigma}{r_o} + P_a$ where σ is the surface tension, P_a is the applied pressure and l_s is streamer length, thus

$$l_s = \frac{2\varepsilon E^2 r_o}{3P_i} \qquad (5)$$

$$l_b = \frac{d}{5} \qquad (6)$$

5 APPLICATION OF STREAMER PROGRESS CRITERION

The new criterion has been applied to the experimental results given after [3]. For gap 8cm, r= 3 µm and applied voltage 95 kV, the streamer length reach 4.2 cm value, see Figure 2, the analysis according to the new criterion is

a) The bush-like structure zone extends from fifth to forth as given after [4].
b) At the periphery of the bush-like structure, the streamer developed with nearly 5 µm radius and extends in the liquids medium till it stop or complete breakdown according to equation (4).

According to the given data, E = 68.3 MV/cm, $P_i = 1.138 \times 10^5$ N/m^2, r_o = 5 µm, ε_r = 2.1. The value of l_s 2.5 cm and l_b = 1.6 cm and the total length 4.1 cm which is nearly the same value as experimentally reported 4.2 cm [3], see Figure 2.

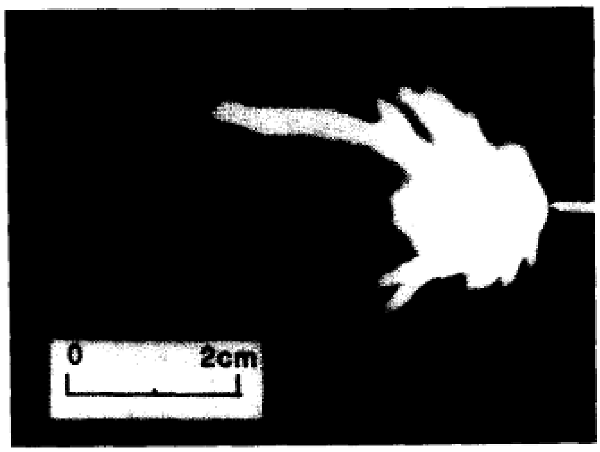

Figure 2: Positive streamer Length L = 4.2 cm. Inception voltage V = 95 kV, point-plane geometry, gap d = 8 cm, tip radius r = 3 µm, after [3].

Also the prospective E at 66% of the gap distance (at 5.28 cm) reach 77.3 MV/cm and $(E/E_{st})^2$ equal 12.8 which is less than the breakdown index (25) and according to the new criterion the streamer must stop which is the same result as given after [3].

The most interesting result [3] is at 15 cm gap, r = 3 µm, applied voltage 150 kV, the prospective E at 66% of the gap equal 113.32 MV/cm and $(E/E_{st})^2$ = 27.5 which is more than 25 (breakdown index), therefore streamer advance and complete breakdown occurs.

Also, the same application can be carried out for V = 100 kV, r = 3 µm, gap 8 cm, streamer length 4.3 cm [3], l_s= 2.8 cm, l_b= 1.6 cm and streamer length = 4.4 cm which agree welll with the experimentally given value (4.3 cm), see Figure 3.

The prospective electric field at 66% of the gap (5.28 cm) reach 81.34 MV/cm and $(E/E_{st})^2$ = 14.18 < 25 (breakdown index). Accordingly, streamer stop, see Figure 3.

5.1 Effect of external pressure on the streamer length

The streamer length decrease as the external pressure P_a increases according to equation (4)

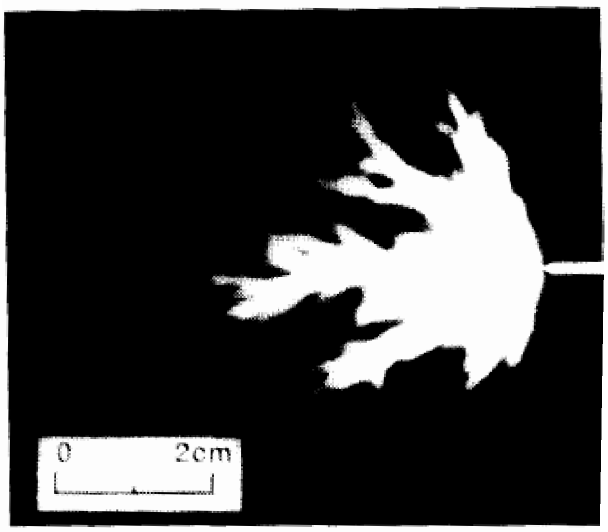

Figure 3: Positive streamer length L= 4.3 cm, V = 100 kV, point-plane geometry, gap d = 8 cm, tip radius r = 3 µm**,** after [3]**.**

which agree well with the result given after [2], (gap d = 2.2 mm, r_o = 1.4 µm, V = 15kV), see Figure 4. The calculated streamer length at P_a= 0.1 MPa is L = 1.054 mm and from experimental data, Figure 4, L =1.016 mm which agree well with it.

Under P_a = 1 MPa, L = 0.465 mm and from experimental results, Figure 4, L = 0.429 mm, which means that the new equation gives reasonable results compared with actual experimental data.

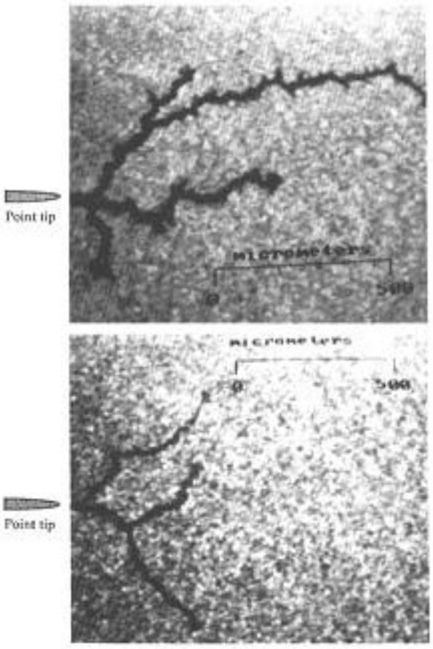

Figure 4: Shadow photographs of filamentary streamers in pentane: (a) P = 0.1 MPa and (b) P = 1 MPa. In both cases, V = 15 kV, tip radius r = 1.4 µm and gap d = 2.2 mm, plane diameter 20mm, after [2].

Also after [5] which shows that the critical length of propagated streamer in insulating liquids, which reach 77% of the gap, the streamer never stop, which agree well with the new devised criterion for streamer advance.

6 CONCLUSION

When the applied electric field is low 3 MV/cm till < 21.5 MV/cm, the streamer assume bush like structure. With low velocities varies between tens of m/s till < 331 m/s.

The distribution of bush channels increase as electric field increase. With nearly 4 µm radius and maximum extends in the gaps from fifth to fourth of the gap distance.

At 21.5 MV/cm and more the streamer is tree like structure emanate from the bush zone with stem of nearly 5 µm radius, with velocity > 331 m/s till 1.4 km/s and increase with field increase till it reaches 7 km/s and more and streamer velocity reach tens of km/s in the last regions of breakdown especially when the breakdown index reach 25 at 66% of the gap distance.

With further electric field increase the streamer advance in the gap and will continue to complete breakdown when the prospective electric field at 66% of the gap achieve a breakdown index 25. If not streamer will stop.

The application of the new streamer advance criterion given by the present paper assume good results with experimental data.

7 REFERENCES

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