Streamers and partial discharges in water

2016 J. Phys.: Conf. Ser. 754 102005

(http://iopscience.iop.org/1742-6596/754/10/102005)

Streamers and partial discharges in water

S M Korobeynikov[1, 2] and A V Melekhov[3]

[1] Lavrentyev Institute of Hydrodynamics SB RAS, 15 Lavrentyev Prosp., 630090, Novosibirsk, Russia
[2] Power Engineering Faculty, Novosibirsk State Technical University, 20 Prosp. K. Marksa, 630073, Novosibirsk, Russia
[3] Institute of Laser Physics SB RAS, 13/3 Lavrentyev Prosp., 630090, Novosibirsk, Russia

E-Mail: korobeynikov@corp.nstu.ru

Abstract. Several types of streamers are considered in the paper, usual streamers, nonelectrode and postbreakdown streamers. Attempts of pulse electrical strength increase with the help of conductive layers and the reasons for unusual streamers appearance are discussed.

1. Introduction

Deionized water is the most suitable dielectric liquid for pulsed power systems for different purposes. This is due to high dielectric permittivity, high pulse electric strength, explosion and fire safety, low decomposition after breakdown. Study of streamers is very important in course of pulse electric strength increase and energy storage increase.

The goal of the paper is an analysis of different forms of streamers in water, using the experimental results obtained in the previous works of the authors [1-4].

2. Streamers

The form of the streamer depends on polarity of the electrode where it originates. Electrical streamer is formation of conductive (may be slightly conductive) area close to electrode and spread of this area in form of branched structure in the direction to the opposite electrode. The form and properties of streamers depends on the polarity of electrode where it was initiated.

2.1. Usual streamers

Streamers are usually initiated on the electrode surface. A cathode streamer (that originates on the cathode and spreads to anode) has form of bush-like structure. These streamers are opaque and have subsonic velocity of propagation to the anode (figure 1). An anode streamers have transparent filament structure which spreads with supersonic velocity (figure 2).

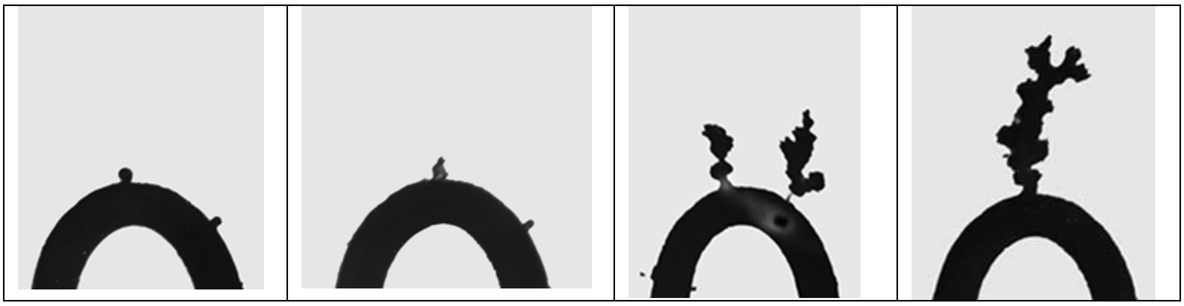

Figure 1. The stages of cathode streamers initiated by the bubble located on the electrode surface [1].

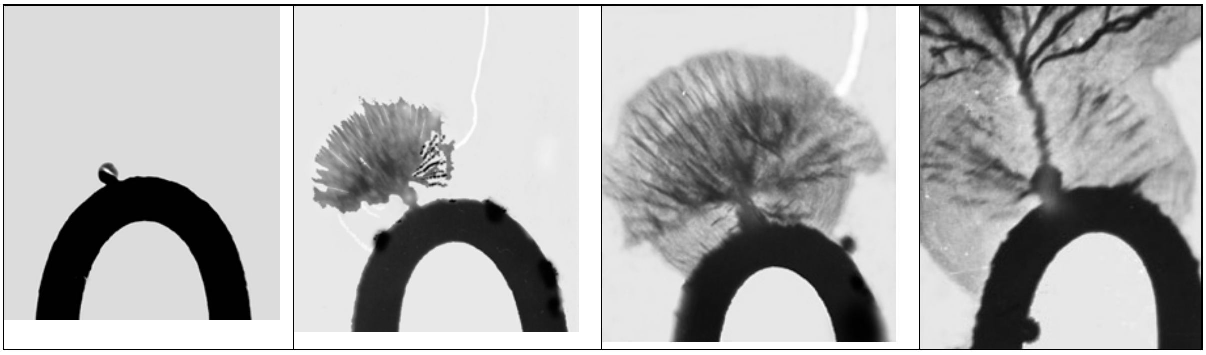

Figure 2. The stages of anode streamer initiated by the bubble located on the electrode surface [1].

2.2. Nonelectrode streamers

These streamers appear in the case of screened electrodes. Screening is electric field decrease near electrodes through formation of conductive layers close to anode or close to both anode and cathode. Nonelectrode streamers are initiated in the region of high field. Their form could be considered as two semi streamers. The anode directed semistreamer is very similar to the usual cathode streamer, and the cathode directed semistreamer is similar to the usual anode directed streame (figure 3). In all registered pictures nonelectrode streamer don't lead to gap breakdown, therefore appearance of this streamer is partial discharge.

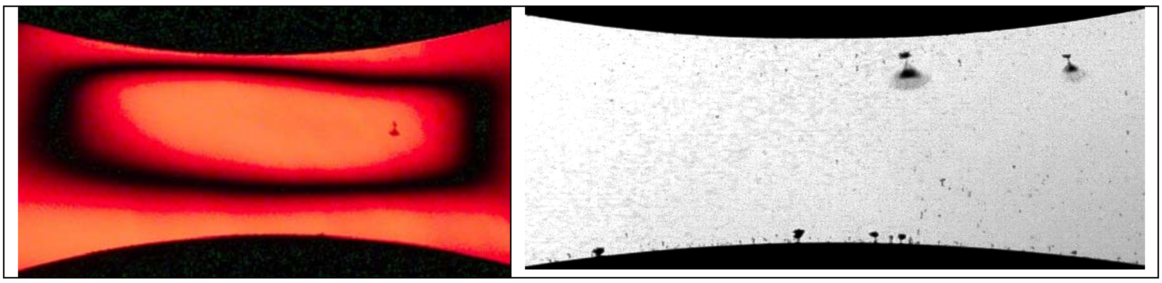

Figure 3. Typical pictures of nonelectrode streamers [2,3].

2.3. Postbreakdown streamers

These kinds of streamers appear in the case of screened electrodes when gap breakdown occurs. It has supersonic filament structure that propagates from main breakdown channel (figure 4).

Figure 4. Postbreakdown streamers [4].

3. Discussion

3.1. Attempts to increase pulse electrical strength.

A pulse breakdown strength is controlled by two main factors. First one is the velocity of streamer propagation. Another one is the streamer initiation. In our opinion, the initiation is the key factor of breakdown process. That is why an influence upon initiation is most evident way to increase pulse electrical strength of water. The initiation requires strong electric field, therefore the decrease at the place of streamer initiation should lead to electrical strength increase. There were two successful attempts to increase pulse electrical strength of polar liquids by formation of conductive layers close to electrodes. First one is electrolyte forcing through porous electrode [5]. The pure water is in central region of the gap, near-electrode regions contain electrolyte that lead to high conductivity of near-electrode layers. Under the action of pulse voltage, its conductivity leads to formation of space charges and decrease of electric field at electrode surfaces and increase in the inner part of gap. Experiments [5] had shown that pulse electrical strength was increased 3-4 times in comparison with strength of gap without conductive layers. Figure 5 shows the sketch of interelectrode gap with conductive layers near electrodes and pure dielectric liquid in the central region of the gap. An approximate diagram of electric field through the gap is shown in figure 6.

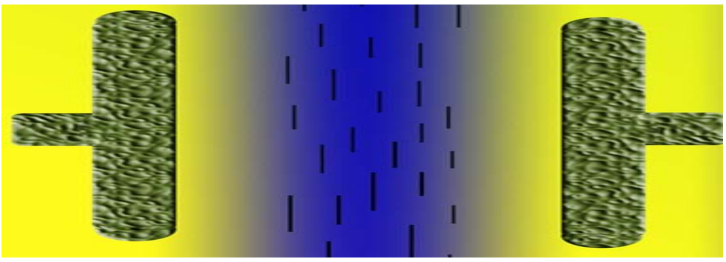

Figure 5. Sketch of the interelectrode gap with the conductive layers.

The same idea concerning near-electrode conductive layers formation was used in [6]. The experiments were performed in glycerol; the conductive layers were formed by pulse heating of electrodes. Heat transfer from electrodes into liquid leads to temperature increase near electrodes that in turn leads to sharp increase of liquid conductivity. In our experiments, the pulse electrical strength of glycerol increased no less than two times in comparison with strength of gap with cold electrodes.

Our experiments [2,3] with screened electrodes exploited the same idea, but conductive layers in water were formed by application of the special modified electrodes. As far as the increase of the pulse electrical strength, the effect was obtained. According to electrooptical measurements, the maximal electric field in the center of the gap was 1 MV/cm, and the electric field near electrodes was 400 kV/cm. The mean electric field strength was 700 kV/cm. If we take into account that the breakdown field strength of the gap without conductive layers was 400 kV/cm, then the pulse breakdown strength in these experiments was increased approximately by 1.7 times.

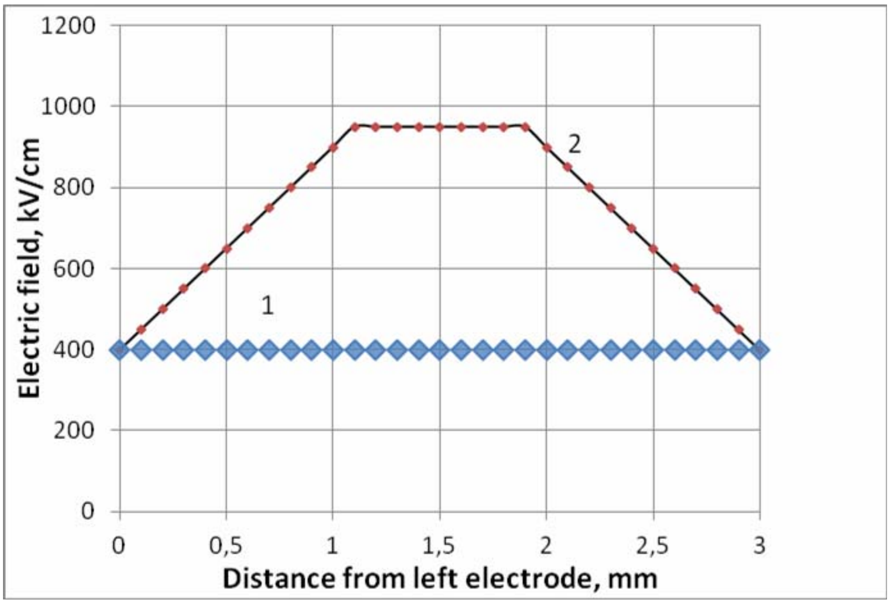

Figure 6. Qualitative diagram of electric field without the conductive layers (1) and with the conductive layers (2). The electric field E near the electrodes is equal to 400 kV/cm.

3.2. Peculiarities of streamers

The main features of positive and negative streamers were discussed earlier [7]. Here one should consider other features that appear in the case of screened electrodes: non-electrode and postbreakdown streamers.

3.2.1. Nonelectrode streamers. As it was discussed in section 3.1 electrodes screening leads to hinder of usual streamer initiation. That is why sometimes another possibility of streamer initiation could be realized. The electric field inside the gap is higher than for usual non modified electrodes. The problem of initiation in this area lies in the absence of initiating electrons. Usually it is supposed that electrode surface is the source of initiating electrons that appears as a result of absorbed negative ions break-up under the action of electric field. In our opinion the initiating electrons in the bulk of liquid could appears due to the same reason in case of microparticles presence in the liquid. If we take into account that particles amount with sizes from micrometer to hundred of micrometer is from 100 to 1000 per cubic centimeter [8], the total specific surface is small, then number of negative ions is small too. Hence, the number of potentially free electrons is small and the probability of breakdown initiation is not so high, so the electric field strength should be greater than in the case of usual electrodes.

Nonelectrode streamers have two other features. First one is form of semistreamers. Anode directed semistreamer looks like usual cathode streamer and cathode directed semistreamer looks like usual anode streamer. It points out on the conclusion that mechanisms of semistreamers propagation is the same as for usual streamers. The additional argument of this conclusion is length of cathode directed and anode directed semistreamers. The cathode directed semistreamer is 4 times longer than the anode directed one. It coincides with the velocity relation of usual streamers. If we take into account that semistreamers are initiated simultaneously then the length of subsonic cathode streamers should be 4 times less than the length of anode supersonic streamers.

Another feature is the mechanism of streamer propagation. It is clear that the field intensity is high at the head of streamer. According to our estimations, its value is E ~10 MV/cm [9]. How could this value be supported during propagation while streamer surface is increased? Evidently that additional charge should be brought to the tip of streamer branches. In the case of the usual streamer, this additional charge is supplied by conductive connection of streamer branches with electrodes. In the case of the nonelectrode streamers the source of additional charge for one semistreamer is propagation of other semistreamer only. As it was shown early [1], a set of usual anode streamers disappear after some growth. In our opinion it is due to impossibility of high field support at the tip of long low conductive streamers. That is why all except one usual anode streamers disappear and only one streamer becomes more conductive and, as a result, the new set of streamers emerges at its tip. In the case of nonelectrode streamers when the cathode directed semistreamer gets in touch with the cathode, this will not lead to breakdown acceleration but to termination of streamer propagation. So, one can conclude that conductivity of cathode directed semistreamer is not high.

3.2.2. Postbreakdown streamers. The reason of this kind of streamers appearance is space charge that appears in conductive layer as a result of voltage rise. When breakdown of the gap occurs this space charge produces high electric field. The mechanism is described below.

The electrical properties of a layer with specific conductivity σ are determined by the Maxwell relaxation time $\tau_m \approx \varepsilon\cdot\varepsilon_0/\sigma$ and the voltage rate, e.g. the characteristic time rise τ_r in case of pulse voltage increase or trailing edge τd in case of pulse voltage decrease. When $\tau_r >> \tau_m$ in near-electrode area, the space charge is formed during the total pulse time rise duration. This space charge leads to electric field redistribution. It is clear from Poisson's equation that gradient conductivity σ leads to electric heterogeneity in the gap and emergence of space charge with density $\rho(x) \approx \varepsilon\cdot\varepsilon_0\cdot(dE/dx)$. The electric field intensity decreases near the electrodes but increases in central region of the gap. Breakdown is equivalent to sharp decrease of voltage. When $\tau_d << \tau_m$, the current space charge couldn't disappear instantly and according to Poisson's equation should form fundamentally new electric field distribution. The electric field is created here by the space charge only but with the new boundary condition: the potential of both electrodes and of the breakdown channel becomes equal to zero. In this case the strongest field appears at the conductive layers boundary near the breakdown channel. It is interesting that in the cathode layer (negative space charge) electric field is directed from breakdown channel that is why this part of channel becomes transient anode. Analogically, the anode conductive layer (positive space charge) electric field is directed to breakdown channel, therefore this part of the channel becomes transient cathode. One could show that the electric field intensity in both cases is high enough for streamer initiation: subsonic bush-like streamers in the positive space charge zone and supersonic filament streamers in the negative space charge zone. The last kind of streamers can be seen in figure 4. Subsonic streamers are in the afterbreakdown shock wave region and couldn't be displayed due to a change of the refractive index in the shock wave region.

4. Conclusion

As a result of optical and electrooptical investigations of streamers in water, the following conclusions can be made:

1. Conductive layers near electrodes lead to electric field decrease on the electrodes that, in turn, lead to pulse electric strength increase.
2. Nonelectrode streamers develop in form of two semistreamers: the anode directed semistreamer looks like a usual cathode streamer, while the cathode directed semistreamer looks like a usual anode streamer.
3. Registered postbreakdown streamers develop as usual supersonic anode streamers.
4. The reason of both nonelectrode and postbreakdown streamers is the conductivity of thin layers near the electrodes that leads to space charge appearance.
5. Nonelectrode streamers are new type of partial discharges.

Acknowledgments

One of the authors (S.M.K.) is grateful to RNF (grant No. 16-19-10229) in part concerning new form of partial discharge – nonelectrode streamers.

5. References

[1] Ushakov V Ya, Klimkin V F and Korobeynikov S M 2007 *Impulse Breakdown of Liquids,* (Berlin: Springer-Verlag GmbH) p 397

[2] Korobeynikov S M and Melekhov A V 2011 Nonelectrode streamers in deionized water *IEEE Trans. on Plasma Science* **39** 2632–3

[3] Korobeynikov S M, Melekhov A V and Posukh V G 2014 Nonelectrode and postbreakdown ionization processes in water *IEEE Trans. on Plasma Science* **42**(4) 965–8

[4] Korobeynikov S M, Melekhov A V and Vagin D V 2016 Prebreakdown processes and electric fields in water with screened electrodes *Proc. Int. Conf. on Dielectrics* (Montpellier: University Press) 808–12

[5] Vorob'ev V V, Kapitonov V A, Kruglyakov E P and Tsidulko Yu A 1980 Breakdown of water in a system with 'diffusion' electrodes *Soviet Physics Technical Physics* **25**(5) 598–602

[6] Korobeynikov S M, Yanshin E V, Ovchinnikov I T,Yanshin K V, Sarin S G, Kopylov V M and Klepikov A V 1995 Physical processes limiting the pulse energy release in liquid dielectrics. *Conf. Record of Int. Conf. on Pulsed Power* (Albuquerque) p 2

[7] Tobazéon R 1988 Streamers in liquids *The Liquid State and its Electrical Properties* Kunhardt E E, Christophorou L G and Luessen L H eds. (New York: Plenum Press) 465–78

[8] Besov A S, Kedrinskii V K and Pal'chikov E I 1984 Study of the initial stage of cavitation by a diffractive-optics method *Soviet Technical Physics Letters* **10** 100–2

[9] Korobeynikov S M and Melekhov A V 2014 Estimations of the electric field strength of nonelectrode streamers in water *High Temperature* **52**(1) 129–31