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Abstract

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NEW MATERIALS ON THE INITIAL STAGES OF A SPARK

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In discharge gaps with a substantially nonuniform field, the development of a spark passes through several stages: pulse corona, leader, main, and final. Over the long period of study of these stages, extensive material has been accumulated on them ([1]). New possibilities for studying spark development were obtained thanks to the development of an electro-optical converter (image-converter camera) with amplification of the luminous flux. Below are set forth some results obtained with the aid of an image-converter camera constructed in the high-voltage gas-discharge laboratory of the G. M. Krzhizhanovsky Power Engineering Institute.

The pulse corona in a positive sphere–plane gap (+ sph—pl), as is known, consists of branching formations, shown (for the case of a sphere $d = 12.5$ cm and gap length $S_0 = 105$ cm) at a wave amplitude $U_m = 400$ kV and a front shape of 2 μsec, with a fall to half the amplitude value of 100 μsec, in Fig. 1A. On the basis of static photographs, these formations were given the name ([2]) of "elements" of the pulse corona, each consisting of a stem and a branch. With the aid of static photographs and voltage cutoff across the gap, the ([3]) average velocity of branch development was determined to be $5 \cdot 10^8 \div 10^9$ cm/sec. Later E. N. Brago, from a photograph with time sweep made by an image-converter camera, showed that in reality the stem and the branch develop simultaneously, but the first with an average velocity $\sim 10^8$ cm/sec, and the second with an average velocity $\sim 10^9$ cm/sec. The use of an image-converter camera with amplification, and the implementation of a faster sweep while using highly sensitive film, allowed us to discover that the corona branch has, during development, substantially different velocities and structure.

Figure 1B shows a photograph with a sweep of several elements of the pulse corona. Photographing a branch with the aid of a sweep calibrated by an electronic oscilloscope showed that the corona branch develops with a substantially varying velocity. In the first stage of branch development, in which it reaches approximately half of its full length, the velocity is $V_1 \approx 5 \cdot 10^9$ cm/sec, and in the second stage $V_2 \approx 2 \cdot 10^8 \div 3 \cdot 10^8$ cm/sec*.

Determination of the velocity of development of stems is made difficult by their great brightness and the width of the image.

Investigation by an image-converter camera of the pulse corona in a sphere + plane gap at various S_0 and U_m revealed an analogous structure of its branches

Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

and stems.

In Fig. 2A are shown a static photograph of the pulse corona and, in Fig. 2B, its sweep at $S_0 = 52$ cm and sphere diameter 12.5 cm, $U_m = 440$ kV (without cutoff). As can be seen, in its first stage the branches develop with velocity $V_1 \sim 5 \cdot 10^9$ cm/sec, and in the second with velocity $V_2 \sim 2 \cdot 10^8$ cm/sec. Further, contrary to the existing opinion ([2]) that only after contact of the branches of the negative corona of the plane with the latter does development of stems and plasma channels begin, the image-converter records showed that development of these phenomena is observed long before the visible contact of the corona branches with the plane. In this case the average velocity of the plasma channels is $\sim 2 \cdot 10^7$ cm/sec.

The photograph in Fig. 3 shows, in addition to the pulse corona, the initial stage of the leader. The discharge developed in a + sph—pl gap at $S_0 =$

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* A. V. Shkilev took part in carrying out the experiments and processing the materials.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

= 55 cm. The voltage was cut off by the second gap at an amplitude $U_m = 350$ kV. A photograph of the initial stage of the leader makes it possible to see that its channel is formed by a bright head of small extent (2–3 cm). After forming, the leader head quickly goes out and flashes again in the immediate vicinity of its previous position. Thus the leader channel and its branches are lengthened.

With each flash of the leader head, bundles of filaments arise from it, propagating toward the plane with an average velocity of $4 \cdot 10^7$ cm/sec. It is interesting to note that the velocity at which the bundles emerge from the leader head

Figure 3

Figure 3: Figure 3

Figure 4

Figure 4: Figure 4

is considerably greater than the velocity of their subsequent advance in the gaps. This feature, as has been noted, is characteristic of a pulsed corona. The role of the bundles in creating through-conductivity and in orienting the leader channels is seen in Fig. 4, where the spark develops in a + rod—plane gap, with a small rod simulating a lightning conductor mounted on the latter. Here, already at leader-channel lengths of 10–12 cm, the bundles of filaments terminate on the plane and on the rod. At the same time, as the heads of the leader channels advance, the intensity of the bundles increases and the through-conductivity (as shown by the current oscillograms) increases. When a sheet of polyethylene (of thickness ≈ 0.5 mm) is placed in the path of the development of the filaments, the latter cease their development upon contact with the obstacle. The reason for this may be both absorption of photon radiation and direct deceleration of electrons.

The formation of filaments apparently occurs analogously to the development of the branches of a pulsed corona (3), owing to the displacement from the high-voltage electrode toward the plane of a narrow ionization front. However, essentially new factors are present here. The lengthening leader channel, possessing high conductivity, changes the potential distribution in the gap in a step-like manner, increasing the gradients, which promotes the lengthening of filaments that arose at earlier stages of channel development. Although the filaments emerging from the leader heads propagate in a region of space where filaments from earlier-formed heads have already passed, no noticeable influence on the velocity of the filaments or on their external appearance is observed.

The development of filaments (in static photographs) was observed in + rod—plane gaps at lengths S_0 up to 400 cm. In this case, when the length of the cut-off leader was only 50–60 cm, the filaments developing from it crossed the entire gap. Since, with increasing overvoltage in the gap, the intensity of the filaments increases, it may be concluded that filaments can reach considerably greater lengths. The development of the counterleader occurs in that bundle of filaments whose intensity is sufficient for the detachment of a thermoionized channel. It is fundamentally important to note that, contrary to existing notions, it is not the leader head that "seeks" the lightning conductor, but the bundles of filaments that predetermine the possibility of its being struck. In this connection, the cessation of development of a leader branch from the upper electrode, even when a lightning-conductor leader is formed, stops the development of the latter. However, the appearance of another branch may lead to the lightning conductor being struck by the spark. Thus, the striking of a lightning conductor is a probabilistic process of formation of bundles of the leader developing from the upper electrode.

It should nevertheless be emphasized that extrapolation of these results to the case of lightning remains as yet unsubstantiated. On the other hand, the materials obtained should influence the modification of theories describing the corona and leader stages of a long spark.

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Note: Figure translations are in progress. See original paper for figures.