Statistical Investigations
of the Electrical Breakdown

The statistical nature of the breakdown forces the researchers to use statistical methods of measuring its key parameters and processing measurement results.

The statistical approach not only increases the reliability of the data used in practice but also provides a method of investigating a breakdown nature. This is especially valuable when direct methods of observation of the discharge processes in space and time cannot be employed. In the study of the pulsed breakdown, the most important time characteristics are the statistical discharge time lag, discharge formation time, and discharge (or breakdown) time lag. (A description of the special features of the application of the term statistical discharge time lag applied to the discharge in liquids see in Sect. 2.4.4).

5.1 Possibilities and Methods of Statistical Investigations

5.1.1 Relationship between the Statistical Characteristics
and Nature of the Discharge Processes

The statistical theory of liquid dielectric breakdown, first formulated in [1,2], was further developed by other authors (for example, see [3]), and statistical approaches to calculations of high-voltage insulation, including liquid one, were generalized in [4].

A character of distribution of the discharge formation time \( t_f \) can be elucidated experimentally if the average statistical time lag is \( \bar{t}_{st} \approx t_f \). Measurements of the breakdown time lag for \( n \)-hexane at high field strengths (in the nanosecond range) have demonstrated that the \( t_f \) distribution is close to a normal one [5]. With allowance for this, the distribution of the total breakdown time lag is determined as a superposition of the exponential (\( t_{st} \)) and normal distributions (\( t_f \)) [6]. Exponential distributions of the breakdown time lag were obtained in [7] for the nanosecond breakdown of the transformer oil and distilled and tap water in gaps 31 and 36 \( \mu \)m long with uniform fields.
Results of statistical investigations of the time breakdown characteristics including $t_f$ were used in [8,9] to estimate the mobility of charge carriers in strong electric fields. In connection with the contradictory conclusions about the character of the $t_{\text{lag}}$ distribution and in connection with the fact that very short (a few tens of microns) interelectrod gaps were used in these studies, the time lag distributions for the nanosecond liquid breakdown of long (0.75 and 1.5 mm) gaps with a uniform field were investigated in [10]. As in [5,6], a normal $t_{\text{lag}}$ distribution was obtained, and it was concluded that the relative contribution of $t_{\text{st}}$ to the total breakdown time lag $t_{\text{lag}}$ is small for nanosecond breakdowns of liquids in comparison with the relative contribution of $t_f$.

Investigations of the electric discharge propagation from anode in distilled water (with a quasi-uniform field) performed in [11] demonstrated that $t_{\text{st}}$ strongly decreased with increase in the field strength. Statistical measurements of $t_f$ demonstrated that the average discharge propagation velocity amounted to $\sim 10^6$–$10^7$ cm/s as a function of the field strength.

Important information on the pre-breakdown processes can be obtained from an analysis of probability distributions of some characteristic quantities, for example, the duration of pre-breakdown luminescence, breakdown field strength, breakdown time lag, etc.

Pre-breakdown light pulses were observed in hydrocarbon liquids at field strengths $E \sim 0.4$ – 0.7 MV/cm with the use of a photomultiplier [12]. It appeared that their occurrence is random in character. The statistical analysis of the time lag between the moment of voltage application and the first and second light pulses demonstrated that the average frequency of their occurrence depends on the field strength, electrode material, and liquid type. It was assumed that the light flashes were due to microscopic discharges near the electrodes caused by small charged particles and initiating the gap breakdown in strong electric fields. The time lag distribution for the first light pulse in $n$-hexane was investigated in [13]. It was found that the character of distribution changed at high field strength $E \sim 2.3$ MV/cm (in the nanosecond range), thereby indicating the change of the discharge initiation mechanism.

Results of statistical analysis of the breakdown field strength in liquid helium were presented in [14]. The two characteristic maxima caused by a superposition of two distributions were established. Different characters of the pressure influence on these distributions were revealed. The dependence of the position of the first distribution (characterized by a lower breakdown field strength) on the pressure was in agreement with the hypothesis about the bubble breakdown mechanism. The position of the second distribution was determined by the liquid density and was independent of the pressure. The different mechanisms of liquid helium breakdown were hypothesized.

The breakdown time lag distribution for $n$-hexane (in the Laue coordinates) versus the interelectrode distance was investigated in [15] for voltage pulse duration of $\sim 100$ ns. It was found that at a certain critical interelectrode distance ($E$ was kept constant), the character of the distributions changed. The critical distance depended on the electric field strength and decreased