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Development of FEM Programs for Assessing the Risk of Electrical Breakdown of Devices Operating in High Humidity Conditions

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Abstract. This study explored a scenario of a new mechanism of electric shock. Using computer simulation using the finite element method, the possibility of the existence of unlikely short-term electrical breakdowns caused by synergistic effects is shown. A method for assessing the risk of a self-organizing conductive cluster of moisture droplets is proposed.

INTRODUCTION

A significant economic risk in the manufacture and maintenance of electrical equipment is the likelihood of an electric shock. Studies conducted in the field of electric power showed that the proportion of fatal electric injuries at work is 20 - 40% of the total number of all fatal accidents [1]. The damage lies not only in the need to pay compensation, but also in the possible reputational losses of the enterprise.

Growing public attention to ensuring the safety of both industrial and household appliances requires the development of mathematical methods describing dangerous incidents. The most important method for predicting accidents is to build a tree of causes and consequences of an incident. The most productive is the application of the Monte Carlo method, which allows to calculate the probability of an event, taking into account the probabilities of intermediate events. The values of the latter are set on the basis of the accumulated operating experience.

The lack of a traditional approach is based on the neglect of events that have a synergistic (i.e. illogical) nature. The proposed report reports on the feasibility of implementing an approach using the finite element method (FEM) to detect and calculate the likelihood of such "unlikely" incidents.

The objective of research is to curb the risks associated with electrical breakdown developing on a wetted surface - which can be realized both in electric power industry and in living conditions. When designing conditions that ensure the safety of electrical equipment, it is necessary to adhere to the optimum cost of ensuring the safety and consumer attractiveness of the product. In particular, an excessive increase in electrical safety of an electric hair dryer can lead to an increase in its cost and dimensions, that is, a decrease in its overall consumer attraction.

THE RESEARCH PROBLEM

One of the most common sources of danger is the breakdown of an insulator, which develops on a wetted surface. However, when assessing its danger, it is taken into account that there is a “self-purification” mechanism, which is as follows:

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- Under the action of high voltage, a leakage current flows through the humidified conductive layer [2], which leads to the heating of the electrolyte and, gradually, to the evaporation of moisture.
- As a result, dried zones are formed.
- As a result of the mechanism described, technical failures are avoided.

We will show in this paper that this, however, does not eliminate the danger of short-term breakdowns that can create a non-zero probability of electric shock to others.

Consider in the proposed work a situation in which an electrical voltage is applied to the wetted surface of an insulator, characterized by a strength value that is many times less than the breakdown value corresponding to a dry surface. We take into account the following features of the formation of moisture by condensation of atmospheric moisture. As a rule, the wetted surface is covered with a number of drops, the distances between which are randomly changed. In this case, we assume that the concentration of droplets is still far from the flow threshold for electric current. We take into account that the dielectric constant of water is abnormally high, equal to about 80.5, that is, much higher than that for air.

Under these conditions, it can be expected that water droplets significantly distort the picture of the initial uniform electric field. Under such circumstances, effects of a noticeable concentration of the electric field strength near the surface of the droplets should be realized. Previously, a similar effect of concentration of thermal stresses on the surface of inclusions turned out to be essential for assessing the thermal destruction of two-phase materials, [3].

CALCULATION METHOD

In this section we calculate the distribution of the electric field strength along the surface of the dielectric, covered with round sections (drops) of water. To this end, it is advisable to apply in this paper an approach based on the use of the finite element method.

Let us single out in the system under consideration an elementary rectangular cell, shown in Fig.1, containing circular areas of varying sizes and positions imitating water droplets.

Gray color - drops, black rectangle - breakdown area, arrow - direction of unperturbed electric field E0.

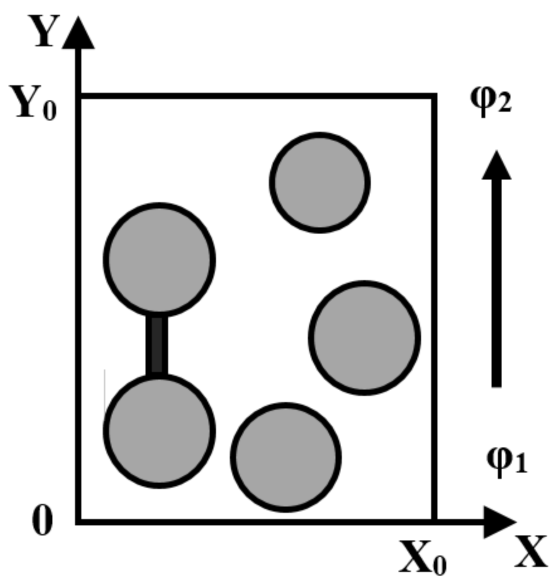

FIGURE 1. An elementary rectangular cell imitating water droplets

We use the system of Cartesian coordinates X, Y. Calculate the distribution of the electric potential φ (X, Y) and, accordingly, the electric field strength E (X, Y) = grad φ (X, Y).

For this purpose, we use the variational formulation of the transfer process, according to which the desired potential distribution is determined by the extremum of the functional [4].

$$\chi = \int_{S_c} \varepsilon(grad\ \varphi)^2\, dS \qquad (1)$$

We take into account the presence of boundary conditions. For Y = Y0 and Y = 0, we accept the is potential condition, φ = φ1 and φ2, respectively. For X = 0 and X = X0, we accept the adiabaticity condition, that is, ∂φ / ∂X = 0. We divide the computational domain with triangular simplex elements, adapting the partitioning grid to the boundaries of inclusions [3].

The conditions of the minimum of the functional χ allow, using the finite element method, to establish in a standard way the nodal values of the potential at all points of the computational domain and, accordingly, the magnitudes of the gradients of the potential grad (φ). To solve this problem, in the present work an original computer program in the Fortran language was created and a series of computer experiments were conducted.

RESULTS OF COMPUTATIONAL EXPERIMENTS

In the process of calculations, we analyzed the patterns of the spatial distribution of the intensity E (X, Y) depending on the relative position of the droplets and as a result of the action of "bridges" arising from inter-drop breakdowns. As an example, Fig.2 depicts typical calculated spatial field strength distributions for a two-part cluster and a third particle. L is the cluster length, Δ is the distance between particles, y = Y / R is the local dimensionless coordinate, r is the drop radius, k = E / E0, E0 is the strength of the unperturbed field.

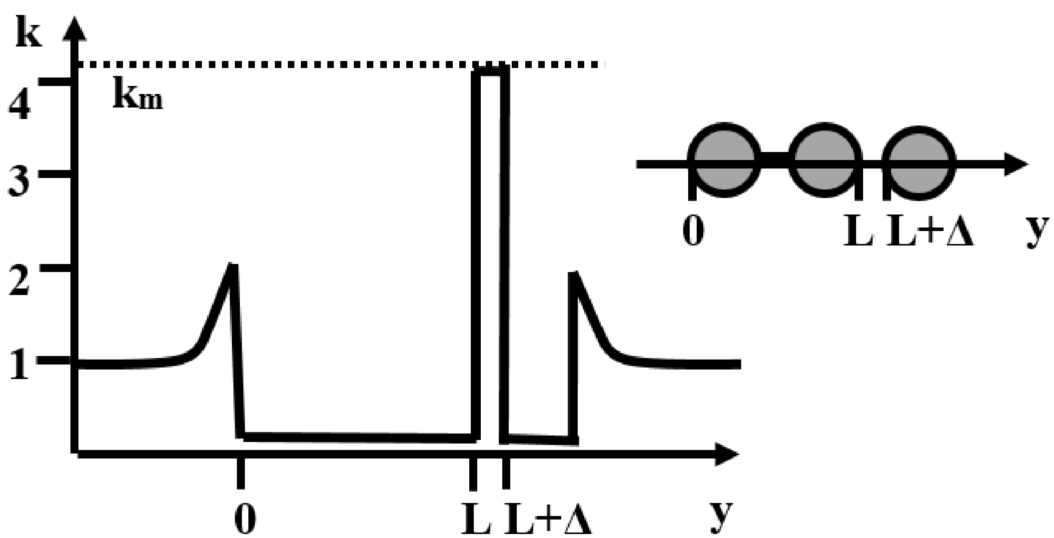

FIGURE 2. The typical calculated spatial field strength distributions for a two-part cluster and a third particle.

Analysis of the results of computer experiments led to the conclusion
that an insignificant (approximately 2 times) increase in the electric field intensity occurs on the surface of a single drop. That is, the initiation of a breakdown is unlikely. However, between the drops, the effect of concentration is significantly enhanced. It is inversely proportional to Δ - the distance between the drops. In this case, the scale of the electric field strength k can increase ten or more times.

The next mechanism of exacerbation of the concentration of the electric field intensity is intersperse breakdown and the occurrence of conductive clusters. If the cluster contains N particles, then the scale of intensity k increases approximately by 2N times. Thus, intersperse breakdown is a synergistic self-organizing process that proceeds with an exacerbation. The analysis also showed that the conductive cluster is also a concentrator of Joule heat release. Therefore, it can exist only for a limited time due to the drying of cluster drops.

CONCLUSIONS

The finite element method is promising for risk assessments of accidents. In the works on optimization of electrical insulation, it is necessary to take into account the mechanism of electrical breakdown of a wetted surface discussed above. Its characteristic feature is short duration and weak predictability. It can be likened to the process of Black Swan N. Talleb. Such unpredictable processes can lead to huge financial losses. An example is the recent series of Boeing aircraft crash incidents.

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