

Improving the reliability of electric motors during startup using electroosmotic drying of insulation

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Abstract. The article considers the actual problem of electric motors (EM) operation associated with wetting of winding insulation. The condition of wet insulation is getting worse due to aggressive environment of premises of agro-industrial complex, and some workshops in industry. It is noted that together with humidification, the effect of insulation “steaming” occurs after EM is put into operation. In this case, the insulation resistance R sharply decreases and its breakdown may occur, after which a major overhaul of EM is required. A new method for EM drying based on the electrokinetic phenomenon of electroosmosis has been developed. Under the influence of electric field forces, moisture is extruded from insulation capillaries onto the surface of EM winding and stator iron. R increases, and EM becomes ready to turn on. Under further operation, EM is heated and moisture evaporates into the environment. It is shown how electroosmotic drying (EOD) and the developed device (DEOD) help to get rid of the effect of insulation “steaming” and thereby ensure trouble-free EM operation.

1 Introduction

Currently, one of the topical issues of electric motors (EM) operation is wetting of windings insulation. The number of EM failures associated with insulation wetting reaches 20–30% [1,2,3].

The aggressive environments of livestock complexes in agricultural and individual workshops in industrial production further deteriorate the condition of wet insulation. Hydrogen sulfide, carbon dioxide, ammonia and other gases form acids and alkali when combined with water. Conductive bridges appear in insulation, which reduce the insulation resistance R [4].

Moisture changes the dielectric properties of insulation, and worsens almost all its electrical characteristics: dielectric strength, resistance R , dielectric loss tangent, etc. Breakdown can occur not only through the insulation thickness, but also on a wet surface. Moisture causes chemical changes: hydrolysis of insulation and formation of molds [5].

Humidified EM in an aggressive environment is a galvanic cell. One of the plates of this element is a copper winding, the other is stator iron. A mixture of various acids formed in a humid aggressive environment acts as electrolyte. Hydrogen sulfide and carbonic acids are obtained by interaction of moisture with hydrogen sulfide and carbon dioxide, other acids can be formed by hydrolysis and decomposition of insulation in water. In this case, chemical reactions occur that are typical for a galvanic pair, and the copper wire of winding is destroyed. The latter circumstance leads to a break in windings and turn-to-turn short-circuit.

Humidification leads to the emergence of the insulation “steaming” effect after EM setting in operation [6]. EM switching-on is accompanied by heating of wet insulation. Moisture in pores and capillaries expands and additionally shunts the dielectric. The insulation resistance sharply drops, and a breakdown may occur. The smaller is R before EM turning on, the stronger the “steaming” effect is, and the more probable the EM failure is. If the accident is avoided, then with further EM operation the insulation will dry up.

Thus, EM must be periodically dried. Today, there are a significant number of different ways of EM drying. As a rule, they all are thermal: light bulbs, ovens, blowers, welding transformers, etc. [6,7].

Thermal methods of EM drying can cause warping, thermal degradation, local overheating and thermal aging of insulation. These methods are implemented with dismantling and disassembly of EM at the operation fields. They require special equipment, significant labor costs and increased energy consumption [8-11]. In this regard, there is a need to develop and apply new drying methods that would not have disadvantages of thermal drying.

A new method of drying EM has been developed at the Department of Electrical Equipment of the Vologda State University (VoGU), based on the electrokinetic phenomenon of electroosmosis [12-15]. The essence of electroosmosis is the motion of fluid in capillary systems under the influence of electric field [13]. The materials used for EM windings insulation are capillary systems, therefore, the electroosmotic effect of moisture removal can be realized in EM insulation [17].

Electro-osmotic drying (EOD) is cold and does not heat the EM insulation. The energy consumption during EOD is 2 to 3 orders of magnitude less than that of traditional thermal drying methods. EOD does not require to disassemble and dismantle EM from its workplace, which reduces labor costs by 2 to 3 times [13-15].

The purpose of research is to effectively use EOD not only for EM drying, but also for eliminating the insulation “steaming” effect when EM is switched on.

2 Materials and methods

The serial AIR electric motors of common industrial use of 1.5 kW power were used as experimental samples. The insulation system is as follows: groove box and groove wedge are made of Laviterm, phase-to-phase gaskets are made of film-asbestos millboard, winding wire is made of PETV-2.

Similar EM samples with insulation system additionally encapsulated with organosiloxane rubber to enhance moisture resistance were also used in studies [6].

For statistical reliability, three EM were used in each experiment. In order to smooth the insulation “steaming” effect, an EOD device (DEOD) developed and manufactured at VoGU was used [15]. Measurements of insulation resistance R were made using the F4101 megaohmmeter. A positive plus from DEOD output was connected to EM windings connected in a star, and the negative was connected to the case. Preliminarily, the EM windings were moistened in a KTV-0.4 moisture chamber at a temperature of $T = 20 \pm 20^\circ\text{C}$ and a relative air humidity of $\omega = 97 \pm 3\%$ without moisture condensation for 96 hours. To speed up the humidification process, the EM bearing shields were removed.

3 Results and discussion

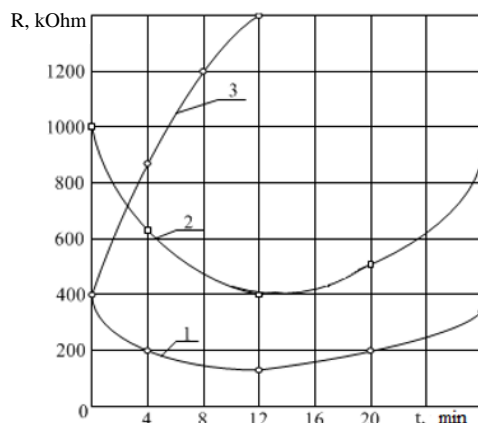


Fig. 1. Relationship between insulation resistance and operation duration of wet electric motors after startup: 1,2 - conventional startup of electric motors of general industrial design and encapsulated ones; 3 - startup of electric motors of general industrial design after preliminary processing of insulation by electric field from EOD device.

Figure 1 shows the curves of change in insulation R after switching on the electric motor. Curves 1,2 correspond to EM insulation, which were not pre-treated by electric field before startup (DEOD was not used). Curves 1, 2 show a rather strong manifestation of the “steaming” effect: the insulation resistance of non-encapsulated EM decreases to almost 100 kOhm, which is significantly less than the allowable 500-1000 kOhm. Obtaining experimental data for curve 1 was accompanied by such a pronounced “steaming” effect that one of EMs failed due to a short circuit in the groove part of insulation. The insulation R of this EM apparently decreased below 100 kOhm, which could not be recorded during measurements. In encapsulated EMs, the “steaming” effect is less pronounced (curve 2), which can be attributed to a high initial resistance and a more moisture-resistant electrical insulation design. Curve 3 presents the EM startup without insulation “steaming”. The insulation system of this EM batch was characterized by initial $R = 250$ kOhm and was subjected to a 15-minute exposure to electric field from DEOD before starting. As a result, R increased to 400 kOhm. After switching on the EM in the network, after 12 minutes, the resistance reached 1.5 MOhm due to self-feeding effect, and the increase in R occurred continuously without jumps. Thus, “steaming” was excluded.

To explain the experimental results (curves 1, 2, 3 in Fig. 1) we use the theory of contact drying of capillary-porous bodies [16].

Figs. 2 (a), 3 (a) show idealized versions of the structure of EM insulation dielectric with an extensive network of microcapillaries partially filled with water (1-1', 2-2' – through capillaries). When EM is switched on, the current-carrying part is heated, the moisture in contact with it partially evaporates and condenses on the walls of capillaries, forming conductive bridges (Fig. 2, b). Heating of air in microcavities leads to its expansion and causes moisture motion in capillaries. Water is redistributed and another possible option for appearance of a conductive bridge is shown in Fig. 3 (b). Thus, “steaming” is associated with appearance of shunting fluid bridges. Redistribution of moisture, and consequently, a decrease in R , is observed until the insulation warms up throughout the volume and evaporation of moisture from the surface begins. From this moment an increase in R begins.

Physical processes occurring in the insulation system of EM during EOD enable quite simple and reliable eliminating the undesirable effect of “steaming”. For this, immediately before startup, voltage from DEOD is supplied to EM insulation system (plus to the windings, minus to the case). Exposure by external electric field causes water to move toward the negative electrode and frees the near-anode regions of capillaries, which are located near the current-carrying parts of EM. Fig. 4 (a) shows the EM insulation dielectric in humidified condition before DEOD connection. The same dielectric after exposure to electric field is shown in Fig. 4 (b). The near-anode regions are dehydrated, there is no contact of water with current-carrying parts in microcapillaries,

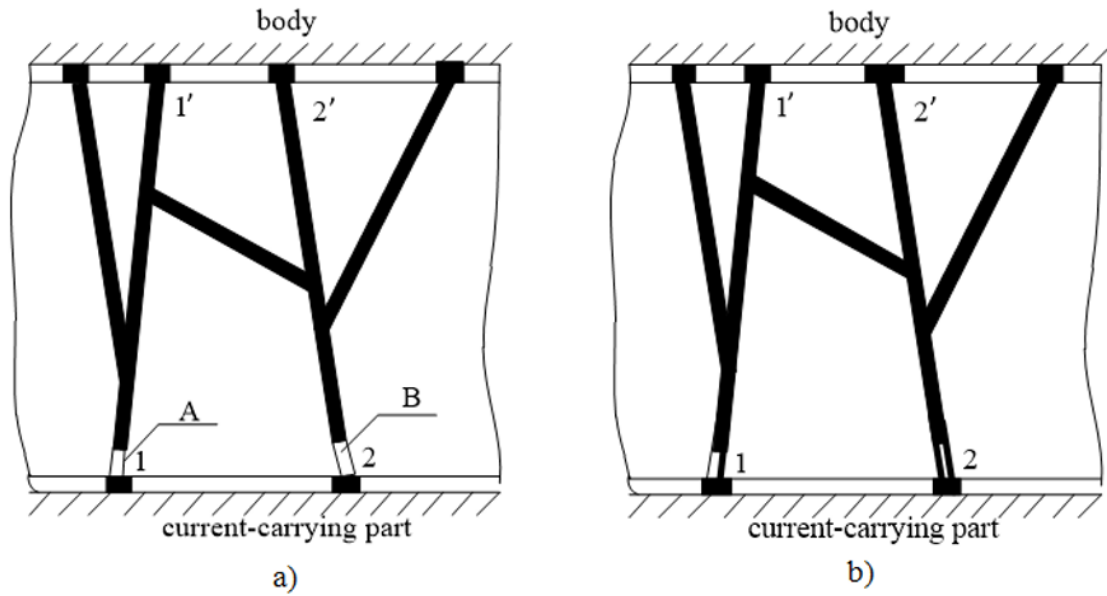


Fig. 2. Structure of a humidified dielectric of electric motor insulation (1st option): a) over- humidified condition; b) moisture condensation on the walls of capillaries after starting the electric motor; A, B are air inclusions.

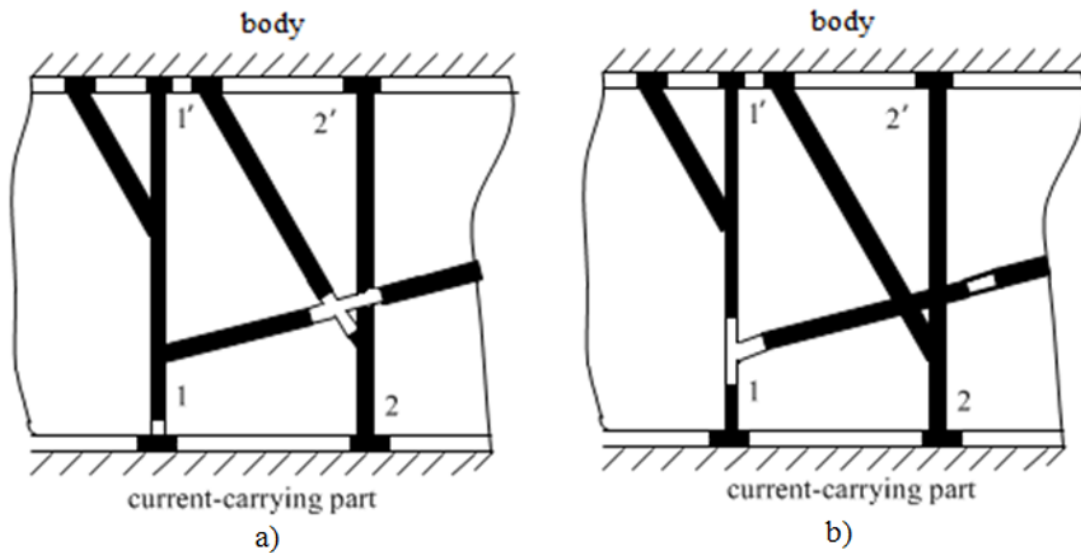


Fig. 3. Structure of a humidified dielectric of electric motor insulation (2nd option): a) over- humidified condition; b) redistribution of moisture in capillaries after starting the electric motor.

there will be no water evaporation and through conductive bridges are not formed. After EM switching-on, the heat released in windings heats the air in the near-anode regions. The volume of air inclusions that appeared after DEOD connection (Fig. 4, b) increases when heated, and continues to displace moisture from the center to the periphery, resistance of the EM insulation system increases.

It should be noted that after DEOD disconnecting, moisture in EM insulation system can be redistributed. As a result, the initial unfavorable state of insulation can be restored (Fig. 2,3). Therefore, to reliably eliminate “steaming”, one needs to turn on EM immediately after DEOD disconnecting. If EM insulation is dried more than enough up to 1.5-2 MOhm, then one should not be aware of “steaming” and there is no requirement for EM

switching-on immediately after drying. The method of EM starting without insulation “steaming” expands the practical use of electroosmosis and DEOD to increase the operational reliability of EM.

Implementation of EOD as part of the developed devices [13,15] into the practice of EM operation allowed us not only to eliminate the disadvantages of traditional thermal drying methods, but also to remove the effect of insulation “steaming”. Consequently, this very significantly increased the level of accident-free operation of EM.

4 Conclusions

1. The developed new method for cold drying of EM winding insulation excludes thermal degradation,

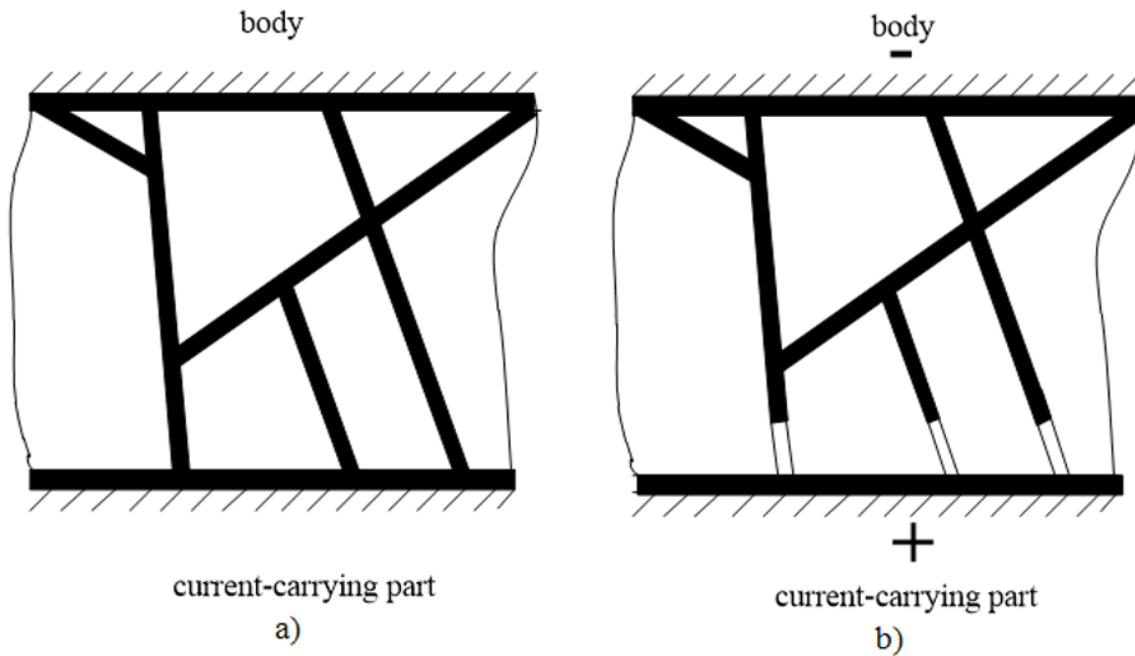


Fig. 4. To the issue of “steaming” of an electric motor insulation: a) insulation condition before DEOD connection; b) the same after connection of DEOD, which eliminates “steaming”.

reduces power consumption by 2–3 orders of magnitude and labor costs by 2–3 times, increases the EM operational reliability by eliminating the “steaming” effect during startup.

2. Connecting the humidified EM to DEOD for 15 minutes will eliminate the “steaming” effect and possible breakdown of EM insulation during startup. A further increase in insulation resistance occurs due to self-drying by EM heating during startup and operation.

3. In order to reliably eliminate the insulation “steaming” effect, it is necessary to turn on EM immediately after DEOD disconnecting. If EM insulation is dried more than enough up to 1.5-2 MOhm, then one should not be aware of “steaming” and there is no requirements for EM switching-on immediately after drying.

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