FORECASTING OF RELIABILITY OF SEALED ELECTROMECHANICAL CONVERTORS

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ABSTRACT

The sealed electromechanical converters' application field is limited by deterioration of heat transfer conditions between active elements and the environment. The theory of strength specifies the qualitative character of external factors impact on hermetic electromechanical converters reliability. The laboratory tests were taken to identify the qualitative characteristics. These tests identified the dependencies of turn and frame insulation from moisture, vibration and temperature for operation of transport vehicles and other devices, intended to have enhanced hermetic features.

Background. *Expediency, and in some cases the need for sealed electromechanical converters (SEC) is primarily related to their resistance to major external factors – humidity and vibration. Design features and consideration at the design stage the possibility of using SEC in humidity conditions, while the presence of significant vibration make them indispensable in pumping units with electric drive, submerged power equipment, various transport devices.*

SEC are of particular interest in both practical and scientific aspects due to the appearance of new composite materials with unique physical and chemical properties that allow not only to ensure the reliability requirements and environmental protection, but also improve the performance of the equipment. Capsulation of the most damaging elements of conventional electromechanical converters – stator`s heavy windings with polymeric thermosetting bondings or use of new supplementary separating baffles in operating clearance is the technological basis for the creation of SEC.

The main task of sealing is the maximum reduction in the influence of humidity on the performance of electromechanical converters. The moisture is accelerating factor in aging and destruction of insulation of stator`s windings, resulting in approximately 90% of cases in system failures.

Low viscosity and other properties of water cause its high penetration in isolation, with particularly intense this process is during power converters' turning off after work in longstanding thermal conditions, because in this period, the pressure in the pores and capillaries of the electrical insulation is slightly below atmospheric. Getting into the technological voids and cracks, moisture creates the conductive bridges, reduces electrical resistance and the loss of electrical strength and even insulation breakdown at turning-on. Under the influence of moisture occurs hydrolytic degradation of insulation material, consisting in the splitting of the polymer chains. Periodic penetration and removal of moisture increase the porosity of the insulation. In proportion to separation and aeration breaking isolation increases its absorbability. These processes develop in parallel with other phenomena of insulation`s aging and mutually stimulate each other.

Another task of the transition to a fully sealed design by encapsulation of the stator`s winding is to raise the vibration resistance of electromechanical converters that during production, transportation, operation are exposed to external mechanical factors.

These effects are the result of mechanical and electromagnetic processes. The former include mechanical unbalance of rotating parts, causing increased vibration with rotor speed and due to such factors as increased surface roughness of rolling or sliding friction, obliqueness to shaft axis, weak of mounting surfaces or their destruction, improper alignment, defects in transmission devices, improper installation of labyrinth sealing on the shaft, lack of rigidity, foundation fluctuations due to vibration transmission through building links, resonance of individual nodes at the coincidence of their natural frequency with the frequency of vibration of the rotor.

The second group of reasons has an electromagnetic nature. All electromagnetic phenomena, leading to violation of the symmetry of the magnetic field in the converter, lead to all kinds of vibrations: wrong connection of stator`s windings, short-circuit, breakage of bars of short-circuited rotor`s windings, uneven air gap, the weakening of active steel, improper value number of teeth of the stator and rotor, unbalanced load or power of converters.

In most cases, these reasons lead to the cyclic alternating vibrations. By transient processes, short-circuit, the amplitudes of vibration increases tenfold and have a significant impact on the process of destruction of the insulation. It should be noted that although the nominal amplitude of the vibration modes are usually negligible and are about 10–100 micrometers, but the number of cycles during the operation period of the order 10^{10} effective vibratory impacts lead to irreversible structural changes in insulation.

Vibration has a destructive effect on all elements of the stator`s winding, and insulation of slotted, frontal and transition areas is damaged. Slot insulation is exposed to compression under the action of electrodynamic forces, and if there are air-gaps in the slot it is additionally exposed to impact and abrasion of slot sides. In the absence of free movement of the winding in a slot of the insulation, besides expansion and compression shear deformation may also appear. When bending the frontal parts of the windings, the largest stresses occur in places where rods or reels fall out of the slots, where the insulation is experiencing compressive stress and tension. In addition, it is crushed on the pads and the contact areas with bandages.

It should be noted that the most of commonly used in electric machine industry polymeric material has relatively low fatigue strength, thus a continuous vibration causes in the isolation formation and increase in the number of cracks, delaminations and other defects. The degree of influence of vibration loads increases with prolonged use and natural aging of the insulation, which occurs mainly due to the weakening of the winding`s fastening. Under the action of vibration gradual destruction of the impregnating composition and cementation violation occur, individual conductors are able to relative movement, which significantly increases the likelihood of turn-to-turn short-circuits, which are the major cause of failures of electromechanical converters.

Objective. *Since the transition to a sealing structure along with increased moisture and vibration resistance at the same time leads to a change in the heat exchange conditions between the active elements and the outside environment, prediction of reliability parameters of sealed electromechanical converters in a humid environment*

and vibration loads, associated with considering the temperature at the points of its maximum concentration is necessary.

Methods. *A priori estimation of the impact of mechanical stress on the reliability of SEC can be made on the basis of the fluctuation theory of strength, establishing a connection between polymeric insulation strength and exposure time of mechanical stress.*

According to this theory, the main mechanism of destruction is the breaking of chemical interatomic bonds under the influence of thermal fluctuations. Applied mechanical stress reduces the energy barrier of the chemical bonds and increases the likelihood of the destruction process, i. e. degradation of the material can be considered as a gradual thermal activation process in which mechanical stress is a factor that provides and accelerates thermal degradation.

Strength theory makes it possible to determine the qualitative nature of the effect of external factors on the reliability of SEC. To obtain quantitative indicators of reliability experimental studies of damage to insulation elements when exposed to moisture or vibration while taking into account the temperature are required.

Results. *The approach described above is implemented in laboratory testing of encapsulated windings prototypes for 1000 hours, the results are shown in Pic. 1–4. As an indicator of reliability for the turn insulation increment of the failures' number is used per unit length for main (slot) – increment of the failures' number per unit area before and after exposure of external factors.*

Comparative analysis of experimental data and statistical failures of windings' insulation of electromechanical converters of leaky execution leads to the following conclusions.

Dependence of damage of both slot and turn insulation of SEC on the humidity level and the vibration acceleration is practically linear. Increasing humidity of 70 to 100% leads to an increase in increment of damage formation by approximately 12–18% depending on the operating temperature. Under similar external influences conventional windings' insulation defects increase by 27–40%.

Vibratory loads in the range of 1–6 g lead to a slight reduction in the strength of turn insulation of sealed electromechanical converters and thus do not have a significant impact on their maintainability.

For industrial equipment the change in vibration acceleration level during tests from 0 to 6 g, even for a short time of about 150–450 hours and a temperature of 1300C increases the increment of turn insulation defects by 28%, slot – 24%, respectively, at 160^{0}C by 77 and 70.5% respectively. That is, the stator`s winding encapsulation can significantly reduce its damage rate under the influence of humidity and vibration. At the same time sealing of the windings, especially when using the conventional composite materials based on thermosetting binders leads to a substantial tightening of the thermal state of the winding.

Analysis of experimental studies' results shows that the dependence of the increment of damageability of both turns and slot insulation of the winding on temperature is exponential. Increasing the temperature of the windings when tested for 300 hours from 130^{0}C to 190^{0}C increases the increment of damageability of turn insulation from $1{,}931 \cdot 10^{-4}$ to $34{,}74 \cdot 10^{-4}$ mm^{-1}, slot – from $0{,}04901 \cdot 10^{-4}$ mm^{-2} to $0{,}5028 \cdot 10^{-4}$ mm^{-2}.

Conclusions.

To improve the heat mode various methods can be recommended, including those associated with the use of modified encapsulating materials. It should be borne in mind that at the same time SEC are simultaneously destructively affected by electromagnetic, thermal and mechanical factors. Therefore, the composite material must not only provide a high electrical resistance and mechanical strength but also thermal resistance. An example of heterophase composite material, distinct phases of which have different functions, while providing features, which do not have any of the components of the composite alone, is non-conductive anti-friction material based on epoxy-diane resin with filling material from PTFE powder, molybdenum disulfide, chopped glass or basalt fiber and silica-alumina.

Determining the optimal balance between the individual components of a highly dispersed structure in which the individual elements are in state of aggregation, and colloidal particles have the thermodynamic properties of the corresponding phase state is a separate task that requires consideration of preliminary grouping of individual elements, which is determined by non-chemical factors of intermolecular effects [1].

Key words: sealed electromechanical converter, moisture, vibration, temperature, frame insulation, turn insulation.

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