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QUESTIONS OF RESILIENCE OF ISOLATION OF TRACTION TO DYNAMIC OVERLOADS

Abstract. In this article, questions and the reasons of damage of isolation of traction at dynamic overloads are considered. At operation, the electrical traction periodically experiences dynamic thermal influences. Negative influence of temperature loadings affects isolation of windings electric traction. The operating experience and pilot studies confirm that it is the main reason for weakening of resilience of insulating material the thermal loadings determined by the size of temperature of windings, duration of influence of loadings and gradients of temperature.

Operational reliability of the equipment is defined first by working temperature and heat stability of the applied electroinsulating materials, and their electric durability, moisture resistance and mechanical durability.

Increase in service life of traction machines - a complex task, and in this regard, the detailed analysis of factors, the greatest image of the traction machines influencing reliability is useful: an overload of machines, long start-up, marriage at production of isolation and rewind of windings.

Keywords: isolation, electrical machine, operation, reliability, temperature, resilience, control of a state.

The trend of transport development using electric energy is characterized by an increase in the amount and power consumption of electrical energy. Kazakhstani railways are a powerful transportation system that occupies by the size, volume of transportation and the level of technical means used.

With the further increase in the intensity of train traffic and the widespread use of electric traction, power supply in transport will be developed and improved, requiring a small and sufficient reliable electrical equipment with high performance characteristics that provide the required quality of electricity for consumers.

Electrical equipment of railway transport is difficult and it works under severe extreme conditions caused by dynamic forces, atmospheric influences, sharp temperature changes and other factors. Under these conditions, the work of electrical isolation of equipment is particularly difficult [1].

The exploitation of worn-out electrical equipment in recent years has become a very pressing problem for the electric power industry. Separate attempts to solve it do not allow to answer most multifaceted questions. The solution of technical problems is related to the need to systematically study other aspects. Let us consider the basic components on an example of operation of traction machines.

The analysis of failure maps and accident reports compiled immediately after the damage to long-running traction machines, in most cases, does not allow to unequivocally indicate the cause of the damage. As a rule, the reasons are revealed and refined after the dismantling of traction machines. This is due to the fact that the traditional set of instrumentation and diagnostic methods does not provide an opportunity to fully interpret the new information that has appeared, typical for worn-out electrical equipment. The unexpectedness, inexplicability, uniqueness and randomness of the behavior of worn-out electrical equipment are due to insufficiently comprehensive information for a single diagnostic model. Therefore, for each type of electrical equipment, we need our own model that takes into account the multidimensionality of the indicators, the multiplicity of the constituent elements of the worn-out electrical equipment having direct, inverse, recursive (irreversible, cause-effect), synergistic (amplifying), cyclic, rigid, flexible and other connections [2].

Modern traction machines are machines of ultimate performance, which provide for the fullest use of structural, technological and resource capabilities. Traction motors operate under conditions of high acceleration caused by locomotive motion, a sharp change in electric loads, a large drop in ambient temperatures, a dusty cooling air that is significant in a number of hot regions of the country and salinity in the air.

During operation, the electric traction machine periodically experiences dynamic thermal effects. The negative effect of temperature loads affects the isolation of windings of electric traction machines. Operational experience and experimental studies confirm that the main reason for the weakening of the resistance of the insulating material is the thermal loads determined by the temperature of the windings, the duration of the action of the loads and the temperature gradients.

It is known that the effect of the load on the traction machine is the loss under the effect of heating the isolation of its properties. The aging process is long, it usually takes years. Without taking it into account, it is impossible to choose the right power, to take into account the used part of the service life in the future. To increase the economic efficiency of the operation of the power supply system, and to more accurately select the timing and means of enhancing it, it is necessary to take into account the aging of the windings of traction machines during operation.

The aging of isolation is determined by a number of factors, on the basis of which the deterministic basis of the model can be constructed. The most significant factor that determines the tendency of changing the load on the traction machine, and, consequently, the aging of isolation, is the power consumption. The second significant factor is seasonal load fluctuations. However, a number of factors are purely random in nature, necessitating the inclusion of a random component [3].

The load of traction machines, being a random variable, fluctuates in a very wide range, practically from zero to one and half value. The large multiplicity is not included in the category of systematic and refers to emergency overloads, the duration of which is limited to protective devices.

At an asymmetrical load, which is the alternating current traction, the root-mean-square current is determined from the condition that the energy losses in the windings are equal to the equivalent effective currents of the symmetrical load and the actual currents flowing through the windings.

Short-circuits are characterized, on the one hand, by significant current excesses against the rated current, on the other hand, by the short duration of the action due to the disconnection of the short-circuit current by the protectors. For these conditions, the winding temperature increasing above the surrounding environment can be significant, determining a very high aging rate of insulation. At high temperatures, it is necessary to take into account the increase in their resistance.

The excess of temperature over the initial temperature, taking into account the increase in resistance, is determined by expression [3]:

$$\theta = (\theta_0 + \theta_{н})(e^{BI_{kt}} - 1), \quad (1)$$

whereB – temperature coefficient.

At constant temperature over time, the mechanical strength of insulation is reduced. It is measured by the number of kinks held by the insulation during the test. At constant temperature, the insulation strength decreases uniformly, then, reaching a value equal to about 20% of the initial, it decreases very slowly. However, by this time, practically insulation is not suitable for further operation.

The period of complete uniform wear of the insulation T (up to the point at which its strength is about 20% of the initial), according to the experimental data, is:

$$T = Ae^{-\alpha \vartheta_0}, \quad (2)$$

where A – constant coefficient, determined by the insulation class; θ_0 – winding temperature, ^{0}C; α – constant coefficient, determining the aging rate of insulation.

Under traction conditions, the load varies greatly. The winding temperature is approximately quadratic with current, and wear is an exponential function of temperature. From this, it is clear that the rate of heat deterioration is extremely variable when the load changes. Therefore, regimes with increased traffic intensity, especially if they are often repeated, largely determine the average rate of wear, therefore, the necessary power of the machines.

In conditions of operation of electric locomotives, it is required to determine not only the highest temperature, but also the location on the profile of the road section where it arises, in order to correct the mode of motion or engine power, if necessary. To do this, you need to know the dependencies of *τ(s)* or *τ(t)* (figure 1).

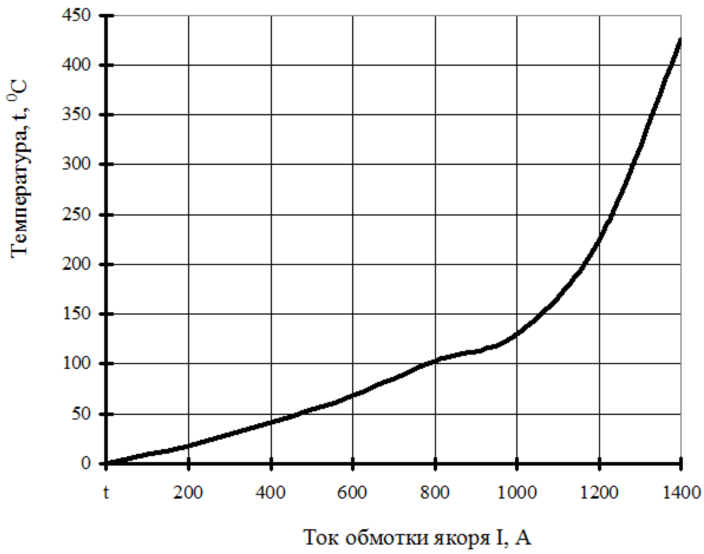

Figure 1 – Thermal parameters of the armature winding of the engine NB-418K of electric locomotives VL80, VL60

In addition to temperature, the change in air pressure or oxygen concentration, the presence of ozone, which is a stronger oxidant than oxygen, and various chemical reagents that accelerate aging, can have a significant effect on the rate of aging. Thermal aging is accelerated by the illumination of the specimen with ultraviolet rays, the action of an electric field, mechanical loads, etc.

The possibility of increasing the operating temperature of isolation for practice is extremely valuable. In traction machines, the increase in overheating, which is usually limited to the materials of electrical insulation, makes it possible to obtain a higher power in unchanged dimensions or, while maintaining power, to achieve a reduction in overall dimensions and the cost of the product. Increasing the operating temperature, especially for traction machines and other mobile devices, where the tasks of reducing weight and overall dimensions come to the fore. The issues of permissible temperature are closely related to fire safety and explosion safety measures.

In accordance with the recommendations of the International Electrotechnical Commission, the separation of electrical insulating materials for electrical materials in general-purpose electrical equipment, operating for a long time in normal operating conditions for this type of electrical equipment,:

Heat resistance class	Y	A	E	B	F	H	C
Maximum permissible operating temperature, °C	90	105	120	130	155	180	above 180

Electric machines usually count for a service life of 15-20 years without major repairs. The main causes of aging insulation are: high temperature, large temperature differences between individual machine parts; electric field; high humidity; mechanical effort.

High temperature causes oxidation of various components of insulation. Therefore, to ensure the specified life of electrical machines, the heating temperature of the individual parts should be limited. When the temperature rises, intensive wear of the insulation and its rapid destruction occur. Consequently, the maximum temperature, at which an electric machine can operate, is determined by the heat resistance of the insulation used in it. The higher the permissible limiting temperature of individual parts of the machine is, the shorter the service life due to the gradual aging of the insulation is. However, the higher this temperature is, the more you can load this machine.

The operational reliability of the equipment is determined primarily by its operating temperature and the heat resistance of the applied electrical insulating materials, as well as their electrical strength, moisture resistance and mechanical strength.

The probability of damage to the engine can be considered in the form of expression [4]:

$$P_{повр} = P_1 + P_2 + ... + P_n \,, \qquad (3)$$

where P_1 – probability of damage due to overload; P_2 – probability of damage due to rejection during the manufacture and restoration of the engine; P_n – probability of damage for n-th reason.

Effective is the reduction of the largest term, for example, P_1. A significant reduction in any one of the damage probabilities for other reasons may not result in a noticeable decrease in $P_{повр}$, at this the costs of implementing this measure vary (based on the known position of the reliability theory) in a power-increasing curve so that a further decrease in $P_{повр}$ is beneficial at the expense of decrease of already another term, etc. For this reason, it is important to know the distribution of damage according to the degree of decrease in their probabilities and the rate of increase in the cost curves for all factors of damage.

Thus, increasing the service life of traction machines is a complex task, and in this regard, a detailed analysis of the factors most influencing the reliability of traction machines: machine overload, long runs, defective products in the manufacture of insulation and rewinding of windings, is useful.

The conducted analysis of the efficiency of insulation protection against overload showed that the electrotechnical personnel of the vast majority of enterprises had an opinion about the ineffectiveness of any protection against overload. Often there is a situation where thermal and other types of protection are dismantled. Overloading of insulation by current of traction machines, 20-30% higher than nominal, with rough protection can significantly reduce the service life. In this connection, it is useful to conduct the following analysis of the thermal conditions of traction machines [5].

Overheat $\theta_{п.ном}$ of isolation with respect to the ambient temperature in the nominal mode determines the thermal resistance of the winding, ^{0}C/ W [6]:

$$R_\theta = \theta_{ном} / P_{ном.маш}, \qquad (4)$$

where $P_{ном. маш}$ – nominal rating power of traction machines, kW.

Then in the overload mode, the stator winding overheat is:

$$\theta_n = P_n R_\theta = I_n^2 r R_\theta, \qquad (5)$$

where I_n - overload current, A; r - stator winding resistance, O; P_n - Overload power, kW.

By introducing an overload factor:

$$k = I_n / I_{ном} \,, \qquad (6)$$

we get

$$\theta_n = \kappa^2 I_{ном}^2 r R_\theta \,. \qquad (7)$$

In the nominal mode

$$\theta_{ном} = I_{ном}^2 r R_\theta \,. \qquad (8)$$

It can be seen from the expression that the overheating temperature of the stator winding of traction machines is quadratically dependent on the overload factor.

Figure 2 shows the curve 1 of overheating $\theta_{n.}$ and curve 2 of insulation temperature $\theta_{маш}$ at ambient temperature 40 ^{0}C.

In Figure 3, which shows the insulation service curves of classes A and B, it can be concluded that an acceptable survice life at a multiplicity of up to 1.5 can withstand only Class B insulation, for class A overload insulation of more than 1.25 are only permissible for a short time [7].

The question of the highest permissible operating temperature is solved on the basis of a thorough study of the short-term and long-term temperature resistance of the insulation material, taking into account the safety factor that depends on the operating conditions, the required degree of reliability and the service life of the insulation.

If the deterioration in the quality of insulation can only be detected by prolonged exposure to high temperatures due to slow chemical processes, this phenomenon causes thermal aging of the insulation.

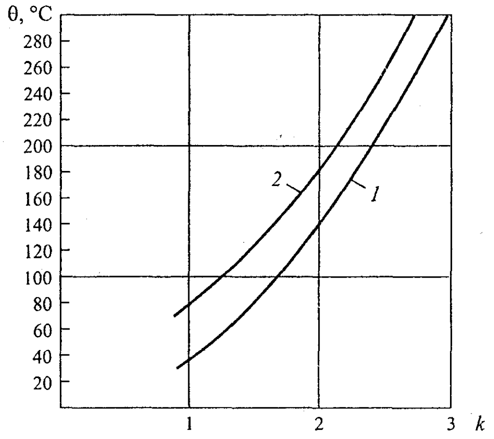

Figure 2 – The curve 1 of overheating $\theta_{п.}$ and curve 2 of insulation temperature $\theta_{маш}$ at ambient temperature 40 °C

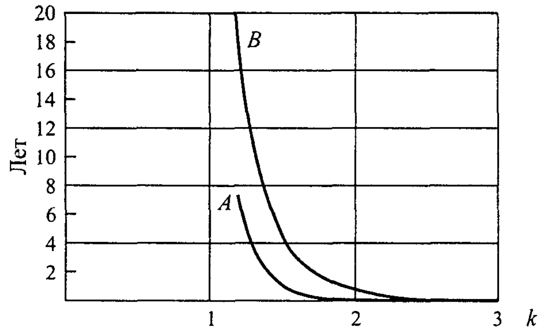

Figure 3 – Insulation service curves of classes A and B

Aging can occur, for example, in lacquer films and cellulosic materials in the form of increasing hardness and brittleness, cracking, etc. To test the resistance of electrical insulating materials to thermal aging, samples of these materials are held for a long time at relatively low temperature, not causing immediate destruction of the material. Properties of samples that have aged some time are compared with the properties of the initial material. Other things being equal, the rate of thermal aging of organic and organoelement polymers increases significantly with increasing aging temperature, obeying the general laws governing the temperature change in the rate of chemical reaction.

For the quantitative analysis of any processes of physicochemical interaction between heterogeneous substances, the use of thermodynamic methods has been adopted. Thermodynamic estimates are associated with the determination of the interaction temperature, the composition of the final products of the reaction, and are necessary to justify the choice of components and barrier coatings on the fiber and the processes of their synthesis, and kinetic estimates are used to select rational methods, technologies, and regimes for obtaining the components themselves, semi-finished products and products.

The thermodynamic analysis of interaction develops in two directions. The first direction is based on the methods of classical Gibbs thermodynamics and is related to the calculation of the final equilibrium products of the reaction between the components. These calculations are currently developed not only for the simplest cases of interaction in two-component systems, but also for a number of more complex and practically important cases, for example, for pairs such as chemical compound - multicomponent solid solution based on metal, etc. In the latter case, the necessary thermodynamic functions and activity coefficients for multicomponent systems are determined by the method of successive approximations on the basis of data for a number of corresponding binary systems [7].

The second direction is based on the thermodynamics of the "small" (disperse) Hill systems and is associated with calculations of metastable states due to the highly disperse structure of one or both interacting components. In these cases, the corresponding terms are introduced into the thermodynamic functions, taking into account the substantial contribution of the surface energy and structure defects to the chemical potentials of phases with a dispersed structure.

Conclusion.

1. To improve the efficiency of electrical repair in general, it is necessary to diagnose the condition of the equipment, study the conditions of its operation, improve the reliability of repair through the use of high-class insulation for heating.

2. Control of thermal insulation aging provides a significant economic effect due to the ability to prevent severe accidents and reduce the cost of repair of traction machines. During the operation of the electrical machine, irreversible changes occur in the state of insulation, which is called aging of insulation. At the same time, the mechanical strength is reduced, fragility appears and cracks are formed. The presence of cracks in the insulation reduces its electrical strength, as a result of which an insulation breakdown can occur, and therefore a major overhaul of the electrical machine is required.

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ВОПРОСЫ СОПРОТИВЛЯЕМОСТИ ИЗОЛЯЦИИ ТЯГОВЫХ МАШИН ДИНАМИЧЕСКИМ ПЕРЕГРУЗКАМ

Аннотация. Рассмотрены вопросы и причины повреждения изоляции тяговых машин при динамических перегрузках. При эксплуатации электрическая тяговая машина периодически испытывает динамические тепловые воздействия. Отрицательное влияние температурных нагрузок сказывается на изоляции обмоток электрических тяговых машины. Опыт эксплуатации и экспериментальные исследования подтверждают, что основной причиной ослабления сопротивляемости изоляционного материала является термические нагрузки, определяемые величиной температуры обмоток, длительностью воздействия нагрузок и градиентами температуры.

Ключевые слова: изоляция, электрическая машина, эксплуатация, надежность, температура, сопротивляемость, контроль состояния.

К. Ж. Калиева, Л. Ш. Утешкалиева, Ж. Ж. Тойгожинова

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ТАРТЫЛЫМ МАШИНАЛАР ОҚШАУЛАМАЛАРЫНЫҢ ДИНАМИКАЛЫҚ ЖҮКТЕМЕЛЕРГЕ ҚАРСЫ ТҰРУ СҰРАҚТАРЫ

Аннотация. Тартылым машиналар оқшауламаларының динамикалық жүктемелерге қарсы тұру сұрақтары қарастырылған. Тартылым машиналары пайдалану кездерінде жиі динамикалық жылулық ісерлер астында болады. Температуралық жүктеме электр машиналарының оарм оқшауламаларына кері әсерлерін тигізеді. Пайдалану және эксcерементті зерттеулер тәжірибесі нәтижесінде оқшауламалық материалдардың жылулық жүктемлердің орама температура шамасымен және градиентімен және жүктеме әсер ету ұзақтылығымен анықталынатын әсерлерінен қарсы тұру босаңсуына әкелетіні бірден бір негізгі себебі екені дәлелденіп отыр.

Түйін сөздер: оқшаулау жай-күйін бақылау, электр машинасы, пайдалану, сенімділігі, температура, төзімділік.

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