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STUDYING FACTORS DETERMINING THE SERVICE LIFE OF ELECTRIC MACHINES

Jamilov Sh.
Tashkent State Transport University, Tashkent Uzbekistan.
Email: shuhratjamilov@mail.ru

Abstract– In this article, the process that occurs during the use of electric machines, that is, what reactions occur in the insulating part of electric machines as a result of temperature rise, when the temperature of electric machines exceeds the external ambient temperature specified in the regulatory documents, i.e. 40^oC, the temperature of electric machines increases. The composition of the insulation materials, which should be used for the thermal class permitted in the insulation materials, is also analyzed.

Key words– electric machine, temperature, insulation, coil, durability, material, collector, ring, temperature, heat resistance, reliability.

I INTRODUCTION

Electric machines heat up during operation. Temperature changes can vary, meaning that some electric machines will heat up less, while others will heat up more. The stable value of the temperature of electric machines depends on the load on its shaft. With a large load, a large amount of heat is released per unit of time, that is, the temperature in the steady state of the electric motor is higher. The permissible temperature of electric machines depends on the insulation class of the coils [1].

Since temperature is an important factor in the deterioration of electrical insulation materials and insulated systems for electric machines, heat resistance classes are adopted to evaluate the temperature resistance of electrical insulation.

The heat resistance class of insulation of electric machines reflects the maximum operating temperature characteristic of these electric machines under nominal load and other conditions.

II EFFECTS ON THE SERVICE LIFE OF ELECTRIC MACHINES

In electrical machines with all information, the insulation class is indicated. Heat resistance is one of the most important qualities of electrical insulation materials, because it determines the permissible loads of electrical machines and devices. The ability of electrical insulating materials to withstand high temperature effects, as well as sudden changes in temperature, without damaging them, is called heat resistance. You should know that when the temperature of the windings of electric machines exceeds the permissible values, the service life of the insulation decreases sharply. Therefore, the heat resistance of the insulation is the main requirement that determines the reliability and service life of electric machines, which should usually be 15-20 years [2].

Electric machines with class A insulation are almost never produced, and class E is used in limited areas in low-power machines. They are mainly used for insulation of B and F classes and H class in special machines working in difficult conditions (metallurgy, mining equipment, transport). In the last 60-70 years, the mass of electric machines has been reduced by 2.5-3 times as a result of increased use of heat-resistant materials, improvement of the properties of electrical engineering steels and improvement of constructions [3].

With a constant load on the shaft, in electric machines, a certain amount of heat is released per unit of time. The maximum allowable temperature increase of active parts of electric machines is shown in Table 1.

In Table 2, as an example, when measuring the temperature of coils using the resistance method, the maximum permissible temperature rises for individual parts of electric machines for general use (U) and traction (T) for continuous operation.

The temperatures of the collector and slip rings are determined by matching (i.e., by measuring the coil resistance) and thermometers as a result of the temperature rise. These data are assumed for an ambient temperature of +40^oC for U machines and +25^oC for T machines [4].

The temperature of the ambient air at which electrical machines used in general industry can work at rated power is considered to be 40^oC.

For electric machines used in general industry, if the ambient temperature is more or less than +40, then the standard allows certain changes in the permissible temperature rise.

Heat resistance class	**Temperature, characterizing the heat resistance of this class ^{o}C**	**Electrical insulation materials corresponding to this heat resistance class**
Y	90	Textile and paper materials made of organic fillers from cotton, natural silk, cellulose and polyamides (ribbons, paper, cardboard, fibers), wood and plastics
A	105	Fibrous materials made of cellulose or silk impregnated or impregnated with a liquid electrical insulating material and other materials and combinations of materials of this class. In fact, class Y materials impregnated with insulating material or immersed in liquid dielectrics (natural resins, oil, asphalt, cellulose ether varnishes, transformer oil, thermoplastic compounds); varnished fabrics, insulating tapes, varnished papers, electrical cardboard, getinax, textolite, impregnated wood, wood laminates, some synthetic films, wire insulation made of cotton, silk and lavsan (PBB, PEVLO, PELSHO, etc.), enamel wire insulation (PEL PEM PELR and LDPE, etc.);
E	120	Some synthetic organic films, as well as other materials and combinations of materials corresponding to this class, synthetic varnishes, some lacquered based on thermosetting synthetic resins and mixtures (epoxy, polyester, polyurethane, PLD wire insulation, PEPLO from lavash, enamel wire insulation) fabrics. PEVTL, PETV, etc., based on polyurethane and polyamide resins);
B	130	Mica-based materials (including organic substrates), asbestos and glass fibers used with organic binders and impregnations, as well as other materials and combinations of materials suitable for this class. Materials based on paper, cloth or organic substances, mica (micanites, mica tapes, mica, mica-plastics), fiberglass (glass cloth, glass fiber), asbestos fibers (thread, paper, fabrics); film glass plastic "Isoflex"; plastics with inorganic filler; laminated plastics based on fiberglass and asbestos materials; thermosetting synthetic compounds; enamel insulation of PETV, PETVP, etc. wires based on polyester varnishes and thermoplastic resins. Absorbent compositions are bitumen oil-resin varnishes based on natural and synthetic resins;
F	155	Mica-based materials (including organic substances), asbestos and glass fibers used with organic binders and absorbents, as well as other materials and combinations of materials suitable for this class. In fact, mica, fiberglass, asbestos are listed in class B, but unsupported or inorganic supported materials; fiberglass "Imidoflex", PSD, PSDT type wires with fiberglass and asbestos insulation, as well as capron-based PET-155, PETP 155 type enamel insulation. Absorbent compositions are heat mresistant synthetic varnishes and resins.
H	180	Materials based on mica, asbestos and glass fibers used in combination with synthetic binders and absorbents, as well as other materials and combinations of materials suitable for this class. In fact, the materials listed in class B are mica, fiberglass and asbestos without substrate or with inorganic substrate, organosilicon elastomers, fiberglass and asbestos insulation of PSDK wires, PSDKT types, enamel insulation of PET-200 wires, types based on PETP-200 Organosilicon varnishes, etc.; impregnating compositions are organosilicon varnishes and resins.
C	above 180	Mica, ceramic materials, glass, quartz, unbindered or with inorganic binders, as well as other materials and combinations of materials suitable for this class.

TABLE 1: THE MAXIMUM ALLOWABLE TEMPERATURE INCREASE OF ACTIVE PARTS OF ELECTRIC MACHINES.

Electric machine parts	Maximum permissible temperature rise, with insulation class ^oC									
	A	E	B	F	H	A	E	B	F	H
	U in general use					traction T				
Armature windings of DC machines and windings of synchronous machines	60	75	80	100	125	85	105	120	140	160
Multi-layer excitation coils of DC and AC machines, compensation coils	60	75	80	100	125	85	115	130	155	180
Single-line excitation coil on non-insulated surfaces	65	80	90	110	135	85	115	130	155	180
In the collector part and connecting rings	60	70	80	90	100	95	95	95	95	105

TABLE 2: MEASURING THE TEMPERATURE OF COILS USING THE RESISTANCE METHOD.

When the ambient temperature exceeds 40^{o}C, the load on electric machines should be reduced so that the temperature of its individual parts does not exceed the permissible values. When using the car in mountainous areas, where the heat transfer decreases due to the decrease in atmospheric pressure, the standard allows for a slight decrease in temperature rise [5].

Despite the decrease in ambient temperature, it is not allowed to increase the current load by more than 10% of the nominal current. Asynchronous electric machines can be affected by changes in the supply voltage, which, along with the decrease in voltage, reduces the power on the machine shaft by the square, and in addition, when the voltage is below 95% of the nominal, there is a significant increase in the current of the machine and the causes ams to heat up. An increase in voltage above 110% of the nominal also leads to an increase in the current in the machine windings, and the heating of the stator increases due to inrush currents [6].

When the temperature rises, many materials begin to burn and become conductors. As a result of prolonged exposure to elevated temperatures, all materials become brittle long before burning, are easily destroyed, and lose their insulating properties. This process is called thermal aging. Experience shows that an increase in insulation temperature by 10^{o}C reduces its service life by about half. Thus, for Class A insulation, an increase in temperature from 95 to 105^{o}C reduces its service life from 15 to 8 years, and an increase in temperature to 120^{o}C reduces it to two years. This phenomenon is based on the general law of the dependence of the rate of chemical reactions on temperature, described by the Van't Goff-Arrhenius equation.

The rate of many reactions increases with temperature.

According to Van't Goff's rule: for every 10^{o}C increase in temperature, the rate of most reactions increases 2-4 times.

$$\frac{vt_2}{vt_1} = \gamma^{\frac{t_2 - t_1}{10}} \tag{1}$$

where γ is the temperature coefficient, which shows how many times the reaction rate increases with an increase in temperature by 10^{o}C.

An increase in the reaction rate with an increase in temperature is not only due to an increase in kinetic energy and the number of collisions of reactant particles. If all the colliding particles were to react with each other, the reaction would be like an explosion. But some collisions do not lead to the formation of new substances (a, Figure 1).

The reaction occurs only as a result of effective collision (b, Figure 1) of particles with excess energy - activation energy.

This energy is sufficient to break or weaken bonds, which can cause atoms to rearrange into new molecules.

As the temperature increases, the percentage of active molecules increases; the number of effective collisions increases. Thus, the rate of chemical reaction increases.

Van't Goff's rule is very inconvenient and can be used only in a very limited temperature range.

The Arrhenius equation describing the temperature dependence of the rate constant is more accurate.

$$k(T) = Aexp\left[-\frac{E_A}{RT}\right] \tag{2}$$

Here, R is the universal gas constant; A is a pre-exponential multiplier that does not depend on temperature and is determined only by the type of reaction; E_A is the activation en-

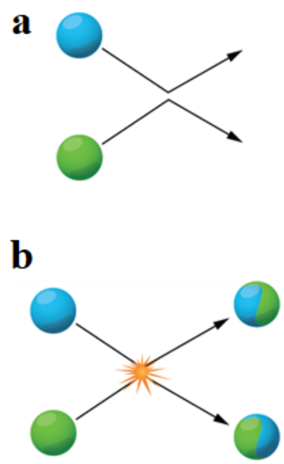

Fig. 1: Collision of inactive and active particles.

ergy, which can be described as a kind of threshold energy: if the energy of the colliding particles is less than E_A, then no reaction will occur in the collision, if the energy exceeds E_A, the reaction will occur ladi The activation energy does not depend on the temperature. E_A

Graphically, the relationship k(T) looks like this:

Chemical reactions almost do not occur at low temperatures: $k(T) \to 0$. At very high temperatures, the rate constant tends to a limiting value: $k(T) \to A$. This means that all molecules are chemically active and each collision causes a reaction.

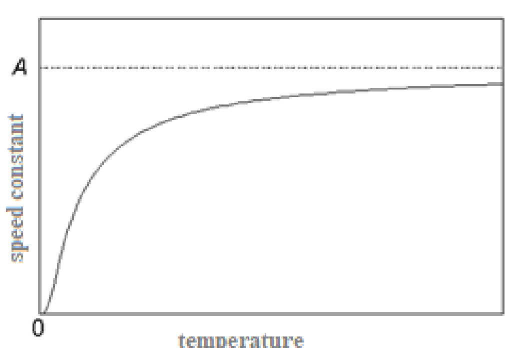

Fig. 2: Graphical dependence of k(T)

The activation energy can be determined by measuring the rate constant at two temperatures. Equation (3) implies the following:

$$E_A = \frac{R \cdot T_1 \cdot T_2}{T_2 - T_1} \cdot ln\frac{k_2}{k_1} \quad (3)$$

More specifically, the activation energy is determined from the rate constant values at several temperatures. For this, the Arrhenius equation (3) can be written in logarithmic form.

$$lnk = lnA - \frac{E_A}{RT}$$

we record experimental data in $lnk - \frac{1}{T}$ coordinates. The tangent of the slope of the obtained straight line is equal to $-\frac{E_A}{R}$. For some reactions, the pre-exponential factor is slightly dependent on temperature. In this case, the so-called experimental activation energy is determined:

$$E_{taj} = RT^2\frac{dlnk}{dT} \quad (4)$$

If the exponent factor is constant, then the experimental activation energy is equal to the Arrhenius activation energy: $E_{taj} = E_A$.

For example, using the Arrhenius equation, we estimate at what temperature and activation energy the Van't-Hoff law holds [8].

We express Van't-Hoff law (1) as a power-law dependence of the rate constant:

$$k(T) = B \cdot \gamma^{\left(\frac{T}{10}\right)}$$

Here B is constant. We compare this expression with the Arrhenius equation (2), taking the value $\sim e = 2.718$ for the temperature rate coefficient:

$$Bexp\left(\frac{T}{10}\right) \approx Aexp\left[-\frac{E_A}{RT}\right]$$

We get the natural logarithm of both parts of this approximate equation:

$$lnB + \left(\frac{T}{10}\right) \approx lnA - \frac{E_A}{RT}$$

That is, technological overloading of working machines or changes in the voltage in the supply network lead to an increase in the current in the machine coils and the temperature of the coil is higher than allowed for this class, as a result of which the service life of the machine decreases rapidly [7]. By differentiating the obtained relationship depending on the temperature, we find the desired relationship between the activation energy and the temperature:

$$E_A \approx \frac{RT^2}{10}$$

If activation energy and temperature roughly satisfy this relationship, Van't-Hoff's rule can be used to determine the effect of temperature on reaction rates.

III CONCLUSION

The basis for establishing rational temperature limits for insulation is made only on the basis of experience or appropriate tests (see: GOST 8865-93). The above-mentioned limited heating temperature for individual classes of insulation is not fully applicable in practice, since it is impossible to establish exact control over the temperature of the insulation of the hottest parts in the use of electrical machines and devices. Therefore, the current standards for electric machines set lower limits for the permissible temperatures of individual machine parts, depending on the appearance and location of these parts in the machine.Taking into account the above, it should be noted that insulation is a factor that determines the long-term operation of electric machines.

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