MATHEMATICAL MODEL OF ASYNCHRONOUS MOTOR DIAGNOSIS

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Increased thermal deterioration of an asynchronous motor insulation is one of the reasons that affect its reliability. Thermal overloads occur due to a number of factors leading to an excess of the rated current. Among them, the most significant are asymmetrical supply voltage, phase failure, short circuits in power lines. Thermal deterioration of motor insulation is influenced by the ambient temperature, the loading ratio, which may differ from the nominal values, both in the smaller and in the larger direction. This leads to under-utilization of the insulation resource consumption or, on the contrary, to increased consumption. The task of diagnosis is to limit the operation of the electric motor, the thermal deterioration of the insulation keeps within the limits limited by the manufacturer, in spite of electric motor operation mode.

The existing diagnosis systems for operating modes of electric motors do not take into account thermal overloads during one year of operation, which affects on the acceptable additional thermal deterioration of the insulation.

To find a relation between the acceptable motor operating time and load ratio, ambient temperature and additional thermal deterioration of insulation per thermal overload, let us assume the electric motor operates with a nominal load has a nominal insulation temperature excess τ. If a current overload occurs, the motor winding temperature during overload time t_o rise to maximum value τ_{max} (fig. 1) and when the load drops during cooling time t_c it reduces back to τ.

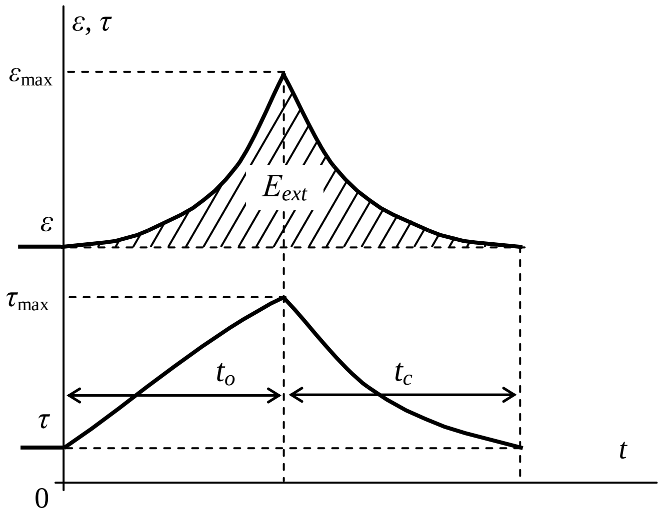

Fig. 1. Dependencies $\tau = f(t)$, $\varepsilon = f(t)$ under motor overload

At the same time, the winding insulation deterioration rate increases from the nominal ε to maximum value ε_{max}. As a result, additional thermal deterioration of insulation occurs during overload and cooling E_{ext}, which is the area bounded by the curve $\varepsilon = f(t)$ above the nominal value of the insulation deterioration rate ε.

Find the acceptable extra thermal deterioration of the motor insulation during overload per one emergency event. The planned thermal deterioration E_y of insulation during a year operation of the electric motor is determined by expression [1]:

$$E = \frac{D}{T}, \quad (1)$$

where D – base life of motor insulation, base hour (bh);

T – motor life, year.

The actual thermal deterioration of insulation per year E_f is usually less than permissible, since it depends on the load curve:

$$E_f = N \cdot e^{B\left(\frac{1}{\theta} - \frac{1}{\tau_f + \vartheta_a + 273}\right)}, \quad (2)$$

where N – number of hours the motor operates in the year, hour (h);

θ – absolute nominal insulation temperature, °K;

ϑ_a – ambient temperature, °C;

τ_f – equivalent average annual winding temperature excess during a motor working period, °C;

$$\tau_f = \tau \frac{a + k^2}{a + 1}, \quad (3)$$

where k – equivalent annual average load factor during a motor working period.

Thus, the acceptable additional thermal deterioration of the motor winding insulation during a year is equal to

$$\Delta E = E - E_f . \quad (4)$$

During a year the motor operates, n thermal overloads occur so acceptable additional thermal deterioration of insulation per thermal overload can be determined

$$E_{a.ext} = \frac{\Delta E}{n} = \frac{1}{n}\left(\frac{D}{T} - N \cdot e^{B\left(\frac{1}{\theta} - \frac{1}{\tau\frac{a+k^2}{a+1} + \vartheta_a + 273}\right)}\right). \quad (5)$$

where n – probable number of thermal overloads during a year [2].

According to statistic the probable number of thermal overloads during a year varies from 50 to 100, so the value of acceptable extra thermal deterioration of motor insulation per one emergency event is $E_{a.ext} = 2\ldots4$ bh.

It can be represented as the sum of additional thermal deterioration of insulation during overload $E_{ext.o}$ and cooling $E_{ext.c}$:

$$E_{a.ext} = E_{ext.o} + E_{ext.c}; \quad (6)$$

$$E_{ext.o} = \int_0^{t_o} \varepsilon_o dt, \quad (7)$$

where ε_o – thermal deterioration rate of insulation during overload, bh/h.

$$\varepsilon_o = \varepsilon \cdot e^{B\left(\frac{1}{\theta_n} - \frac{1}{\tau_o + \vartheta_a + 273}\right)}, \quad (8)$$

where τ_o – current isolation temperature under overload, °C.

$$\tau_o = \tau_s\left(1 - e^{-\frac{t}{T}}\right) + \tau \cdot e^{-\frac{t}{T}}, \quad (9)$$

where τ_s – steady insulation temperature excess, °C;

T – motor heating time constant, seconds (s).

Extra deterioration rate of insulation during cooling:

$$E_{ext.c} = \int_0^{t_c} \varepsilon_c dt, \quad (10)$$

where t_c – insulation cooling time to nominal temperature excess, s;

ε_c – thermal deterioration rate of insulation during cooling, bh/h.

$$\varepsilon_c = \varepsilon \cdot e^{B\left(\frac{1}{\theta} - \frac{1}{\tau_c + \vartheta_a + 273}\right)}, \qquad (11)$$

where τ_c – current excess temperature of insulation during cooling, °C.

$$\tau_c = \tau_{\max} e^{-\frac{t}{T}}; \qquad (12)$$

$$\tau_{\max} = \tau_s \left(1 - e^{-\frac{t_o}{T}}\right) + \tau \cdot e^{-\frac{t_o}{T}}. \qquad (13)$$

The acceptable time of motor operation under overload can be determined after extra thermal deterioration $E_{a.ext}$ definition

$$t_a = T \ln \frac{\tau_s}{\tau_s - \tau_a}, \qquad (14)$$

where τ_a – acceptable insulation temperature excess, °C; τ_a = 5…10°C

Using the described mathematical model of diagnosis, acceptable operating time dependencies of an asynchronous electric motor installed in submersible pump PED 2,8-140 were obtained (fig. 2).

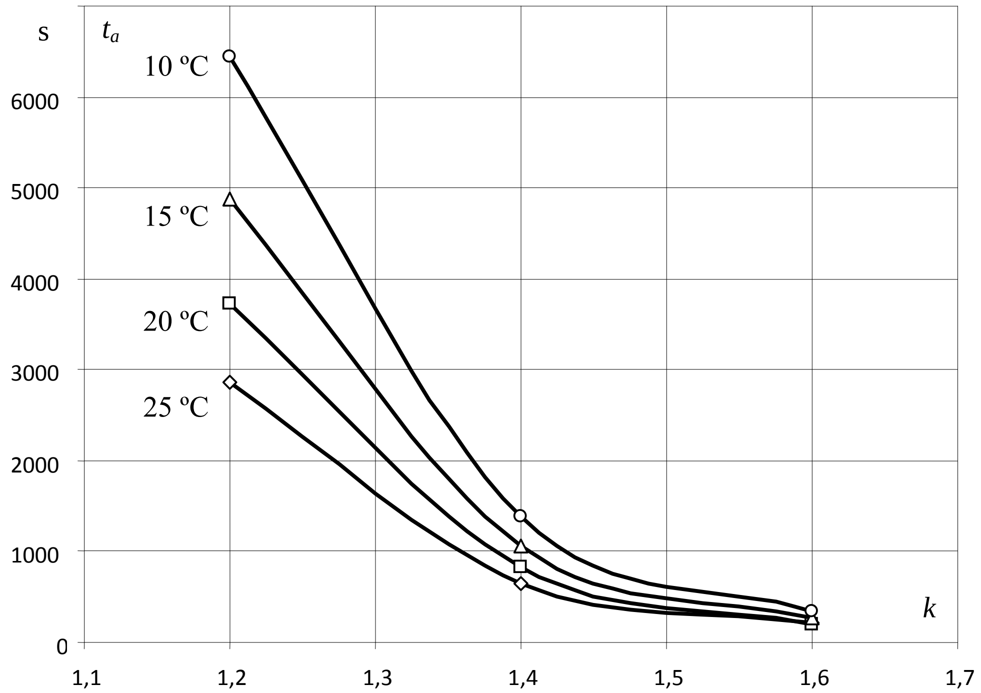

Fig. 2. Dependencies $t_a = f(k, \vartheta_a)$ for $E_{a.ext}$ = 4 bh

These curves can be approximated by method of least squares and the regression equations can be used in the diagnostics device to determine the operation acceptable time of an asynchronous motor with current overload by various reasons.

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