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ABOUT THE TEMPERATURE REGIME OF AN INDUCTION MOTOR, SUPPLIED BY A CONTROLLED INVERTER

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ABSTRACT
The heating of the induction motor that aggravates its frequency control is a subject of this article. With a view the motor to be used to the highest degree when it runs in a preset frequency range, some possibilities for an optimization of the motor construction are examined.

FORMULATION OF THE PROBLEM

The modern means of the induction motors control put a number of new problems about the losses in the motor and its heating. The value and the frequency variations in the supply voltage within very large limits require the formulation of a larger criterion of the loss optimization in the copper and the steel. As it is known in [1], when the induction motor is supplied with a rated voltage with a constant and unchanging frequency, the optimal designing requires, if the load is rated, the losses in the copper and the steel to be with close values. If the motor concerned is supplied by a controlled inverter, works in a steady-state regime and the rotation frequency is low, the heating balance changes considerably. On the one hand the losses in the steel of the motor decrease considerably, as they are approximately proportional to the square of the frequency. The square of the current, which depends on the frequency and on the value of the supply voltage, that is also liable to control, determines the losses in the copper. On the other hand, when the rotation frequency is low, the ventilation deteriorates, which leads to deterioration of the cooling, unless an independent fan is used. Consequently, in the case in question, a revaluation of the constructionally determined losses in the motor is necessary with a view to its better use in the whole control range**.** In the analysis of the so put question, the maximum enhancement of the motor possibility, more exactly the mechanical work accomplished for a long period of time with different settled rotation frequencies, is accepted for criterion. Besides in this article the efficiency of the rectifier - inverter – motor system is not accepted as an additional criterion, i.e. the optimum power effectiveness of the system is not sought.

FORMULATION OF THE OPTIMIZATION PROBLEM

The heating balance of the stator is expressed with the following formula $P_{st} + P_{cop} = P_{cool}$, where P_{st} and P_{cop} are the losses in the steel and the copper, and P_{cool} is the power emitted as a result of the cooling. The frictional losses are deliberately less and they have to be ignored.

As it is known in [2] if the approximation is greater, the formulas will be the following: $P_{st} = K_{st} . U^2 . f^2$ and $P_{cop} = K_{cop} . I^2$, where K_{st} and K_{cop} depend on the motor construction.

At first the case, when an independent external fan accomplishes the cooling of the motor, will be examined and consequently P_{cool} = const does not depend on the variable frequency f of the supply voltage. In the case in question the motor can be used much better especially when the lower frequency limit value is low.

The following formula about the current can be determined with a sufficient precision from the equivalent circuit of the induction motor [2] (when the sliding is normal):

$I = \dfrac{Uf_n}{U_n f} I_n$, where the index "n" means the rated values of the quantities.

When a substitution in the equation about the heating balance is accomplished the following formula comes out:

$$U^2 = \frac{f^2 P_{cool}}{K_{st} f^4 + K_{cop} \dfrac{f_n^2}{U_n^2} I_n^2}$$

The torque of the motor, when the voltage is U and the frequency –f, is determined by the equation:

$$M = M_n \frac{U^2 f_n^2}{U_n^2 f^2}.$$

Because of the small value of the sliding, when the operation is normal, it can be accepted that $f_2 \approx f_1$ and the mechanical power is:

$$P_{mec} = 2\pi f_1 \ M = 2\pi M_n \frac{U^2 f_n^2}{U_n^2 f^2}$$

If it is accepted that all of the frequencies f of the steady-state regime in the rage between f_{min} and f_{max}, are equally possible, the motor will produce maximal mechanical work "A" during a definite long period of time. It may happen if $A = \int_{t_1}^{t_2} P_{mec} dt = Max$, where ($t_2 - t_1$) is the service life. After some transformations the following problem can be formulated: an induction motor has to operate with different, equally possible frequencies in the rage between f_{min} and f_{max}. It is based on a prototype of an induction motor with preset rated characteristics. What changes about the values of the factors have to be constructionally realized in order the following equation to be observed?

$$J = \int_{f_{min}}^{f_{max}} \frac{f P_{cool}}{K_{st} f^4 + K_{cop} \frac{I_n^2 f_n^2}{U_n^2}} df = Max.$$

SOLUTION OF THE PROBLEM

When the overall dimensions are determined, the correlation between the cross-sections of the magnetic cores and the windings can vary. Let the cross-section of the magnetic cores changes a little, for example $S_{st} = \frac{S_{stn}}{1+\varepsilon}$, where |ε|<< 1. With a first approximation it can be accepted that the total cross-section of the winding will receive opposite, by nature, change $S_{cop} = S_{cop}(1 + \alpha)$, which leads to a relevant change in the cross-section of each conductor $S_{con} = S_{con.n}(1 + \varepsilon)$ when the number of the windings is the same. These changes affect on the factors K_{st} and K_{cop} in the following way. When the magnetic flux is constant, the magnetic induction "B" changes as follows $B = B_n(1 + \varepsilon)$. As a result the losses in the ferromagnetic material change per unit of weight – $P_{st1} = P_{st.n1}(1 + \varepsilon)^2$. On the other hand the overall weight of the magnetic core "G" changes as well $G = \frac{G_n}{1+\varepsilon}$. Therefore the losses in the steel are determined by the following equations: $P_{st} = P_{st.n}(1 + \varepsilon)$ or $K_{st} = K_{st.w}(1 + \varepsilon)$. By analogy

$$K_{cop} = \frac{K_{copn}}{(1+\varepsilon)}$$

It is necessary the value of ε to be determined so as the equation J = Max, to be realized.

After integrating and differentiating in respect of the value (1 + ε). The derivative is reduced to zero. As a result the following formula comes out:

$$\varepsilon_{max} = \frac{f_n^2}{f_{max} . f_{min}} \sqrt{\frac{P_{copn}}{P_{st}}} - 1$$

The same result comes out assuming that the magnetic core is with preset parameters, but the number of the windings "w" changes. Let this number for the initial motor be "w_o". In case of a new value "w" and when all of the overall dimensions are the same, the magnetic induction has got a new value $B = B_0 \frac{w_0}{w^2}$. The losses in the copper depend on the resistance R of the winding:

$P_{cop} = R \,.\, I^2$. This resistance depends on the number w of windings through both the overall length $l = l_1.w$ and the cross-section of the conductor $S_{con} = \frac{\Delta}{w} K_l$, where l_1 is the average length of a winding and Δ is the total cross-section of the coil. Therefore $P_{cop} = P_{cop0} \frac{w^2}{w_0^2}$. As a result, when the motor construction isnstant, the values of the losses in the steel can increase x-times through a relevant change in the numbers of the windings and the losses in the copper decrease approximately x-times i.e. if $Pst = xP_{st0}$, then $P_{cop} = \frac{1}{x} P_{cop0}$.

CONCLUSIONS

The results obtained are achieved on the basis of some approximate suppositions. Nevertheless they correctly reflect the tendency, that has to be observed during the designing with a view to the improvement in the use of the motor. The equations shown above, also afford an opportunity an optimization to be sought when some irregular distributions of the frequencies are expected during the service life. That has been accomplished on the basis of prognosis suppositions.

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