Dynamic processes in the asynchronous machine proceed with the change of the temperature of its particular parts. In its turn it leads to a change in the ohmic resistance of the windings and consequently, to changes in the energy performance of the whole machine.

A task of analysis of asynchronous machines with regard to thermal transition processes arises.

Mathematical model of electromagnetic, mechanical and thermal subsystems, in accordance with the energy approach to the modeling of electro technical complexes and systems, built in canonical form.

In deriving the equations of the transition process of asynchronous machine, with regard to thermal processes, assumptions about the unsaturation of the main path of the magnetic flux, the absence of damping circuits are made:

1. The electric machine is represented in the form of a system of homogeneous bodies, relations between which are determined by the type and the conditions of heat exchange.

2. The electric machine is divided into «parts», in the plane of symmetry of each body the node is set, the resistance of heat exchange with other bodies is connected to him, and concentrated equivalent thermal resistance substituting the actual distributed, are assumed to be not dependent on the magnitude of heat flow; losses that occur in this part of electric machine are put in the nodes.

3. Heat calculation is reduced to the calculation of the average temperature of all machine components. We believe that heat flow in the longitudinal cross section is absent, it allows to consider a flat task in the cross-section of the machine; individual conductors are equal to the average overtemperature in this section in the cross section of the winding overtemperature.

Electric machine is always a complex set of interrelated elements, processes in which mathematically by a system of Poisson’s equations in partial derivatives are described.
Key words: simulation, asynchronous machine, thermal processes, transition processes, mathematical simulation, canonical form of the model, dynamic rating.

Ключевые слова: моделирование, асинхронная машина, переходные процессы, тепловые процессы, математическое моделирование, каноническая форма модели, динамический режим работы.

Dynamic processes in the asynchronous machine proceed with the change of the temperature of its particular parts. In its turn it leads to a change in the ohmic resistance of the windings and consequently, to changes in the energy performance of the whole machine.

A task of analysis of asynchronous machines with regard to thermal transition processes arises.

Mathematical model of electromagnetic, mechanical and thermal subsystems, in accordance with the energy approach to the modeling of electrotechnical complexes and systems, built in canonical form [3, 6].

In deriving the equations of the transition process of asynchronous machine, with regard to thermal processes, assumptions about the unsaturation of the main path of the magnetic flux, the absence of damping circuits are made. After transformations we get the following [1, 2, 4]:

\[
\Psi_s = L_s i_s - \frac{1}{2} L_m (i_b + i_c)
\]
\[+ L_w \left[ i_s \cos \Theta + i_b \cos (\Theta - 120^\circ) + i_c \cos (\Theta + 120^\circ) \right];
\]
\[
\Psi_a = L_a i_a - \frac{1}{2} L_m (i_a + i_b)
\]
\[+ L_w \left[ i_a \cos (\Theta + 120^\circ) + i_b \cos \Theta + i_c \cos (\Theta - 120^\circ) \right];
\]
\[
\Psi_c = L_c i_c - \frac{1}{2} L_m (i_a + i_c)
\]
\[+ L_w \left[ i_c \cos (\Theta - 120^\circ) + i_b \cos (\Theta + 120^\circ) + i_a \cos \Theta \right];
\]

the active resistance of the phase windings of the stator and rotor are given for an ambient temperature of 20 °C.

\[
R_{A,20} = R_{B,20} = R_{C,20};
\]
\[
R_{a,20} = R_{b,20} = R_{c,20};
\]
\[
R_{a,20} = R_{b,20} = R_{c,20};
\]
\[
R_{a,20} = R_{b,20} = R_{c,20};
\]

Accounting changes of the resistance of the windings in dependence on temperature is based on the method of equivalent thermal circuits which suggests the analogy of heat flow with electric current based on a single form of the equations of heat exchange (Fourier’s law)

\[
P = \lambda S_0 \Delta \Theta / \delta = \Delta \Theta / R_s
\]

and electric current (Ohm’s law)

\[
I = k S \Delta U / l = \Delta U / R_s
\]

where \( S_0 \) – the average area of heat transfer surface; \( \lambda \) – thermal conductivity coefficient; \( \Delta \Theta \) – temperature fall on the length \( \delta \); \( R_s \) – the thermal resistance of this portion of the path of heat flow; \( k \) – specific conductance; \( \Delta U \) – the potential difference on the length of the conductor \( l \) with a cross section \( S \); \( R_s \) – electrical resistance.

The basic assumptions of the heat diagram method are the following [5]:

1. The electric machine is represented in the form of a system of homogeneous bodies, relations between which are determined by the type and the conditions of heat exchange.
2. The electric machine is divided into «parts» within the dimensions of which the conditions of heating-cooling remain constant. In the plane of symmetry of each body the node is set, the resistance of heat exchange with other bodies is connected to him, and concentrated equivalent thermal resistance substituting the actual distributed, are assumed to be not dependent on the magnitude of heat flow; losses that occur in this part of electric machine are put in the nodes. Thus the actual distributed heat sources are replaced by lumped.

3. Heat calculation is reduced to the calculation of the average temperature of all machine components. We believe that heat flow in the longitudinal cross section is absent, which allows to consider a flat task in the cross-section of the machine; individual conductors are equal to the average over temperature in this section in the cross section of the winding over temperature; we consider the thermal conductivity coefficient of the materials constant.

Electric machine, including induction motor in thermal relation is always a complex set of interrelated elements, processes in which mathematically by a system of Poisson’s equations in partial derivatives are described. Interrelated and independent boundary conditions for these equations sophisticate the solution. The failure to consider the field of temperatures within individual element allows you to provide thermal processes by the system of ordinary linear differential equations of the first order. Their number depends on the number of bodies in which the machine is broken.

Thermal state of the n-th body taking into account the above assumptions is described as a differential equation of the heat balance:

\[ C_n \frac{dT_n}{dt} = \sum_{i=1}^{q(n)} \Lambda_{ni}(T_i - T_n) + P_n, \]  

(24)

where \( C_n \) – the heat capacity of n-th body; \( T_n \) – the temperature of n-th body; \( T_i \) – the temperature of one of the near bodies \( i \); \( q \) – the number of bodies connected in a heat relation with the considered body \( n \); \( \Lambda_{ni} \) – the heat transfer from one of the neighboring bodies \( i \) to this body \( n \); \( P_n \) – loss of power in this body \( n \); \( t \) – the current time.

We have the following for electrical machines, divided into the system of \( n \) bodies in thermal relation with the given assumptions (1) – (3):

\[ C_1 \frac{dT_1}{dt} = \left( -\sum_{i=1}^{k(1)} \Lambda_{1i} \right) T_1 + \sum_{i=1}^{k(1)} \Lambda_{1i} T_i + P_1, \]

\[ C_2 \frac{dT_2}{dt} = \left( -\sum_{i=2}^{k(2)} \Lambda_{2i} \right) T_2 + \sum_{i=2}^{k(2)} \Lambda_{2i} T_i + P_2, \]

\[ \ldots \]

\[ C_n \frac{dT_n}{dt} = \left( -\sum_{i=n}^{k(n)} \Lambda_{ni} \right) T_n + \sum_{i=n}^{k(n)} \Lambda_{ni} T_i + P_n, \]  

(25)

where \( n \) – the number of bodies, connected in a heat relation with the first body; \( k \) – the number of bodies, connected in a heat relation with the second body.

From the analysis of the pattern of heat transfer of short-circuited induction motor with a degree of protection IP44, on the assumption that the thermal resistance between the frame and panels is missing; heat transfer through the shaft is negligible; assumptions are adhered (1)-(3), and the whole system is symmetric, simplified thermal equivalent circuit can be made (TEC). It consists of seven bodies: the stator teeth with an average temperature of \( T_{st} \); stator with an average temperature of \( T_a \); a shell comprising a frame and end shields, with an average temperature of \( T_{st} \); slot winding of the stator with an average temperature of \( T_{st} \); end-winding of the stator with an average temperature of \( T_{st} \); winding and the rotor teeth with an average temperature of \( T_{st} \); inner air with an average temperature of \( T_{in} \).

Body of TEC are linked by respective thermal conductivities. Sources of heat concentrated at the appropriate nodes are: basic and additional losses in the stator teeth \( \sum_{i=1}^{k(1)} \Lambda_{1i} T_i \); losses in the stator yoke \( P_{sy} = B^2 \cdot M_1 \cdot k_{st} \); copper losses of the slot part of the winding \( P_{sl} = B^2 \cdot M_1 \cdot k_{st} \); losses in the rotor, including the electrical losses in a short-circuited squirrel cage \( P_{roc} \) and additional losses in teeth \( P_{roc} \).

Based on the previously made assumptions, the received split of asynchronous motor into parts with equal temperatures and taking into account equations (24) we have the following:

\[ \frac{d\Psi_{st}}{dt} = -(\Lambda_{st} + \Lambda_{at} + \Lambda_{st} + \Lambda_{st}) r_{st} + \Lambda_{st} r_{st} + \Lambda_{at} r_{at} + B^2 \cdot M_1 \cdot k_{st}; \]

(26)

\[ \frac{d\Psi_{st}}{dt} = -(\Lambda_{st} + \Lambda_{at} + \Lambda_{st} + \Lambda_{st}) r_{st} + \Lambda_{st} r_{st} + \Lambda_{at} r_{at} + B^2 \cdot M_1 \cdot k_{st}; \]

(27)

\[ \frac{d\Psi_{st}}{dt} = -(\Lambda_{st} + \Lambda_{at} + \Lambda_{st} + \Lambda_{st}) r_{st} + \Lambda_{st} r_{st} + \Lambda_{at} r_{at} + B^2 \cdot M_1 \cdot k_{st}; \]

(28)

\[ \frac{d\Psi_{st}}{dt} = -(\Lambda_{st} + \Lambda_{at} + \Lambda_{st} + \Lambda_{st}) r_{st} + \Lambda_{st} r_{st} + \Lambda_{at} r_{at} + B^2 \cdot M_1 \cdot k_{st}; \]

(29)
The dynamic model of asynchronous machines with regard to thermal transition processes has been worked out. The structure of the model – is a mixed system of fluxional and algebraic equations.

The necessity of creation of special numerical method for solution of the built mixed system of fluxional and algebraic equations has been shown.

Conclusions

Problem-oriented numerical methods [3,5] applicable directly to these equations are required for solutions of the built system of equations of the dynamics of induction motor taking into account the thermal processes (26) - (39).

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СПИСОК ИСПОЛЬЗУЕМЫХ ИСТОЧНИКОВ


