# MODELING OF HEAT PROCESSES IN INDUCTION MOTOR AND DETERMINATION OF THERMAL LIFE OF STATOR WINDING INSULATION BY MATHLAB 6.5

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*The analysis of temperature modes of motors in solving of problems related to electric drive in most cases is directed to grounding of simplified methods and engineering ways for motor power preliminary selection and heating terms check. Admissible thermal conditions are such conditions where the duration of insulation work is not less than the assigned. In the process of motor operation there is a constant insulation wear connected with its heating and the speed of this process is determined by the character of temperature mode.*

*Besides during the heating the temperature of motor insulation shall not exceed even for a short time the admissible value because in this case it will be broken.*

*It will be interesting for engineering practice to determine the electric machines heat parameters and work duration in theoretical study of machine processes when the machine is not built yet i. e in a design stage. When the machine is built there are possibilities for heat investigations and heat parameters determination and therefore the insulation system resource will be measured more precisely.*

*The solving of the problem for full calculation of machine heating includes solving of a set of equations for its different parts by taking into consideration their mutual relation. The electric machine is presented with equivalent circuit consisting of several uniform bodies and sources of losses in the respective motor areas. Depending on the mode the heat capacities of separate parts are taken into consideration but this is in case the transition processes are examined. The preciseness of the results obtained depends on the number of bodies included in the equivalent circuit. Usually the preciseness necessary for the engineering practice is reached by examination of 4-5 uniform bodies. As a result of the set of equations solving, the temperatures in the examined areas are found and hence the residual resource can be predicted.*

*This investigation is a method for determination of electric machines heat parameters by means of computer simulation and modeling of temperature mode by MATHLAB 6.5 program product.*

**Keywords:** electrical machines, thermal durability, electrical insulation, computer modeling

## Investigation:

The solving of the problem for full calculation of machine heating includes solving of a set of equations for its different parts by taking into consideration their mutual relation. The electric machine is presented with equivalent circuit consisting of several uniform bodies and sources of losses in the respective motor areas. Depending on the mode the heat capacities of separate parts are taken into consideration but this is in case the transition processes are examined. The preciseness of the results obtained depends on the number of bodies included in the equivalent circuit. Usually the preciseness necessary for the engineering practice is reached by examination of 4-5 uniform bodies. As a result of the set of equations solving, the temperatures in the examined areas are found and hence the residual resource can be predicted.

## Exposition:

The following assumptions are made in order to simplify the equivalent circuit:

1. The thermal conductivity and the heat release coefficients of different surfaces to the coolant are accepted independent of the coordinates and the temperature.
2. The losses are accepted independent of the temperature.
3. Steady-state operating duty is accepted

The equivalent circuit valid for the heating process in a steady-state regime contains conventionally 4 uniform bodies and it is shown in fig.1.

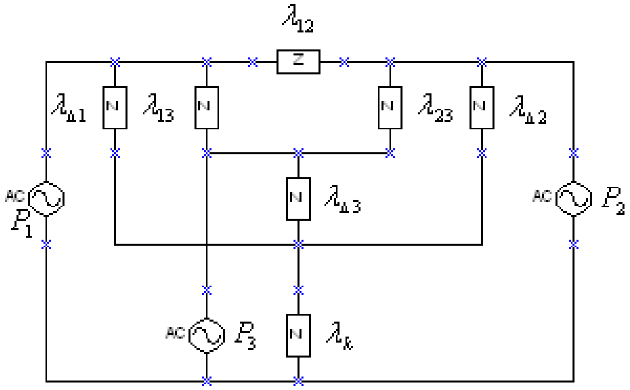


fig.1. Heat equivalent circuit

The individual symbols are as follows:

- $P_1$, $P_2$, $P_3$- losses in the stator package, rotor and the stator winding;
- $\lambda_{12}$ - heat conductivity of the air gap;
- $\lambda_{13}$ - heat conductivity between the copper and the steel by the canal insulation;
- $\lambda_{\Delta 1}$ - heat conductivity of the contact gap between the package and the body;
- $\lambda_{\Delta 2}$ -heat conductivity of rotor to the case by shaft;
- $\lambda_{23}$ - equivalent heat conductivity between bodies 2 and 3;
- $\lambda_{\Delta 2}$ -heat conductivity between body 3 and the case;
- $\lambda_k$ -heat conductivity of the case to the environment;

The four bodies included in the equivalent circuits are as follows: stator package, stator winding, rotor and case. The set of equations describing the temperature regime is as follows:

$$\Theta_1=-(\lambda_{12}+\lambda_{13}+\lambda_{\Delta 1}).\Theta_1+\lambda_{12}.\Theta_2+\lambda_{13}.\Theta_3+\lambda_{\Delta 1}.\Theta_4+P_1.(1+\alpha_1.\Theta_1) \tag{1}$$

$$\Theta_2=\lambda_{12}.\Theta_1-(\lambda_{12}+\lambda_{23}+\lambda_{\Delta 2}).\Theta_2+\lambda_{23}.\Theta_3+\lambda_{\Delta 2}.\Theta_4+P_2.(1+\alpha_2.\Theta_2) \tag{2}$$

$$\Theta_3=\lambda_{13}.\Theta_1+\lambda_{23}.\Theta_2-(\lambda_{13}+\lambda_{23}+\lambda_{\Delta 3}).\Theta_3+\lambda_{\Delta 3}.\Theta_4+P_3.(1+\alpha_3.\Theta_3) \tag{3}$$

$$\Theta_4=\lambda_{\Delta 1}.\Theta_1+\lambda_{\Delta 2}.\Theta_2+\lambda_{\Delta 3}.\Theta_3-(\lambda_{\Delta 1}+\lambda_{\Delta 2}+\lambda_{\Delta 3}).\Theta_4 \tag{4}$$

According to (1) the heat conductivity can be determined by the following relationships, having the constructive data for the respective motor:

$$\lambda_{\Delta 1} = \frac{\lambda_{\gamma 1}.\lambda_{\gamma\Delta 1}}{\lambda_{\gamma 1} + \lambda_{\gamma\Delta 1}} \quad , \qquad (5)$$

where: $\lambda_{j1}$ is the general conductivity of the stator package and $\lambda_{j\Delta 1}$ varies from 0,0025 ± 0,003 cm - for small machines and 0,005 ± 0,0075 cm for big machines.

$$\lambda_{12} = \frac{1}{2}.\alpha_{\delta}.\pi.\ell_{1}.\mathrm{d}_2, \qquad (6)$$

where: $\alpha_{\delta} = 27.(1+\sqrt{\nu_{\delta}})$,[W/m$^2$.°C] (7)

$$\nu_{\delta} = \frac{1}{2}.\frac{\pi.D_{2.}n}{60}, \qquad (8)$$

where: $D_2$ – diameter of rotor.

$$\lambda_{\Delta 2} = \frac{1}{\frac{1}{\lambda_{\gamma 2}} + \frac{1}{\lambda_{\gamma\Delta 2}} + \frac{1}{\lambda_{вп}}}, \qquad (9)$$

$\lambda_{\gamma 2} = 2.\pi.\lambda_{fe}.\dfrac{1}{\ln.\dfrac{D_{в} + h_{\gamma 2}}{D_{в}}}$ - conductivity of package back; (10)

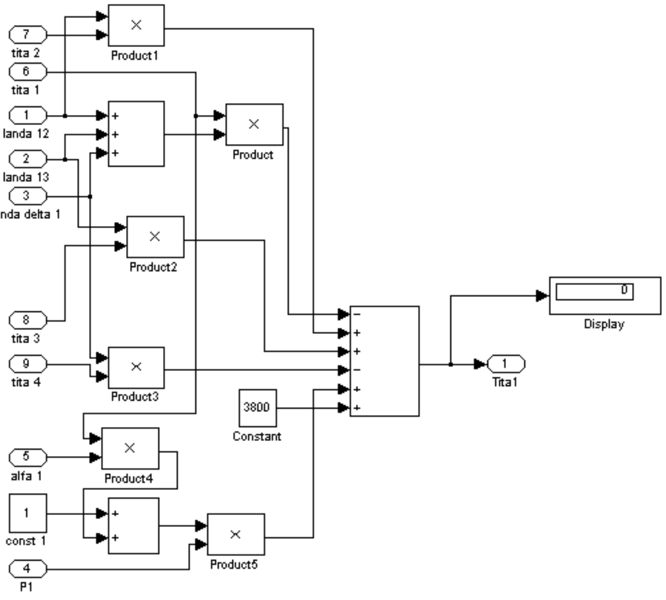
$\lambda_{\Delta\gamma 2} = \dfrac{\lambda_i}{\Delta_{\gamma 2}}.\pi.Dв.l_2$ - conductivity of the gap between the rotor and the shaft; (11)

$\lambda_{23} = \alpha_{k2}.S_{k2}$ - conductivity of rotor, (12)

where $\alpha_k = 27.\left(1+\sqrt{\nu_{\alpha i}}\right)$,[W/m$^2$.°C]- is determined with α sensors fixed to the fan; (13)

$$\lambda_k = \alpha_{c\Sigma}.\pi.D_c.L_c + \alpha_c.S_p, \qquad (14)$$

where: $\lambda_k$ is full heat abstraction coefficient.

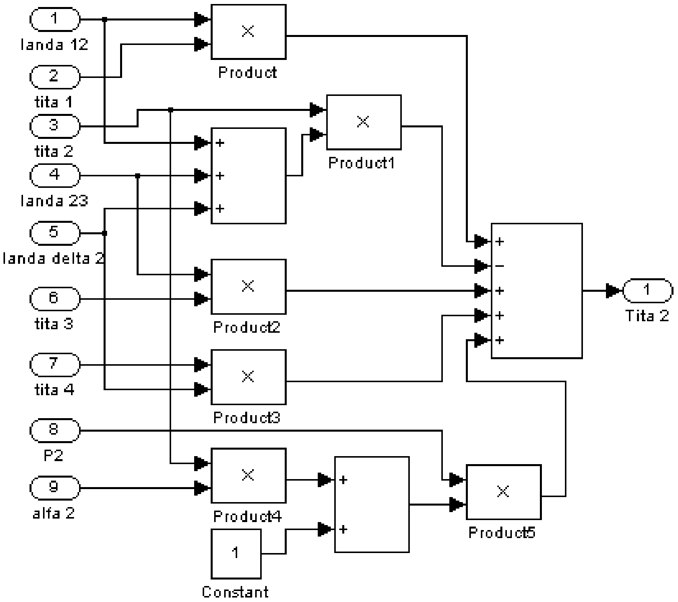


a) Subsystem for determining $\theta_1$

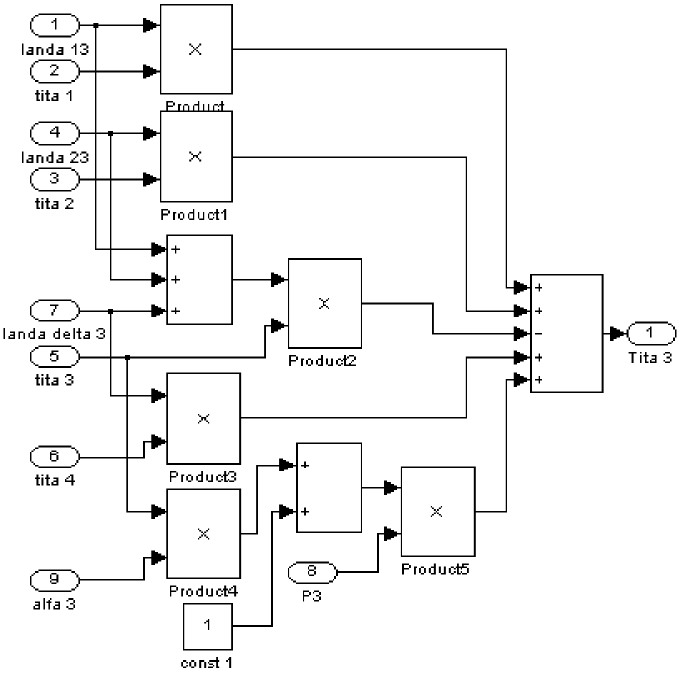
The determination of heating and stator winding resource whose exhaustion is the cause for 70 ± 80 % of electric machines troubles is also interesting. The residual resource of the winding is determined by the following:

$$T_p = \frac{1}{\sum_{1}^{n} \frac{a}{i}.e^{\frac{\Theta}{b}}} \qquad (15)$$

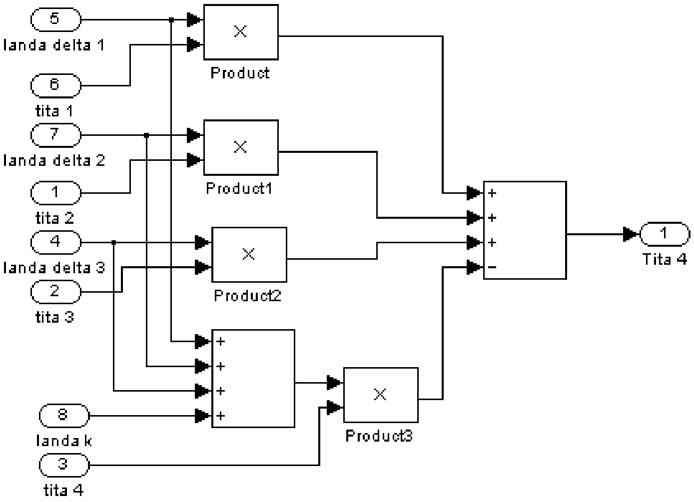
where: a and b are coefficients depending on the insulation class. The complete block diagram of the realized mathematical model is presented in figure 2.



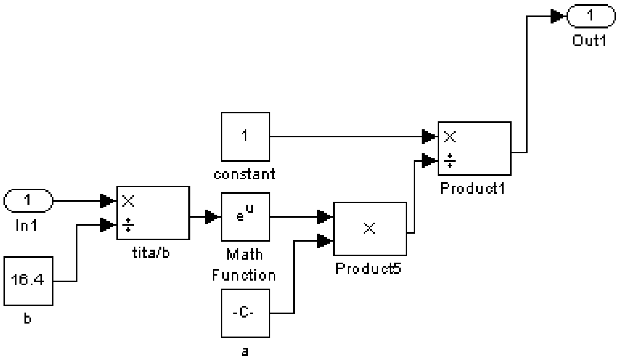
b) Subsystem for determining $\theta_2$



c) Subsystem for determining $\theta_3$



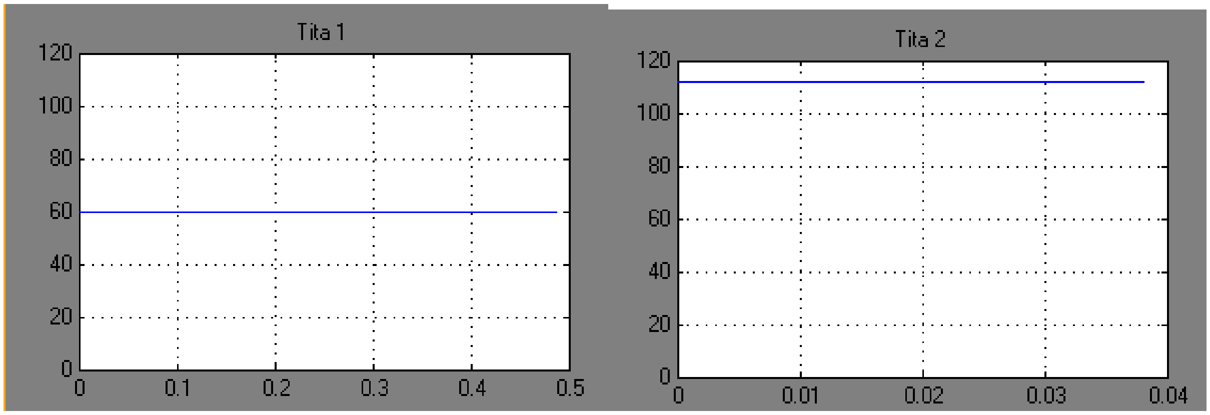
d) Subsystem for determining $\theta_4$



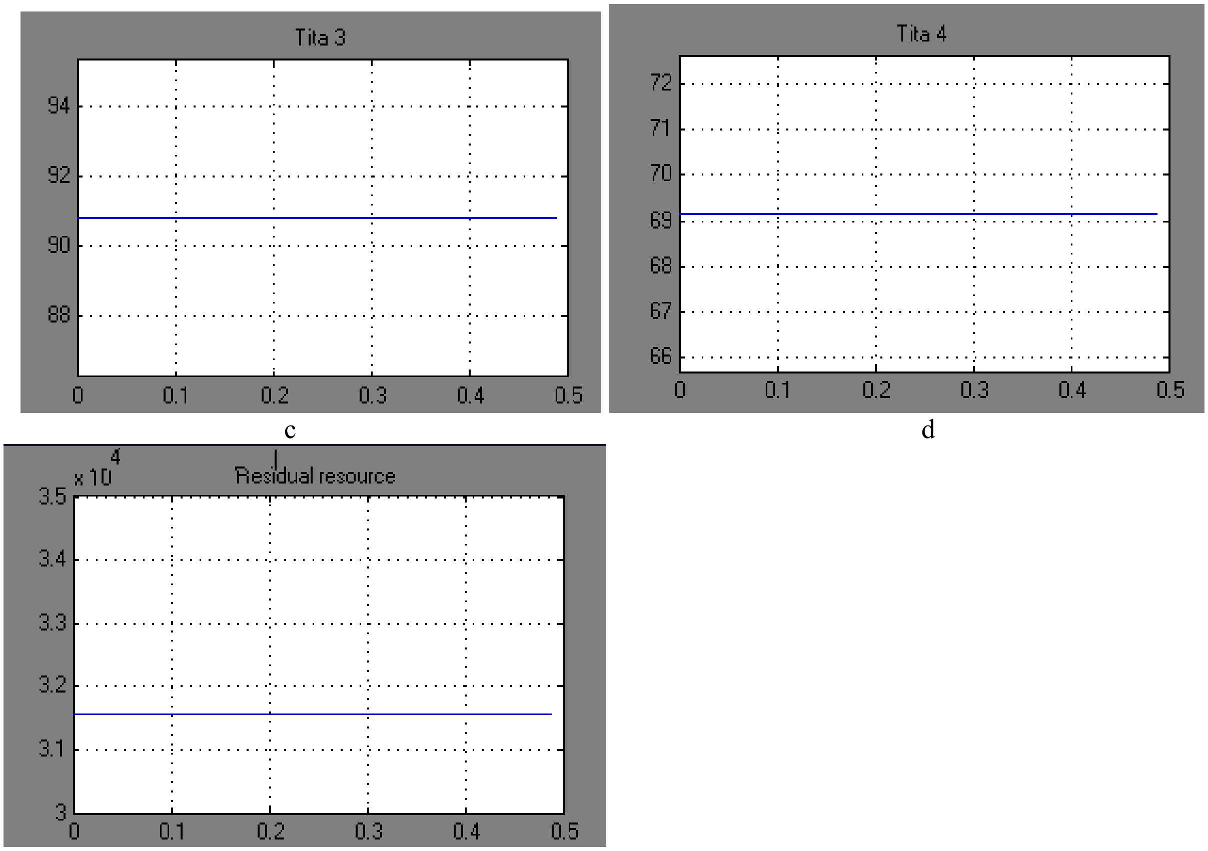
e) Subsystem for determining residual resource

Fig.2. Computer Modeling of the Temperature Regime

Figure 3 presents the graphically obtained temperatures in typical spots and the residual resource of the stator winding.



a b



c

d

e

Fig.3. graphically obtained temperatures in typical spots and the residual resource of the stator winding a)$\theta_1$- temperatur stator package: b) $\theta_2$- temperatur of rotor; c) $\theta_3$- temperatur of stator winding; d) $\theta_4$- temperatur of case

**Appendix:** AM type AT-104-4

: $P_n$=250 kw, $U_n$=380V, $I_n$=470A, n=1470, $\eta$=0.93,

Losses : $P_1$=3850W, $P_2$=5844W, $P_3$=1755W

Calculated heat conductivity:$\lambda_{12}$=124 W/m$^2$.$^o$C, $\lambda_{13}$=0.2 W/m$^2$.$^o$C, $\lambda_{\Delta 1}$=117 W/m$^2$.$^o$C, $\lambda_{23}$=85 W/m$^2$.$^o$C, $\lambda_{\Delta 2}$=0.129 W/m$^2$.$^o$C, $\lambda_{\Delta 3}$=190 W/m$^2$.$^o$C, $\lambda_k$=42 W/m$^2$.$^o$C, $\alpha_k$=0.004K$^{-1}$

**Conclusion:** Comparatively simple and generalized algorithm for determination of heating and thermal life of the stator winding insulation is developed and it can be placed in the basis of developing methods for heat calculation of different electric machines. Results of analytic and experimental tests of some of the most spread types of induction motors are also presented.

## Literature:

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