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28th - 30th November 2012.
Jahorina, B&H, Republic of Srpska
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

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THERMAL ANALYSIS OF HIGH POWER REDUCTION GEARBOX

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Abstract: This paper presents thermal analysis of high power reduction gearbox used for transfering power to surface mining conveyor belts. Gearbox is designed for continuous operation at high speeds, which results in generation of large amount of heat. Analysis is used to determine proper way of fan cooling which drains the entire amount of generated heat from casing. Thermal analysis of gearbox is performed for various convection coefficients out of which in this paper we presented two cases, one that satisfy and other that does not satisfy required conditions.

Keywords: gearbox, heat transfer, finite element method

1. INTRODUCTION

In industrial production gearboxes are required to transfer power from drive to working machines. High power gearboxes transfer a lot of power, so unavoidable power loses generates significant amount of heat which is absorbed by oil and casing. Depending on working conditions cooling of gearbox casing is done by passive or active convection. When passive convection is insufficient, active (fan) convection is applied.

The goal of analysis, presented in this paper, is to determine proper way of fan cooling which drains the entire amount of generated heat. Analysis is done using PAK-T [1] software package, which is based on finite element method (FEM) and heat conduction laws [2-3].

2. EQUILIBRIUM EQUATION OF HEAT CONDUCTION

Derivation and solving Matrix form of equilibrium equation (1) is described in [2]

$$\mathbf{C}\dot{\mathbf{T}}+\mathbf{K}\mathbf{T}=\mathbf{Q} \tag{1}$$

where $\mathbf{C}$ represents capacity matrix and components of matrix $\mathbf{K}$ and vector $\mathbf{Q}$ are determined as:

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$$K_{IJ} = K_{IJ}^{k} + K_{IJ}^{h} + K_{IJ}^{r} \tag{2}$$

$$Q_I = Q_I^{q} + Q_I^{q_n} + Q_I^{h} + Q_I^{r} \tag{3}$$

Indexes *k*, *h* and *r* are notation for conduction, convection and radiation respectively. Exponent q indicates volume source while exponent q_n indicates surface flux.

Calculation of convection coefficient for active cooling

The amount of heat per unit of time that is exchanged from fluid to the wall (or vice versa):

$$Q = Ah\left(T_f - T_z\right) \tag{4}$$

where: T_f fluid temperature, T_z wall temperature, h heat convection coefficienit, A the surface of heat exchange. Value of convection coefficient between wall and fluid can be calculated using:

$$h = \lambda N_u / L \tag{5}$$

where: λ thermal conductivity of fluid, N_u Nusselt number and L characteristic length of the flow. Nusselt number for active convection can be calculated using equation:

$$N_u = C R_e^{\,n} P_r^{\,m} G_r^{\,r} \left(\frac{P_r}{P_{rz}}\right)^{0.25} \tag{6}$$

where: R_e Raynolds number, C, n, m, γ are coefficients depending on Reynolds number and position of convection surface, P_r i P_{rz} are Prandtl numbers that depend on fluid and wall temperatures, G_r is Grashof number. Raynolds, Prandtl and Grashof number can be calculated using following expressions.

$$R_e = \frac{v_f L}{\nu}, \qquad P_r = \frac{\nu}{a} = \frac{\nu \rho C_p}{\lambda}, \qquad G_r = \frac{g \beta \Delta T L^3}{\nu^2} \tag{7}$$

where: v_f fluid velocity, ν kinematic viscosity, ρ density of fluid, C_p specific heat capacity, a thermal diffusivity of fluid, β volumetric coefficient of thermal expansion of the fluid and $\Delta T = T_z - T_f$ difference between the wall and fluid temperature.

3. ANALYSIS OF GEARBOX THERMAL CAPACITY

Analised gearbox have power transfer capacity of 1000 kW, and it is designed for continuous power transfer to conveyor belts used in coal surface mines. Gearbox power losses are 40 kW, and those losses are converted to heat which is absorbed by oil and casing. To protect bearings from overheating and damage, the condition is set that the temperature of the oil in the housing should not exceed 90 ºC at an ambient temperature of 40 ºC. The goal of the analysis is to determine the needed airflow rate when active cooling is applied to gearbox, which is required for total amount of heat generated by the power losses in gearbox to be exchanged with the environment.

Due to symetry of geometry and loads, half of the gearbox casing is modeled. Finite element mesh is generated automatically in FEMAP software. Default element size is 12.5 mm. Generated mesh contains 310382 nodes and 1357714 tetrahedral 3D elements, Figure 1.

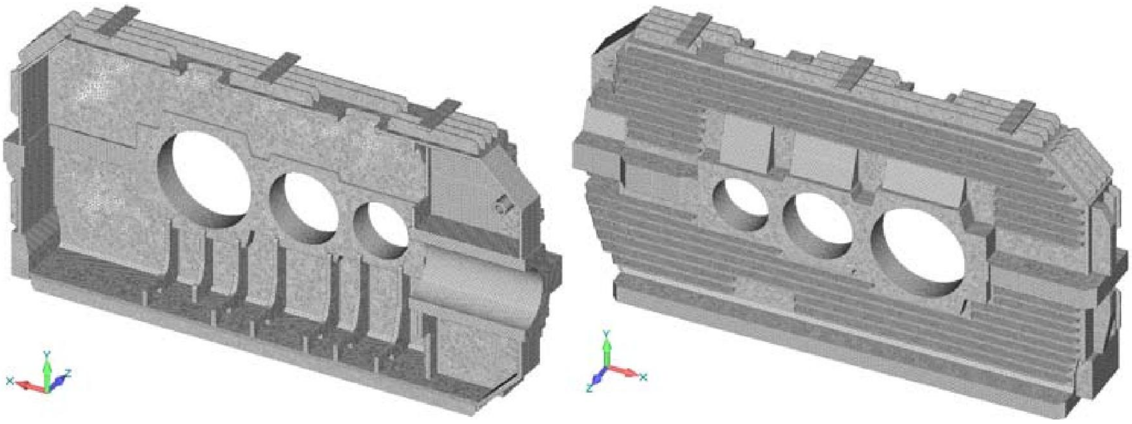

Fig.1 Finite element mesh

Heat conduction coefficient of gearbox casing is k = 40 W/mK. On the inside of the gearbox oil temperature of 90ºC is specified. Heat transfer coefficient between oil and casing is h=1000 W/m^{2}K. The ambient temperature is 40 ºC. Two cases are considered for fan cooling (active cooling), with different heat transfer coefficients between casing and surrounding air (h = 30 W/m^{2}K, and h = 40 W/m^{2}K), corresponding to different speeds of air flow around the casing. As aresult of the analysis we get temperature field, thermal flux field, total thermal flux of outer surface of gearbox casing. As a proof that designed fan cooling sistem meets the requirements, condition that total heat flux exchanged is greater than total power loss in the gearbox was used.

Analysis results for convection coefficient on outer surface 30 W/m2K

Results show that gearbox casing in this operation mode exchange thermal flux of 17.2 kW, which is less then required 20 kW on half of the model. Figure 2 shows temperature field on inner and outer surface of gearbox casing. It also shows that maximum temperatures occur in bearings zones.

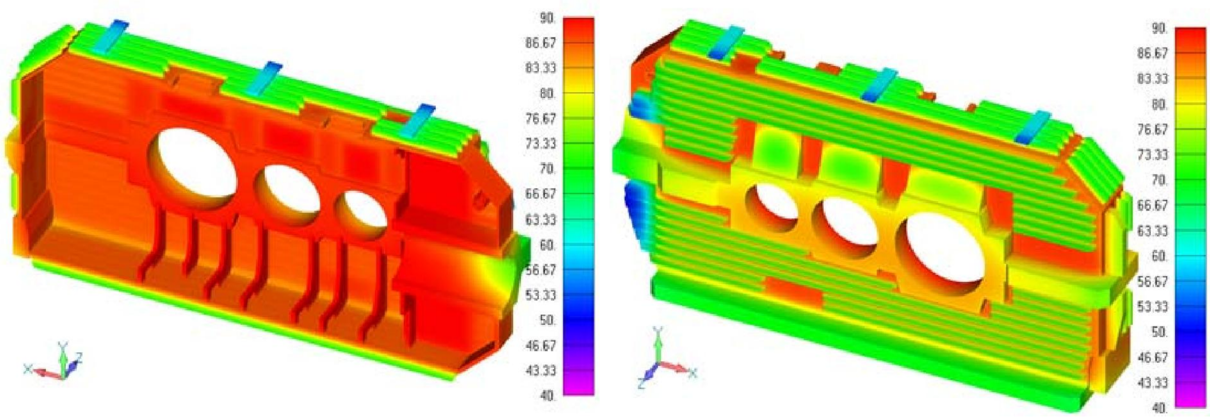

Fig.2 Temperature field on inner and outer surfaces

Analysis results for convection coefficient on outer surface 40 W/m2K

Gearbox casing analysis results show that in this operation mode exchange thermal flux of 21.5 kW, which is greater then required 20 kW on half of the model. Figure 3 shows temperature field on inner and outer surface of gearbox casing. It also shows that maximum temperatures occur in bearings zones. At high speed of convection air flow it comes to increased cooling of fan case as can be seen by comparing Figures 2 and 3.

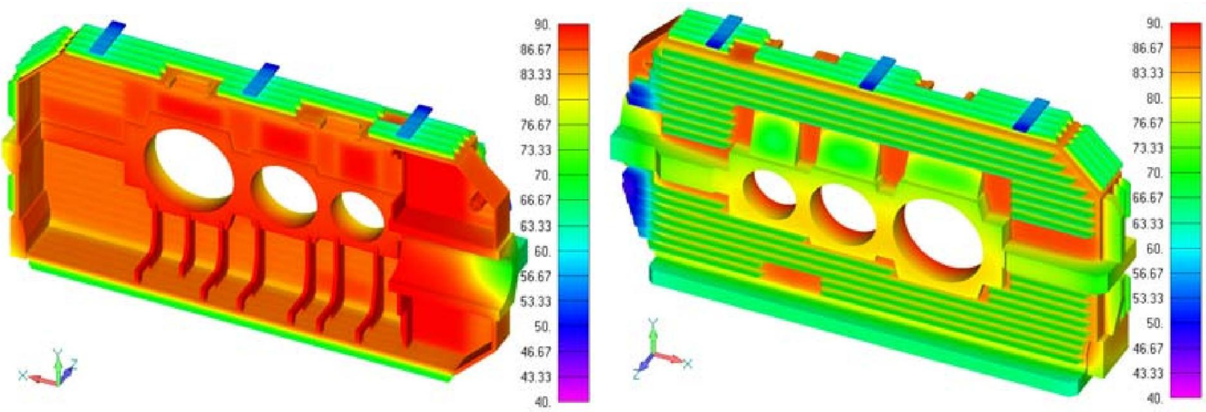

Fig.3 Temperature field on inner and outer surfaces

4. CONCLUSION

Thermal analysis od gearbox casing presented in this paper demonstrate procedure for determination of required airflow speed generated by active fan cooling system. Based on calculated required airflow speed, proper fan was selected, which meets condition that oil temeperature in gearbox casing does not exceed 90ºC. Based on analysis that we performed, we can conclude that in case of active convection with heat transfer coefficient (h = 30 W/m^{2}K), heat capacity of gearbox does not meet the requirements. In case of active convection with heat transfer coefficient (h = 40 W/m^{2}K), heat capacity of gearbox meets the requirements. Also, paper presents successful solution problem of heat transfer in software PAK-T.

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