1. Background

The problem of inadequate high temperature loading of mechanical part can be often observed in engineering practice. In case of electromotor the undesirable conductivity aggravation and additional temperature loading of mechanical parts can happen due to the high temperatures. Because of this fact the designers are forced to solve the problem of motor temperature minimisation. Performance of mathematical simulation of those processes is rather complicated discipline. It is necessary to dispose of both theoretical, necessary for choice of proper mathematical model, and practical knowledge to create the computer model itself. An important role play also related costs (proper software, human resources) and last but not least a big time severity of whole numerical simulation process. The mentioned reasons predestine the more complicated problems in technical practice to be solved within the research activity at the universities. The aim of the work was the analysis of temperature field and cooling parameters of current used motor geometry with expectation of pertinent shape optimisation to achieve better cooling power and to reduce the mass of the motor.

Mathematical model equations

Mathematical model of the general three-dimensional non-stationary fluid flow with heat transfer is described by system of equations which is consist of equation of continuity, momentum transfer equation and heat convection equation. It is necessary to use the statistic turbulence model based on time averaging of the turbulent flow values and on subsequent time averaging procedure of balance equations to solve the given turbulent flow problem. Let us consider the equations for time averaged values and equation of continuity in the shape

$$\frac{\partial \rho}{\partial t} + \frac{\partial \left( \rho \bar{u}_j \right)}{\partial x_j} = 0$$

(1)

where:

\( \rho \) – density [kg \cdot m\(^{-3}\)], \( t \) – time [s], \( \bar{u}_j \) – averaged velocity in generalized direction [m\cdot s\(^{-1}\)], \( x_j \) – generalized direction [m].

Furthermore for numerical CFD analysis momentum transfer equation can be written in the form

$$\frac{\partial (\rho \bar{u}_i)}{\partial t} + \frac{\partial (\rho \bar{u}_i \bar{u}_j)}{\partial x_j} = - \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \left( \left( \mu + \mu_t \right) \frac{\partial \bar{u}_i}{\partial x_j} \right) + \rho \delta_{ij} g + \rho f_c \varepsilon_{ij} \bar{u}_j + \rho f_i ,$$

(2)

where:

\( \bar{p} \) – averaged pressure value [Pa], \( \mu \) – dynamic viscosity [Pa \cdot s], \( \mu_t \) – turbulent viscosity [Pa \cdot s], \( \delta_{ij} \) – Kronecker’s \( \delta \) [1], \( g \) – gravitational acceleration [m\cdot s\(^{-2}\)], \( f_c \) – Coriolis’s
parameter \( [s^{-1}] \), \( \varepsilon_{ij} \) – Einstein’s summing tensor \([1]\), \( f_i \) – generalized volume force \([N \cdot kg^{-1}]\).

For numerical analysis it is necessary to adjust the momentum transfer equation by turbulence model equations – a set of additional equations and empiric formulas which build together with equations (1) and (2) the solvable equation system.

The heat transfer in fluids is described by the equation

\[
\frac{\partial}{\partial t} \left( \rho \overline{h} \right) + \frac{\partial}{\partial x_i} \left( \rho u_i \overline{h} \right) = \frac{\partial}{\partial t} \left( \rho \overline{p} \right) + \frac{\partial}{\partial x_i} \left( \lambda + \lambda_t \right) \frac{\partial T}{\partial x_i} + \frac{\partial}{\partial x_i} \left( \tau_{ij} u_j \right),
\]

(3)

where:

- \( \overline{h} \) – averaged value of enthalpy \([J \cdot kg^{-1}]\),
- \( \lambda \) – molecular temperature conductivity coefficient \([W \cdot m^{-1} \cdot K^{-1}]\),
- \( \lambda_t \) – turbulent temperature conductivity coefficient \([W \cdot m^{-1} \cdot K^{-1}]\),
- \( T \) – temperature \([K]\),
- \( \tau_{ij} \) viscous stress tensor \([Pa]\).

The object of the work whose temperature field is the objective of this paper is a solid body. Let us consider the heat convection equation for description of temperature field in the form

\[
\frac{\partial}{\partial t} \left( \rho c_p T \right) = \frac{\partial}{\partial x_i} \left( \lambda \frac{\partial T}{\partial x_i} \right),
\]

(4)

where:

- \( c_p \) – specific heat capacity \([J \cdot kg^{-1} \cdot K^{-1}]\).

The equation systems for solid and fluid phase are mutually linked by boundary conditions at the boundary shared by both phases, i.e. at the surface of the body flowed by liquid. After completing of equation system by appropriate outer boundary conditions (for the flow problem and for problem of heat convection and transfer) it is possible to approach the numerical simulation of boundary or mixed problem.

2. Methods

The aim of the work is to solve the surface temperatures of electromotor frame. Because of the complicated shape and difficult determination of the flow speeds (its knowledge is necessary for solution of heat transfer problem), especially in the space among the ribs, it was suitable to analyse the flow by numerical simulation.

The numerical model is always certain approximation of the reality because it substitutes the real behaviour by chosen mathematical model. The rate of reality approximation is given especially by the difficulty to determine the parameters of mathematical model and by accessibility of HW and SW equipment.

The preparation and creation of computational models for numerical simulations is usually accompanied by the solution of compromise between model details and computational requirements. Exceedingly actual is this question in solution of flow problems where it is usually required to model relatively large space which has to be meshed very fine in the locations important for solution results. Those spaces are in case of flow modelling especially the places with eddies, in case of heat transfer solution it is the interference layers where the value \( y^+ \) is defined for judgement of mesh quality.

In case of solved electromotor with axial height 315mm it was found out by simple experiment on stand that stream field of the cooling air reaches the distance approximately 200mm from the electromotor surface. For the length of the motor 700mm is the volume of modelled fluid domain approximately 0.365m³. Assuming all geometrical details and all recommendations for mesh
finesse it was necessary to mesh ½ of mentioned volume (the task was solved in plane symmetry) by approximately 15 millions cells (finite volume elements). To create the mesh with this number of elements takes approximately 8 hours and the manipulation with such model was only hardly possible. Based on this fact certain geometrical simplifications were performed which reduce the number of needed elements. By observation of created mesh topology it was found out that the large number of elements is located close to the fillet of all sharp junctions and rib edges. After fillet removing the geometrically simplified model is created which needs for its meshing only approximately 1.5 millions elements.

![Figure 1 Geometry difference between real shape and numerical model](image)

The created model consists of two parts – solid domain a fluid domain. The electromotor frame is made from cast iron, the frame cooling was realized by air flow with known material parameters. The problem was solved as quasi-static, the k-epsilon turbulence model was considered. The boundary conditions for solid domain were applied in the form of heat flux located on inner cylindrical part of the frame. For the fluid domain it is necessary to define following boundary conditions: inlet on the incoming surface (mass flow applied), outlet on the outgoing surface, wall or opening on other surfaces.

The heat flux applied on the inner part of the electromotor frame was for first approximation applied according to the heat losses mentioned in product sheet. The losses in iron-, copper- and aluminium motor section are considered. It is difficult to determine exactly the value of heat flux for appropriate boundary condition because this value includes the contributions of all distinguished loss components. The results of primary frame cooling simulation were used especially to obtain the rough overview and for preparation of measurement by thermovision camera and by thermoelements, i.e. for determination of suitable locations for thermoelements, etc.

In the next step the frame surface temperature measurement was performed with the aim to calibrate the model and to verify the influence of simplified ribs modelling. Within the measurement the motor was scanned by thermovision camera from number of different angles and temperatures were measured by thermoelements in chosen locations. For the calibration purposes the values of electric input, moment of load and revolutions were recorded as well. On the base of those values it was possible to tune the heat flux values so that the agreement between measured and calculated results was sufficient.

### 3. Results

With respect to the aim of the work and its further use the most important result is temperature distribution on the electromotor frame surface. The good agreement between temperatures obtained by measurement and by calculation shows the possibility to accept the performed simplifications (ribs geometry, way of boundary conditions application) and to consider the
calculation model as sufficient, i.e. proper for further numerical simulations. Except the calculation of temperature field on the electromotor frame another, from the motor cooling point of view, important values can be evaluated, i.e. heat transfer coefficients distribution, speed of cooling flow in defined plane or streamline visualization for determining of the air flow efficiency.

4. Conclusion

The CFD analysis of larger mechanical parts is only hardly realisable without certain simplification: CFD model of real geometry contains approximately 15 millions of cells, the model of simplified geometry approximately 1.5 million ones. Also in this case is the model rather demanding on the HW equipment and solution times are in order of hours.

Assuming of simplified geometry modeling it is necessary to provide the calibration of numerical model. This calibration was performed on the base of values measured by thermovision camera and thermoelements. Used procedure is applicable only in cases when experimental data are available.

The well created and calibrated model can be used for determination of values which can be only hardly obtained via experiment. In such way obtained results are in technical problems highly appreciated and are contributions for optimization of current devices or for development of new ones with similar geometry.

5. References


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