Onset of levitation in thrust bearing: FSI study using Abaqus-FlowVision coupling

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Abstract: Lift force formation in a thrust bearing of 800-tons rotor of electric power station is discussed in the given paper. The problem is solved numerically. Direct coupling between finite-element system Abaqus calculating stress and strain state of an bearing parts and finite-volume system FlowVision-HPC calculating oil flow in gap between a collar and a shoe of bearing is used. The shape of the gap between the shoe and the collar, the clearance value, the moment of the friction force, and the temperature distribution of oil over the clearance are determined..

Keywords: Thrust bearing, CFD Coupling, Fluid-Structure Interaction

1. Introduction

Sliding bearing is widely used in machine building, power generation, automobile industry, mining industry. Characteristics of the bearing are defined by using several methods as theoretical calculations, engineering semi-empirical calculations or using numerical simulations (Petrushina, 2006). A calculation of sliding bearing parameters using direct coupling (Aksenov et al., 2004, Aksenov et al., 2006) between Abaqus finite-element code and FlowVision finite-volume code is described in this paper. Novelty of this method for calculating bearing parameters consists in allowing taking into account mutual influence of oil motion with friction heating in the bearing and heat deformation of bearing shoes.

Thrust bearing is one kind of the sliding bearings. Schematically it consists in two main details: rotating collar and several unmoved shoes. Collar transfers loading from heavy rotor on shoes. For normal bearing operation, a small clearance between the collar and the shoes must exist. Clearance is filled by oil. As in lubrication theory well known, a lift force between two surfaces exists if a clearance between the surfaces is wedge-shaped. Before bearing operation the clearance between collar and shoes is constant. Thus, what is the source of lift force in thrust bearing? It turns out that thrust bearing is a good example of design which uses strong fluid-structure interaction phenomena. Oil is heated in clearance by huge friction stresses generated in very thin layer. Direction of average oil motion forms non-symmetrical oil temperature distribution over the clearance, which results in shoe deformation by correct way to form wedge-shaped clearance between collar and shoes. Results of modeling this process is described in this paper. Lift force as function of collar rotating speed and initial clearance between collar and shoes is calculated.

It is shown, that method of defining parameters of thrust bearing offered in this paper allows defining value and shape of clearance between collar and shoes, temperature distribution and heat generation inside bearing, friction torque in bearing and power loss.

2. Bearing design

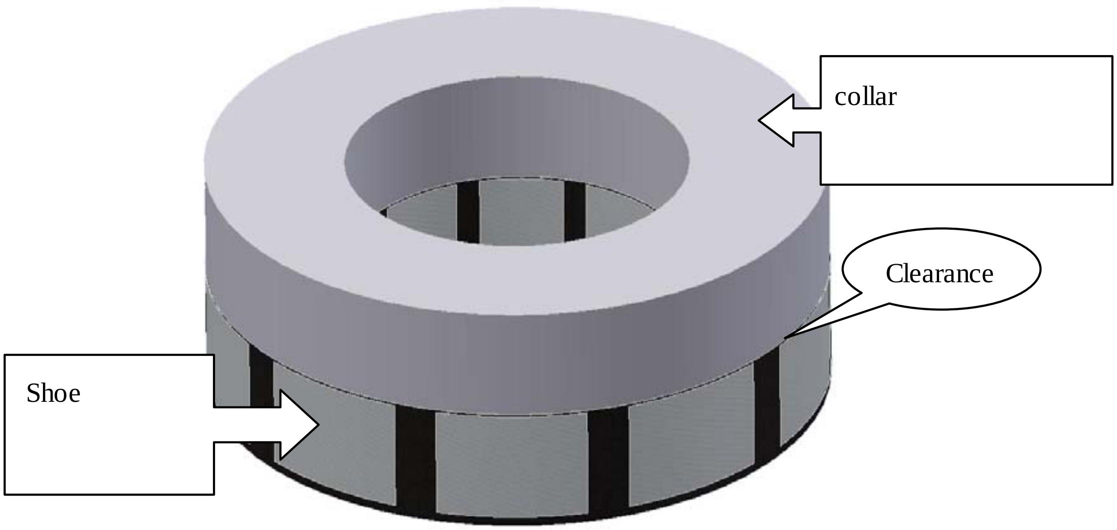

Figure 1. Design of thrust bearing.

The thrust bearing consists in 10 shoes which receive loading from rotating collar (Figure 1). Collar is end face of a heavy vertically standing rotor. The collar is rotating in 400 RPM, inner radius of collar is 630mm, outer radius is 1140 mm, depth is 220 mm. Collar and shoes are made from steel. Between the collar and the shoes there is a clearance with approximate value 0.02 mm. Clearance is filled by oil. Collar and shoes is immersed in oil entirely. As oil is heated in the clearance, it is cooled to 40^{o} C.

3. Numerical method

Direct coupling between Abaqus FEA and FlowVision-HPC CFD code is used. Details of this coupling method is described in papers (Aksenov et al., 2004, Aksenov et al., 2006). In this paper we tried to catch only physics of generating levitation in a thrust bearing. We skip other parts of a thrust bearing (damping devises, springs and so on) which can affect on bearing parameters. Approach for bearing parameters definition developing in this paper can be easily extended for more complicated design of the bearing.

Shoe deformation induced by heat and pressure loading from the fluid and kinematics of the shoe (if exist) is calculated using Abaqus code in developed approach. Oil flow and heat generation in oil is modeled by FlowVision code.

3.1 Governing equations for oil flow

Oil flow is modeled by Navier-Stokes equations:

$$\rho \frac{\partial V}{\partial t} + \rho \nabla (V \otimes V) = -\nabla P + \nabla \mu (\nabla V + (\nabla V)^T),$$

equation of continuity of the fluid (we supposed that oil is incompressible fluid):

$$\nabla V = 0,$$

and equation of energy conservation:

$$\frac{\partial(\rho h)}{\partial t} + \nabla(\rho V h) = \frac{dP}{dt} + \nabla\left(\frac{\lambda}{C_p}\nabla h\right) + Q_{vis}.$$

Where t is time, ρ – oil density, μ - viscosity, λ – conductivity, C_p – specific heat capacity, V – oil velocity, P – pressure, h – specific enthalpy, Q_{vis} – heat source because of friction in oil.

3.2 Clearance model

CFD part of the problem has essentially different scales. Size of the computational domain along collar rotation is much larger then clearance between collar and shoe. Using ordinary CFD approach with introducing mesh refinement in the clearance results in generation of mesh cells with huge aspect ratio. To avoid numerical problems of this approach, FlowVision has so-called Gap Model. Gap model allows accurately define parameters of fluid flow in clearances which are comparable and less then initial mesh cells. Mesh cell that has clearance is defined automatically. Numerical scheme for Navier-Stokes equations in Gap Cells is modified using assumption about quasi steady state laminar fluid flow in clearance. Using this assumption, laminar velocity profile is reconstructed in Gap Cells as:

$$V_i = -\frac{1}{3}\frac{1}{\mu}\frac{dP}{dx}h^2 + \frac{V_{w2} + V_{w1}}{2}$$

Walls of the clearance acts of fluid with force:

$$F_i = 6\mu \frac{-V_i + \frac{1}{2}(V_{w1} + V_{w2})}{h} S$$

Friction forces in clearance generate heat that defined by formula:

$$Q_{vis} = \frac{\mu_{mol}}{4h^2}\left[12\left(V_i - \frac{1}{2}(V_{w1} + V_{w2})\right)^2 + (V_{w2} - V_{w1})^2\right]$$

Here $2h$ – clearance value in computational Gap Cell i, V_i, – average speed in the i-th Gap Cell, V_{w1}, V_{w2} – speeds of both clearance walls, S – area of the walls. Using Gap Model allows to decrease computational resources (memory and CPU time) more the in 10 times..

3.3 Abaqus-FlowVision direct coupling

Two-way coupling simulation is done to solve this problem. Abaqus/Standard is used for simulating stress in the shoe.

Information exchange between Abaqus and FlowVision is performed at some special times - synchronization points, time difference between them is FSI time step. FSI time step is defined by FlowVision from hydrodynamic part of the problem. FSI time step is about 10^{-5} sec for this problem. During FSI time FlowVision makes one time increment, Abaqus makes about 10-50 increments. At the end of each FSI time step FlowVision sends to Abaqus loading on the nodes and heat fluxes, Abaqus sends to FlowVision temperatures and new node displacements.

Approach of Abaqus-FlowVision direct coupling is very easy for user - it doesn't require some special steps for preparing co-simulation. Abaqus and FlowVision projects are prepared by user like for non co-simulation. Shoe is imported to FlowVision as Abaqus INP file, after that automatically FlowVision specifies link with Abaqus. In Abaqus project user just only has to specify contact surfaces for FSI. In a special thin client MP-Manager, user has to specify location of Abaqus and FlowVision projects and executable modules via computer names and local paths. To start co-simulation, user can start only FlowVision, after that it makes all co-simulation steps automatically.

4. Finite-element model of bearing shoe

Finite-element model of shoe is shown in Figure 2. Finite-element tetrahedral mesh is created using C3D4T elements. Number of elements is 44 351. Mesh is refined over the surface that is in contact with oil in clearance between collar with fine mesh in area of maximum shoe face deformation.

Boundary conditions are the following: lowest face of the shoe is fixed, temperature is constant 40C. Lateral faces have constant temperature 40 C and pressure equals 1 bar. Upper face has contact with oil (direct coupling surface), thus, temperature and loading is defined by oil temperature.

5. Finite-volume model of oil flow

CFD simulation domain corresponds to clearance between the shoe and the collar (Figure 3, computational domain is shown without proportion. Rotation of collar is specified by boundary condition, collar wall is set like adiabatic boundary. On lateral sides of the clearance is specified pressure boundary conditions and temperature of the oil is 40C. Last wall of the computational domain is shoe wall, it is coupling surface with Abaqus solution.

We need to make comments here, that for simplifying the simulation we supposed that rotating collar hasn't heat expansion. For more advanced simulations this simplification, of course, can be removed.

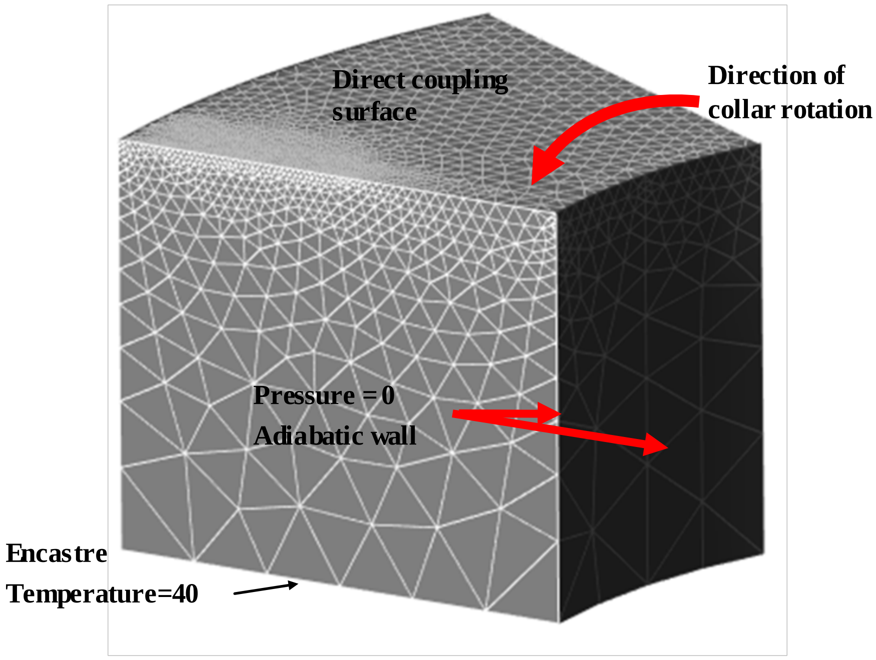

Figure 2. Finite-element model of shoe.

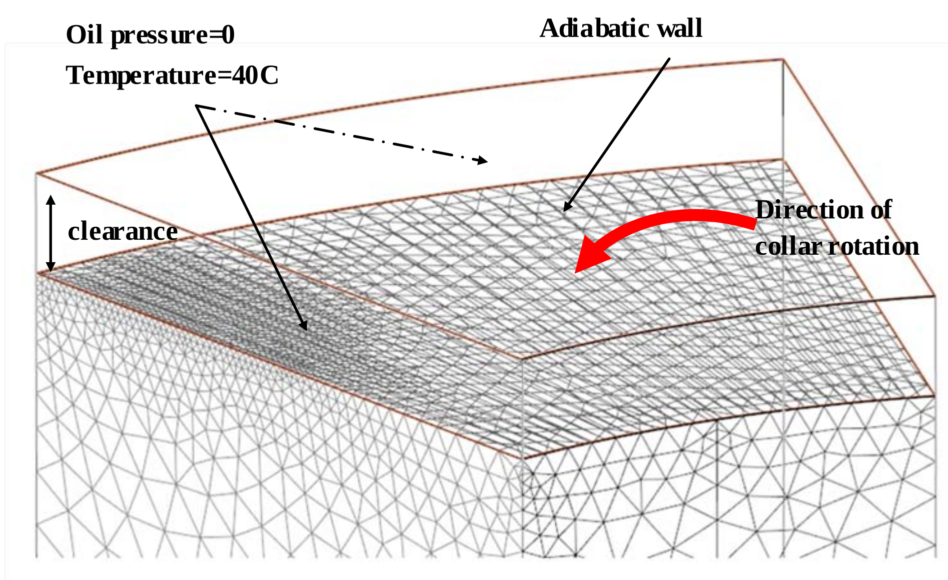

Figure 3. Oil flow computational domain.

6. Results of simulation

Simulation of lift force in thrust bearing is made by the following way. Initially some initial clearance between shoe and collar is specified. The clearance is changed during the simulation because of heat expansion and pressure in oil layer. Several simulations are made to get dependence of lift force on initial clearance. Correct solution for given rotor corresponds to the solution when rotor weight is equal to the lift force in thrust bearing.

The dependence of the lift force on the initial clearance value is shown in Figure 4. As follows from the Figure 4, for rotor with loading 80 kN on one shoe, initial clearance must be about 18,3 micrometer.

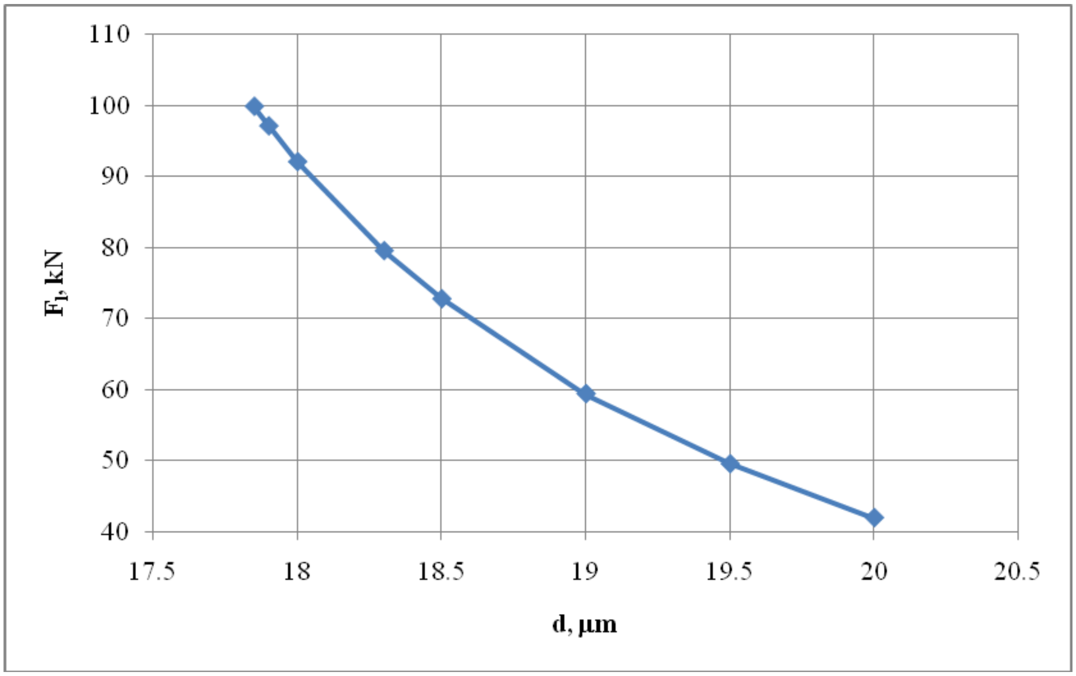

Figure 4. Dependence of lift force in thrust bearing on initial clearance value.

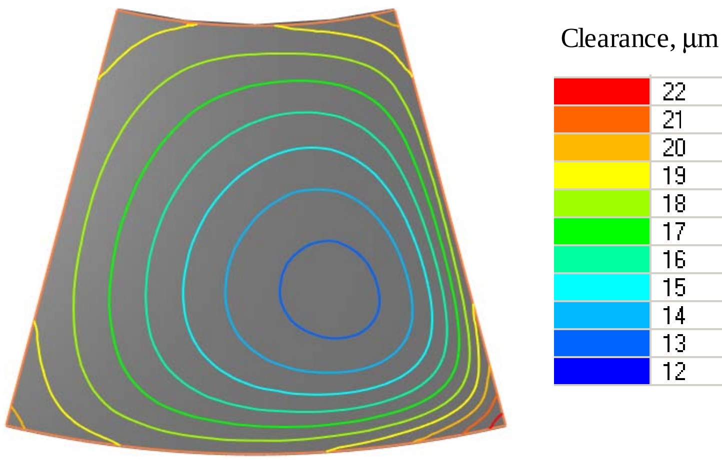

Figure 5. Distribution of distance between shoe and collar for 80 tons rotor.

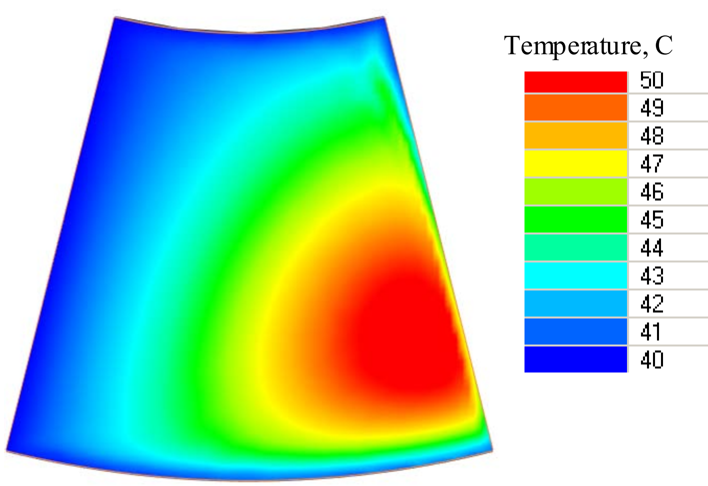

Figure 6. Distribution of temperature in clearance for 80 tons rotor.

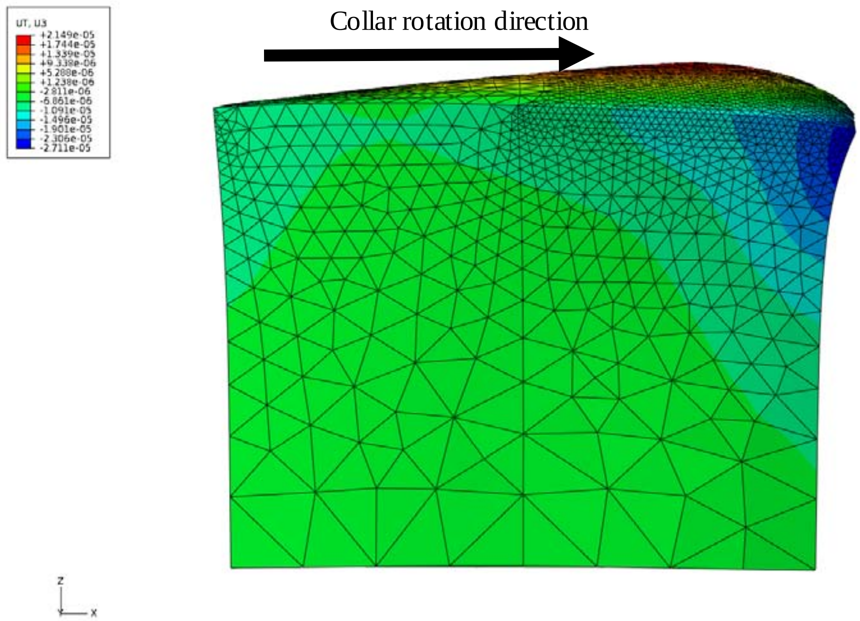

Figure 7. Displacement of shoe material along z axis. Deformation is magnified in 1000 times.

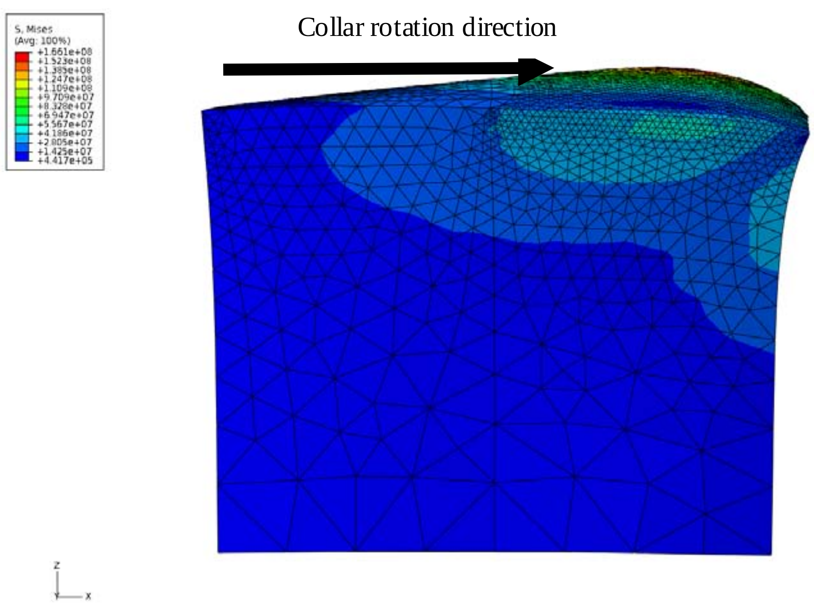

Figure 8. Distribution of stress in shoe.

Distribution of distance between shoe and collar for rotor with weight 80 tons is shown in Figure 5. Temperature distribution for this case is shown in Figure 6. Rotor rotates anticlockwise in this figures. Average oil flow, carrying out by collar surface, makes distribution of temperature biased to side of the shoe along collar rotation. Such temperature distribution results in biased clearance between shoe and collar (Figure 5). Corresponding deformation of the shoe (magnification is 1000 times) is shown in Figure 7. Non-uniform temperature distribution and loading from the collar results in stresses distribution inside shoe (Figure 8). Thus, we have wedge shaped clearance between collar and shoe that allows generating positive lift force in the thrust bearing..

7. Discussion

Source of lift force in thrust bearing is shown in this paper. The reason of lift force generation is heat expansion of a bear shoes because of oil friction heating in clearance between shoe and rotating collar. This problem is a strong fluid-structure interaction problem. To solve it, direct coupling between finite-element code Abaqus and finite-volume FlowVision codes is used.

There are two different ways of solving the problem of lift force generation. The first one is taking into account vertical motion of the collar when oil heating deforms shoe and positive pressure starts to be generated in the clearance. The second way is used in this paper. Collar hasn't vertical degree of freedom. Initial clearance between collar and shoe is specified. Several simulations are made for different initial clearances. The lift force as function of initial clearance is got. Solution when lift force is equal to rotor loading on shoe is getting by interpolation. Second way of getting thrust bearing parameters is characterized by fast speed of convergence and robust for practical use.

8. References

1. Aksenov A. "Drop-Test FSI simulation with Abaqus and FlowVision based on the direct 2-way coupling approach ", A. Aksenov, D. Korenev, A. Shishaeva, D. Vucinic, Z. Mravak, 2008 Abaqus Users' Conference, 19-22 May 2008, Newport, Rhode Island (USA): book of Abstracts = [тез. докл.] / Newport, Rhode Island, 2008, C. 611-624.
2. Aksenov, K. Iliine, T. Luniewski, T. McArthy, F. Popielas, R. Ramkumar "Oil Leakage Through a Valve Stem Seal", Proc. Abaqus User Conference, 2006, Boston, USA, 2006
3. A. Aksenov, A. Dyadkin, T. Luniewski, V. Pokhilko "Fluid Structure Interaction analysis using Abaqus and FlowVision", Proc. Abaqus User Conference, 2004, Boston, USA, 2004
4. Aksenov A, Dyadkin A, Pokhilko V. "Overcoming of Barrier between CAD and CFD by Modified Finite Volume Method", Proc. 1998 ASME Pressure Vessels and Piping Division Conference, San Diego, ASME PVP-Vol. 377-1., 1998
5. Aksenov A., Dyadkin A., Gudzovsky A., 1996, "Numerical Simulation of Car Tire Aquaplaning". Computational Fluid Dynamics '96, J.-A. Desideri, C.Hirsch, P.Le Tallec, M.Pandolfi, J.Periaux edts, John Wiley&Sons, pp. 815-820.
6. Petrushina. M "Thermomechanical Analysis of the Turbo-Compressor Sliding Bearing Mount Units / M. Petrushina, S, Klambozki, O. Tchij , 9-th International LS-DYNA User Conference. Simulation Technology, 4-6 June 2006, Dearborn, MI (USA): book of Abstracts , Dearborn, 2006, C. 1324-1339