Simulation of processes in machines using orthogonal meshes

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Abstract. The paper presents an experience of using orthogonal hexahedral meshes for simulation of different processes in machine-building products. Stress state of the details of suspension of a cargo vehicle during the movement on random road profile was simulated. Orthogonal hexahedral meshes for lower suspension levers and housing and piston rod of shock adsorber were used. Thermal state of the elements of drive axle and its housing during the movement of a cargo vehicle with constant speed was calculated using hexahedral orthogonal meshes for details and inner volume of housing of the drive axle. Lubrication fluid circulation in the reducer of a cargo vehicle was modelled. Orthogonal mesh for inner volume of the reducer was used to calculate the parameters of lubrication fluid circulation.

1. Introduction

Computer simulation is widely used in the development of machine-building products. [1] Computers are used in design process (CAD systems), modeling (CAE and MBS systems), product lifetime management, document management. Modern conception called Industry 4.0, which was first introduced by Klaus Schwab, implies the ongoing automation of traditional manufacturing and industrial practices and includes further development of instruments for modeling and processes simulation. [2]

Numerical simulation allows to decrease the expenses on the development of machine-building products. [3] The use of mathematical model and numerical experiment leads to lower quantity of built experimental prototypes and shortens the time of product improvement.

This paper presents an experience of using hexahedral orthogonal meshes in stress analysis of the details of suspension of vehicles, analysis of temperature fields in these details and circulation of lubricating fluid in different assemblies and details of machines.

2. Materials and methods

Orthogonal hexahedral meshes of higher dimensions for CAD assemblies are used in this work. Method for generation of such meshes was developed. In this method unitary normals for border elements of mesh are used. It allows to increase the quality of mesh on border. In the most common case mesh generation consists of the following steps:

- setting boundary conditions on the source CAD geometry of an assembly;
- surface triangulation of details of an assembly;
- generation of 3D hexahedral orthogonal mesh;
- setting boundary conditions from source geometry to border elements of mesh.

But there are some cases where hexahedral mesh of inner volumes of an assembly is necessary. The examples of such task are heating of a drive axle housing and analysis of the distribution of
transmission oil in its working space. Developed method allows to create hexahedral meshes for inner volumes automatically. The mesh of inner volume is generated based on the source geometry of an assembly.

3. Stress state of the elements of cargo vehicle suspension during the movement on the random profile of the road

Orthogonal meshes were used in the stress state simulation of the elements of suspension. Hexahedral mesh submodels of suspension arm, housing and piston rod of adsorber were added to the computational model of a cargo vehicle. [4]

Figure 1. A computational model of cargo vehicle with mesh submodels of the elements of suspension: a – common view; b – view of suspension arm and shock adsorber.

Computational model of cargo vehicle with is presented on Figure 1a. It contains mesh submodels for six lower arms of suspension and six shock adsorber. Boundary conditions for stress state simulation in submodels are calculated from the computational model of cargo vehicle. The result of stress state simulation is presented on Figure 1b.

4. Heating process in the elements of a reducer and its housing

Thermal stress calculation of the details of drive axle and its housing during the movement of a cargo vehicle with constant speed was performed using orthogonal meshes.

Figure 2. A computational model of a drive axle of cargo vehicle.

Figure 2 shows the model of a drive axle, which was used for numerical experiment. It contains the geometry of a drive axle housing and its details. To make thermal stress simulation border conditions
(thermal flows) must be assigned on the source geometry for the details of the assembly and mesh models for these details must be generated. [5]

![Figure 3](image3.png)

**Figure 3.** A model of a drive axle housing with assigned boundary conditions: a – thermal flow from bearing; b – thermal flow on the housing of a drive axle.

The example of boundary conditions assignment is shown on the Figure 3. Thermal flows are assigned for bearings (Figure 3a), housing (Figure 3b) and other details – planet carrier, input shaft, drive shaft. Hexahedral meshes with assigned boundary conditions for shafts and planet carrier are shown on the Figure 4.

![Figure 4](image4.png)

**Figure 4.** Mesh models of the details of a drive axle: a – planet carrier; b – input shaft, c – drive shaft.

The visualization of the results of thermal stress simulation ids shown on the Figure 5.

![Figure 5](image5.png)

**Figure 5.** Thermal stress in the details of a drive axle of cargo vehicle.

Thermal flows in the housing of a drive axle were calculated using hexahedral meshes of inner volume of this assembly. Resulting mesh was created by subtracting from the mesh model of housing inner volume of mesh models for the details of drive axle. Boundary conditions in the resulting mesh
were combined.

Figure 6. Resulting mesh model for inner volume of a drive axle: a – a view of a section; b – boundary conditions.

The results of heat distribution inside the housing of a drive axle of cargo vehicle are presented on the figure 7.

Figure 7. Thermal distribution in a drive axle of cargo vehicle.

5. Lubrication fluid circulation in the reducer
Simulation of lubrication fluid circulation is very important as it lets significantly decrease the costs on the experimental elaboration of parts of machines. Current methods are based on resource-intensive numeric integration of Navier-Stokes equations. [6] It is very difficult to use them for complex assemblies with lots of details. A new method, which uses particle-in-cell method and Monte Carlo method, is used to calculate statistic parameters of the flows of lubrication fluid in the reducer of a cargo vehicle. In this method a volume of lubricant is presented as a set of particles, which move in
the field of gravity without any interaction between each other inside the volume and slide along inner surfaces of a model with particle velocity, damping coefficient and normal to this surface taken into account. The method is described in [7].

Simulation of lubrication oil circulation was performed using a model of a reducer of cargo vehicle. The model is shown on the Figure 8, the results of simulation are presented on the figure 9.

![Figure 8](image1.png)  
**Figure 8.** A model of a reducer of a cargo vehicle: a – CAD geometry of an assembly; b – hexahedral mesh for inner volume.

![Figure 9](image2.png)  
**Figure 9.** The results of simulation of lubrication fluid into the reducer.

On the Figure 9 areas with lack of lubricant are shown and these areas correspond to broken parts of real reducer.

6. Conclusion
Orthogonal hexahedral meshes can be used for simulation of different processes in machines and mechanisms. The examples of these processes are stress state, thermal state, lubrication oil circulation. For some cases it is necessary to use orthogonal meshes for CAD geometry in the form of assembly, for others – mesh models for inner volumes.

Though it is often very difficult to generate hexahedral mesh models for assemblies in view their complexity, they are very convenient to make calculations and to be visualized.

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