Final drive lubrication modeling with mesh adaptation

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Abstract

In this paper we describe the method based on the finite volume method (FVM) with adaptive mesh refinement (AMR) to solve car final drive inner volume lubrication problem. The computational algorithm is implemented using OpenFOAM parallel library that provides data structures and routines to work with the finite volume method and adaptive mesh. This library supports parallelism through OpenMPI. The paper presents the results of numerical simulation.

Keywords: lubrication modeling; mesh adaptation; final drive modeling; bearing modeling;

1. Introduction

In recent years automotive industry becomes increasingly competitive and global in nature. This forces the car manufacturers to optimize components and assemblies, in order to reduce the cost of their production, but without performance reducing.

This paper considers a design of automobile final drive. One of the problems arising during the automobile final drive design is the lubricity problem. In particular, the authors of this paper solved the problem of the oil flow simulation created by rotating gear wheel of final drive. Then, the calculation results are transferred to design engineer, who will correct the shape of the final drive body accordingly that the oil flow will reach the stuffing box (see Fig.1).

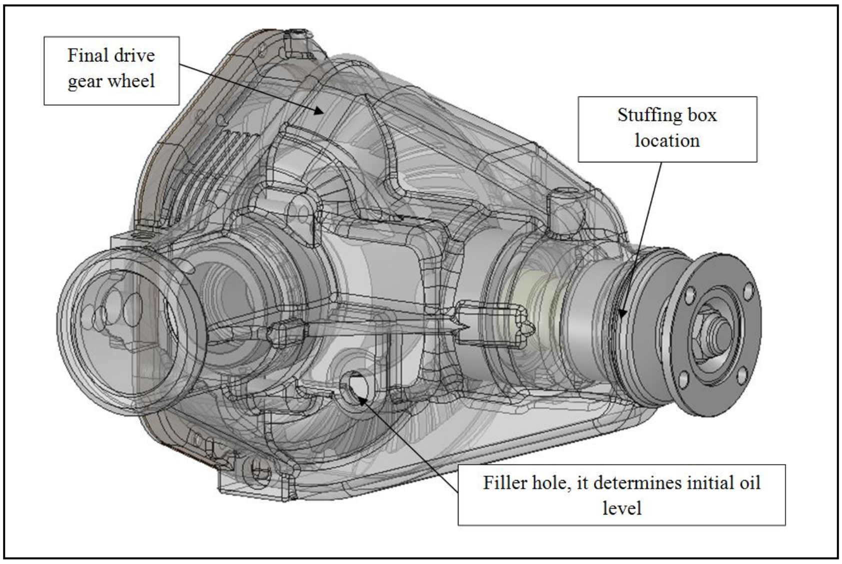

Fig. 1. The original geometry and the basic elements of the final drive.

To simulate lubricity we decided to use a two-phase liquid-air model without taking into account the compressibility, heat transfer and miscibility. For phase separation we use VOF method, such as Lemfeld [1], Chunfeng [2]. For more efficient use of computing resources, we decided to use an approach based on the use of adaptive mesh refinement/coarsening (Adaptive Mesh Refinement - AMR). AMR procedure implemented in the OpenFOAM library [3], but the original library does not support AMR for rotating mesh. In this paper, we conducted the OpenFOAM library modification for final drive lubricity modeling.

2. Adaptation method

There is a large amount of literature which deals with dynamic mesh and mesh adaptation methods. One of the first works on dynamic mesh application were investigations of Miller [4] and Yanenko[5]. Currently, the mesh adaptation technologies are widely used in numerical problems solving. Mesh adaptation methods usually based on minimization of some selected functional. It is achieved by refinement or coarsening of mesh elements (h-adaptation) or mesh nodes moving (p-adaptation).

Adaptive mesh allow to reduce computational cost, to correct mesh in complex areas, to handle moving surfaces, phase transitions and other areas of high gradients. Mesh adaptation approaches was successfully implemented by developers of commercial and non-commercial software packages such as FlowVision, Abaqus, Ansys, OpenFOAM. In this study we used an OpenFOAM open library, which has complete modules for AMR implementation.

For AMR configuration in OpenFOAM user need to provide following information:

- mesh update frequency (update mesh on every first, second or subsequent iteration);
- scalar field, whose values will be used for the mesh refinement/coarsening;
- field values interval, defined by minimum and maximum values, at which we want to refine mesh;
- field threshold value, below which we want to start mesh coarsening;
- maximum cells refinement level relative to initial mesh cells;
- the maximum allowable mesh cells amount.

In this work as scalar field we use field, based on discretization matrix eigenvalues estimation. This method described in more detail in [6].

Current version of OpenFOAM-v1612 does not allow to use mesh adaptation (implemented by dynamicRefineFvMesh class) and rotation of the mesh (implemented by solidBodyMotionFvMesh class) simultaneously. Therefore, to achieve the desired functionality, we have created a new C ++ class solidBodyMotion dynamicRefineFvMesh by virtual inheritance. The sources available at [7].

3. Discussed Problems

We consider the mathematical model, which describes oil distribution during final drive gear wheel rotation.

Oil distribution is described by the following equations [8]:

$$\frac{\partial \alpha_{\varphi} \overline{U_{\varphi}}}{\partial t} + \nabla^{\bullet}\left(\alpha_{\varphi} \overline{U_{\varphi}}\,\overline{U_{\varphi}}\right) + \nabla^{\bullet}\left(\alpha_{\varphi} \overline{R_{\varphi}^{eff}}\right) = -\frac{\alpha_{\varphi}}{\rho_{\varphi}} \nabla \overline{p} + \alpha_{\varphi} g + \frac{\overline{M_{\varphi}}}{\rho_{\varphi}} \qquad (1)$$

$$\frac{\partial \alpha_{\varphi}}{\partial t} + \nabla^{\bullet}\left(\overline{U_{\varphi}} \alpha_{\varphi}\right) = 0 \qquad (2)$$

where φ – phase, α – phase fraction, $\overline{R_{\varphi}^{eff}}$ is combined Reynolds (turbulent) and viscous stress, $\overline{M_{\varphi}}$ – averaged inter-phase momentum transfer term, $\overline{U_{\varphi}}$ – averaged transport velocity, p – pressure, t – time discretization step size, g – acceleration due to gravity, ρ_{φ} – phase density.

Combining equation (2) for two phases with $\varphi = a$ and b yields the volumetric continuity equation for the mixture, which will be utilized to formulate an implicit equation for the pressure. The volumetric continuity equation reads:

$$\nabla * \overline{U} = 0 \qquad (3)$$

where $\overline{U} = a_{\alpha} \overline{U_{\alpha}} + a_{\alpha} \overline{U_{b}}$.

The averaged equations representing the conservation of mass and momentum for each phase.

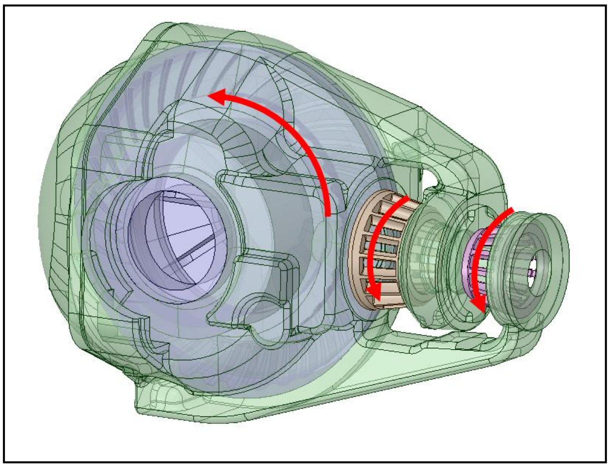

Fig. 2. The final drive internal volume, gear wheel and bearings rotation directions.

Lubrication modeling performed for the following gear wheel rotational frequencies: 551, 800, 1600, 2400 rev/min.

4. OpenFOAM library parallelism

Algorithms parallelization performed by built-in features of OpenFOAM parallel library. The method of parallel computing used in OpenFOAM is based on the computational domain mesh and fields decomposition into separate parts, every single part is assigned to a separate computing core. Thus, the parallel calculation process includes the following steps: mesh and fields decomposition; parallel solver run; postprocessing after mesh and fields reconstruction or right in the decomposed form. OpenFOAM supports OpenMPI implementation of the standard message passing interface MPI by default, it is also possible to connect other MPI implementation libraries.

All computations are performed on cluster "Sergey Korolev". In particular, we used two server types:

- HS22 blade servers, each of them has 2x CPU: Intel Xeon X5560, 4 cores;
- HS23 blade servers, each of them has 2x CPU: Intel Xeon E5-2665, 8 cores.

Execution time comparison for this server types showed on Figure 3.

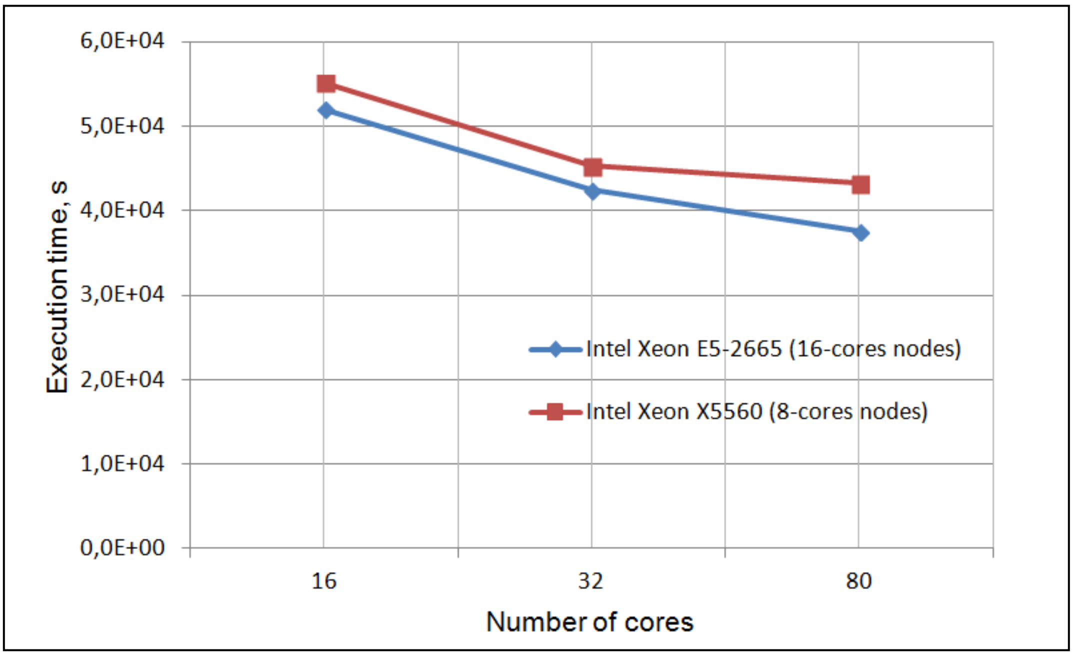

Fig. 3. Execution time for different number of cores and nodes types.

5. Numerical simulation results

Figure 4 shows the oil-air free surface for wheel rotational frequency 551 rev/min, time = 1.7 s.

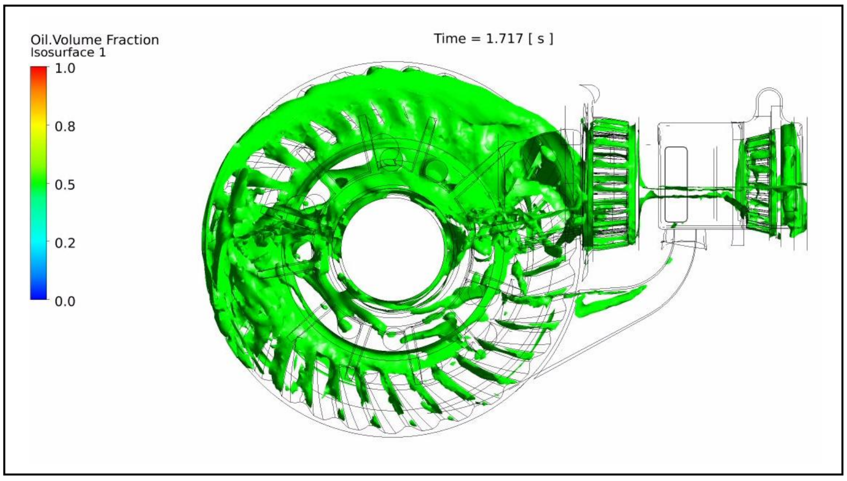

Fig. 4. Oil-air free surface for wheel rotational requency 551 rev/min, time t = 1.7 s.

Figure 5 shows the oil distribution for wheel rotational frequency 551 rev/min, time t = 1.7 s. It can be seen that in this case the oil flow reaches the stuffing box location.

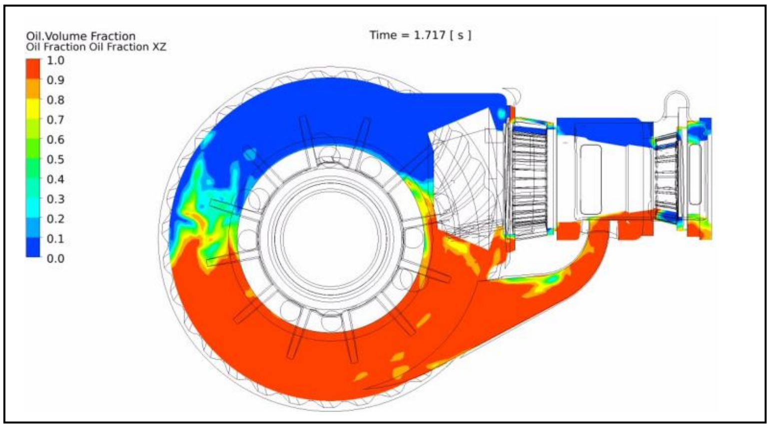

Fig. 5. Oil distribution for wheel rotational frequency 551 rev/min, time t = 1.7 s.

Adaptive mesh refinement more effective in areas of constant oil flow form, less effective in areas with stochastic oil flow behavior.

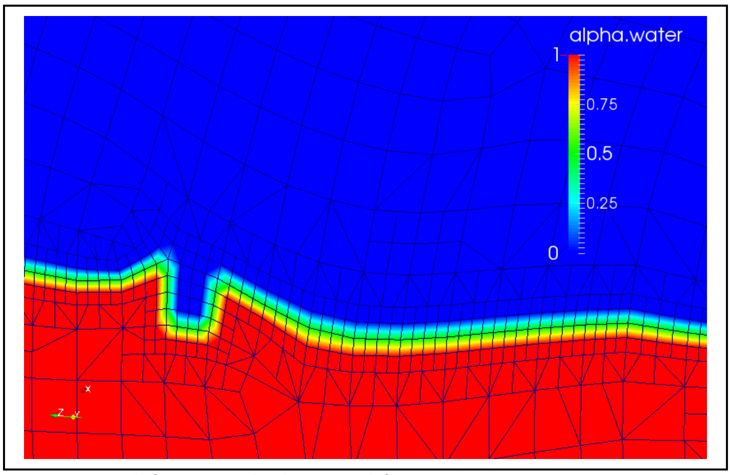

Fig. 6. Mesh fragment, wheel rotational frequency 551 rev/min, time t = 1e-6 s.

Figure 6 shows mesh fragment for case of wheel rotational frequency 551 rev/min, time t = 1e-6 s. More fine mesh formed in areas with a higher α phase fraction gradient, which reduces task computational cost.

6. Conclusion

An implemented by OpenFOAM library model has shown efficiency and stability. Adaptive mesh refinement along with the ability to use parallel computing also provides computational costs reduction compared to the static mesh.

Acknowledgements

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