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Visualization of the Oil flow in the Gap of Helical gearing based on Numerical Simulations

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Abstrakt: The key topic of this article is a visualization of the oil flow in the wheel gap investigated using numerical simulations. Particularly, this paper is focused on a simulation of the multiphase flow composed of oil and air, which is governed by the gearing motion. The numerical simulation of multiphase flow was carried out using the volume of fluid model (VOF). In the case of moving and rotating gearing, it was necessary to use dynamic mesh and procedure of remeshing based on the parameters of quality cells. The visualization techniques such as oil-flow, volume of iso-value, pathlines and streamlines helped to investigate the character of the unsteady flow behavior between two rotating gears.

1. Introduction

The visualization of oil flow is part of study in investigation of flow behavior in the helical gap gearings, which is a reaction to the problem of damages gearing [1], [2]. The research is mainly provided by the numerical simulation and the visualization is one way how to represent results, which help us to understand complex multiphase flow.

For model case was used gearing, which is designed for heavy industry to transmit power of 500 KW. The operation conditions are: gear_1 speed is 1500 rpm and gear_2 speed is 480 rpm at atmospheric pressure. Mineral oil is used for lubrication with following parameters: density 892 [kg/m3] and kinematic viscosity 220 [mm2/s] at ambient temperature.

In this paper is presented visualization of oil flow only in the tooth wheel gap with some simplification, because the main research is not focused on flow in complete gearbox, which is study by other authors [3], [4]. Under this presumption were made some simplification of computational domain, kinematic of gearing.

2. Problem formulation

For numerical simulations, the commercial code Fluent [5] was used and the volume of fluid (VOF) [6] approach was applied for oil flow in tooth wheel gap. This VOF model is commonly adopted for multiphase flows and it agrees well with the basic concept for research of characteristic flows in tooth wheel gap.

In our study the 1mm high layer of oil was created on the surface of gearing at the initial time (Fig.2). The basic character of simulation is unsteady, 3D multiphase flow with moving walls and dynamic mesh.

The multiphase fluids flow is governed by the momentum equation which is shared each of phases. The tracking of the interface between the phases is accomplished by the solution of a continuity equation for the volume fraction of one (or more) of the phases. For the q^{th} phase, this equation is in form:

$$\frac{1}{\rho}\left(\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right)+\nabla\cdot\left(\alpha_q \rho_q \vec{v}_q\right)=S_{\alpha q}+\sum_{p=1}^{n}\left(\dot{m}_{pq}-\dot{m}_{qp}\right)\right) \quad (1)$$

q – index of q^{th} phase, t – time, ρ - density, $\vec{v}$ – velocity vector, $S_{\alpha q}$ - source term, α_q - volume fraction, $\dot{m}_{qp}$ - mass transfer from phase q to p

The quantity α_q can be used for the flow visualization as is demonstrated below (see Figures 6-8).

The single momentum equation Eq.(1) is solved throughout the domain, and the resulting velocity field is shared among the phases [7]. The momentum equation shown in Eq. (2) depends on the volume fractions of all phases through the properties ρ and μ.

$$\frac{\partial}{\partial t}(\rho\vec{v})+\nabla\cdot(\rho\vec{v}\vec{v})=-\nabla p+\nabla\cdot(\bar{\bar{\tau}})+\rho\vec{g}+\vec{F} \tag{2}$$

p – static pressure, $\vec{v}$ - velocity, $\rho\vec{g}$ - gravitational body force, $\vec{F}$ - external body force, $\bar{\bar{\tau}}$ - stress tensor

In the fact, that the study is focused on oil flow in the tooth wheel gap we made several simplification in order to reduce the computed domain and minimize the required computational time.

The first simplification affected a model geometry construction. The geometry of whole gearing is reduced only to the part of tooth wheel as it is seen in Fig.1 The main flow is in the tooth wheel gap, so the construction of gear box and rest of gearing does not influence the flow.

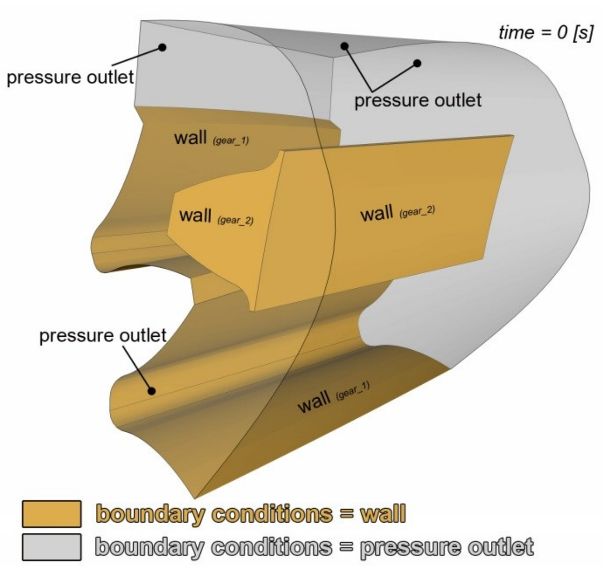

Fig. 1 The sketch of the computational domain

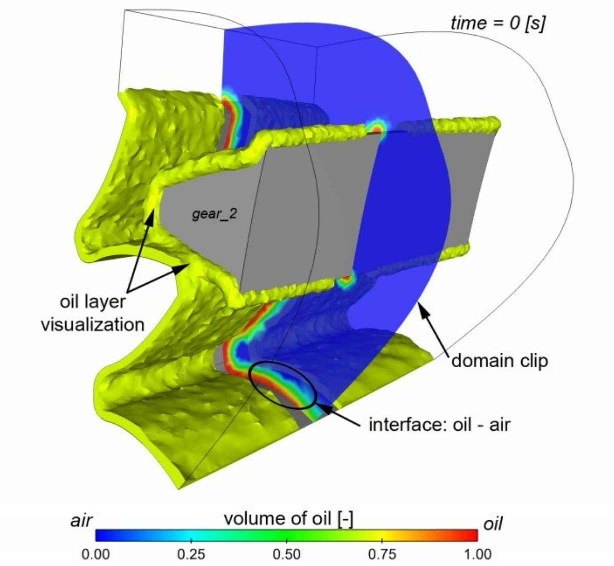

Fig. 2 Sketch of the initialization condition

Fig. 2 depicts the initialization condition of numerical simulation - 1mm oil layer height and position of gearing.

The complex co-rotation of gearings is simplified in the way that only one of the gearing is rotating and the second one is fixed. The new formulation of movement (fixed gear) does not change the kinematics and brings some benefit of data evaluation. Assuming the first gear is fixed then the second gear_2 performs combine motion in order to ensure the conserve kinematics of moving gearing. The gear_2 rotates around the axis around the point O_2 by angular velocity ω_2. The point O_2 is moving on the circle k with the centre of point O1 with angular velocity ω_c defined by equation (5,6,7). The distance between points O_1 and O_2 is the center distance of gearing.

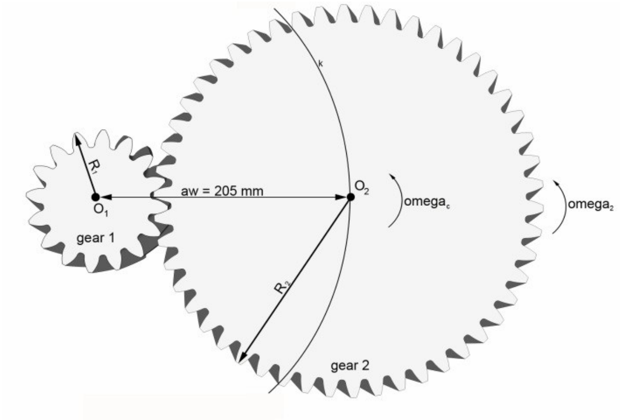

Fig. 3 Sketch of the tooth wheel motion

Figure 3 shows the kinematics of gearing as it was described above. For position of point O2 it can be written as:

$$x = a_w \cdot \cos(\omega_c \cdot t),\ y = a_w \cdot \sin(\omega_c \cdot t) \quad (4)$$

where x, y are coordinates, aw is centre distance of gearing, t is time and is angular velocity. The velocity of point O_2 is:

$$w_x = a_w[-\sin(\omega_c \cdot t)]\omega_c, \quad (5)$$

$$w_x = a_w[\cos(\omega_c \cdot t)]\omega_c, \quad (6)$$

Where: w_x, w_y are velocities in the Cartesian coordinate system. The term for angular velocity of gear_2 is written as:

$$\omega_c = \frac{2\pi \cdot n_1 \cdot n_2}{z_1 + z_2} \quad (7)$$

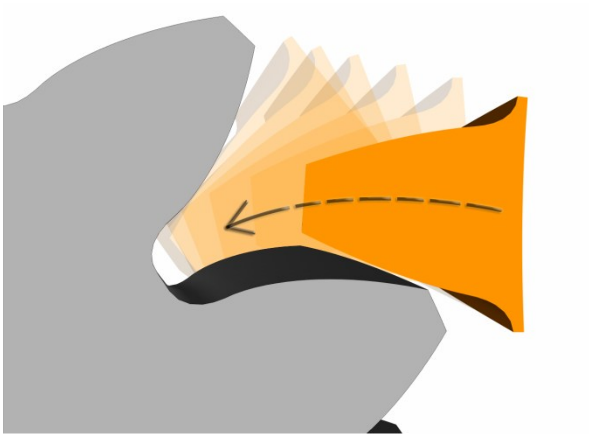

Fig. 4 Sketch of gear kinematic, phase 1

Fig. 5 Sketch of gear kinematic, phase 2

The movement of gear_2 is realized with dynamic mesh function in Fluent. The remeshing of dynamic mesh depends on the skewness of cells and the maxima and minima length of cell edge. Before equations are solved in the new time step, the mesh is updated to the new position.

3. Result visualization

The visualization of the oil flow was carried out using iso-volume of volume fraction of oil > 0.5 [-] illustrated on Fig. 6-8 for the different time period. The change of the oil concentration in the oil film was observed during the simulation. This method of the visualization helps to understand the flow effect and the mixing mechanism of the oil and air on the existence of the pressure minima. The similar method for visualization was presented by many authors.

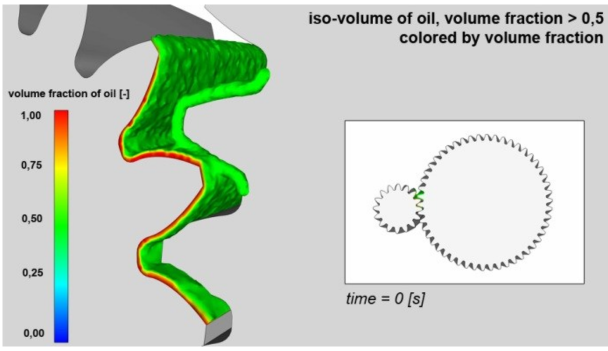

Fig. 6 Iso-volume of oil > 0.5, time = 0 [s]

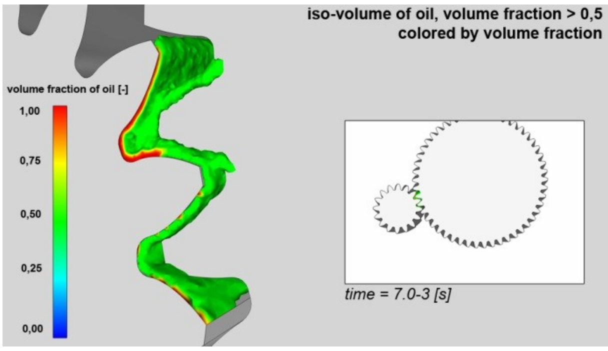

Fig. 7 Iso-volume of oil > 0.5, time = 7e-3 [s]

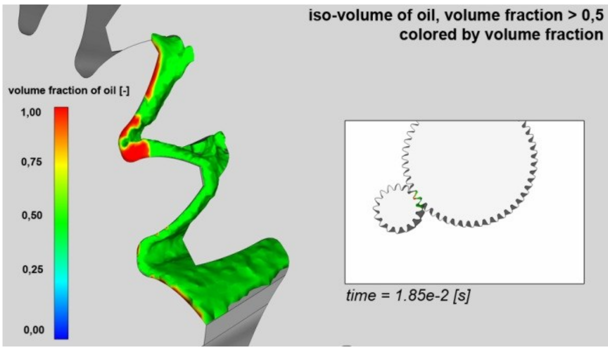

Fig. 8 Iso-volume of oil > 0.5, time = 1.85e-2 [s]

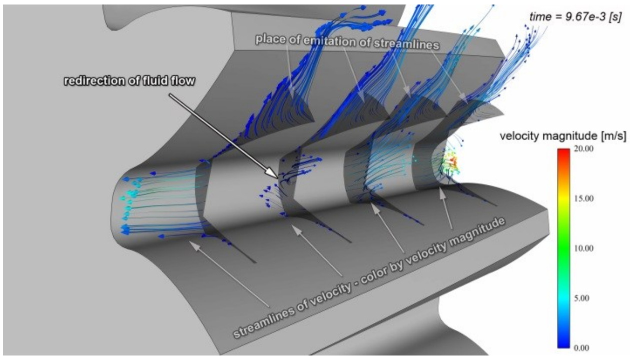

Fig. 9 Streamlines colored by the magnitude of velocity, time = 9,67e-3 [s].

Other information about the flow phenomena is possible to observe from the Fig.9 that depicts streamlines colored by the magnitude of velocity at the time = 9.637e-3 [s]. These streamlines are emitted from clips of computed domain in several clips: z-clips-1, z-clips-2, z-clips-3 and z-clips-4. The streamlines of z-clip-1 are oriented in +z direction, in z-clip-3 and z-clip-4 are oriented in -z direction. In the middle part of z-clips-2 the streamlines of velocity are oriented in both directions.

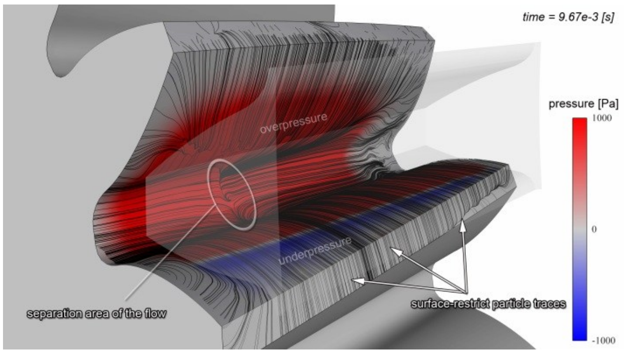

Fig. 10 The snapshot of the pressure distribution on the gear surface, time = 9,67e-3 [s].

Figure 10 shows the pressure field on the tooth wheels surface. The visualization method is based on the fact that the pressure range is restricted to visual area with over-pressure and under-pressure. The negative pressure demonstrates the pressure drop regarding the wheel move. The reference value of pressure at Fig.10 is set to atmospheric pressure. The under-pressure and over-pressure describes the deviations from atmospheric pressure. The place of redirection of the main stream can be better identified using the surface-restrict particle traces [8].

4. Conclusion

This paper shortly presents the investigation of oil flow in the tooth gap. The study of oil flow was investigated numerically and basic premises are mentioned such as VOF approach, dynamic mesh procedure, geometry simplification. Using the appropriate visualization techniques, the particular flow phenomena were discovered and investigated. The visualization of oil flow was created based on iso-volume of volume fraction of oil. This procedure allows to observe the existence of the oil and the tracking of interface between the phases in the gap of tooth wheel. box).The place of main flow redirection was detected using visualization of the surface-restricted particles traces.

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