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Preliminary theoretical results of limited slip couplings

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Abstract Limited slip couplings are a solution for the traction of an all-wheel drive vehicle. The limited slip coupling can be mounted between the front and rear differentials for torque distribution, but also on a front or rear axle to distribute torque between two wheels
Theoretical analysis is performed with a software plug-in with computed fluid dynamics. One of the most important features of a four wheel drive system is the control of the torque transmitted to the wheels. In order to get as much power as possible to the ground, the torque has to be divided among the four wheels to minimize the wheel spin. The limited slip coupling deals with this problem in a new, and, from many points a view, better way. The coupling can be compared to a hydraulic piston pump, which is driven by the slip between input and output shafts. The oil flow from the pump results in an oil pressure that is controlled by a throttle valve. The oil pressure compresses a wet multi-plate clutch that derivers torque to the output shaft. The torque on the output shaft is proportional to the oil pressure. Without the throttle valve the coupling would transfer the torque whenever there is differential rotational speed between the two shafts. One of the objectives of this paper is to present the importance of using CAD and CFD programs and to simulate the behavior of the coupling introducing a momentum, an energy and the material used for the disks, and to obtain results for heat flux and temperature.

1. Introduction
When driving under demanding conditions such as snow, ice and mud, a regular two wheel driven car will fall short. To increase safety and performance many car manufacturers offer a four wheel driven alternative. However, there are a vast variety of four-wheel drive setups. Some systems are full-time AWD (AWD- All Wheel Drive), which means that all wheels receive torque from the engine at all time. The amount of torque distributed between the front and rear axis can have a fixed ratio, typically 50/50 or could be variable. These kinds of full time systems are common among the Asian car manufacturers, such as Subaru and Toyota [1].

As an alternative to the full time systems there are systems called part time systems. Cars using a part time system can either be front or back wheel driven under normal driving conditions. To distribute torque to the other axis some kind of torque transferring device is needed (Figure 1). There are a variety of different solutions achieving it. To transfer torque between the right and left wheels, a differential able to split the available torque is needed.

One of the objectives of this paper is to present the importance of using CAD and CFD programs and to simulate the behavior of the coupling introducing a momentum, an energy and the material used for the disks, and to obtain results for heat flux and temperature.

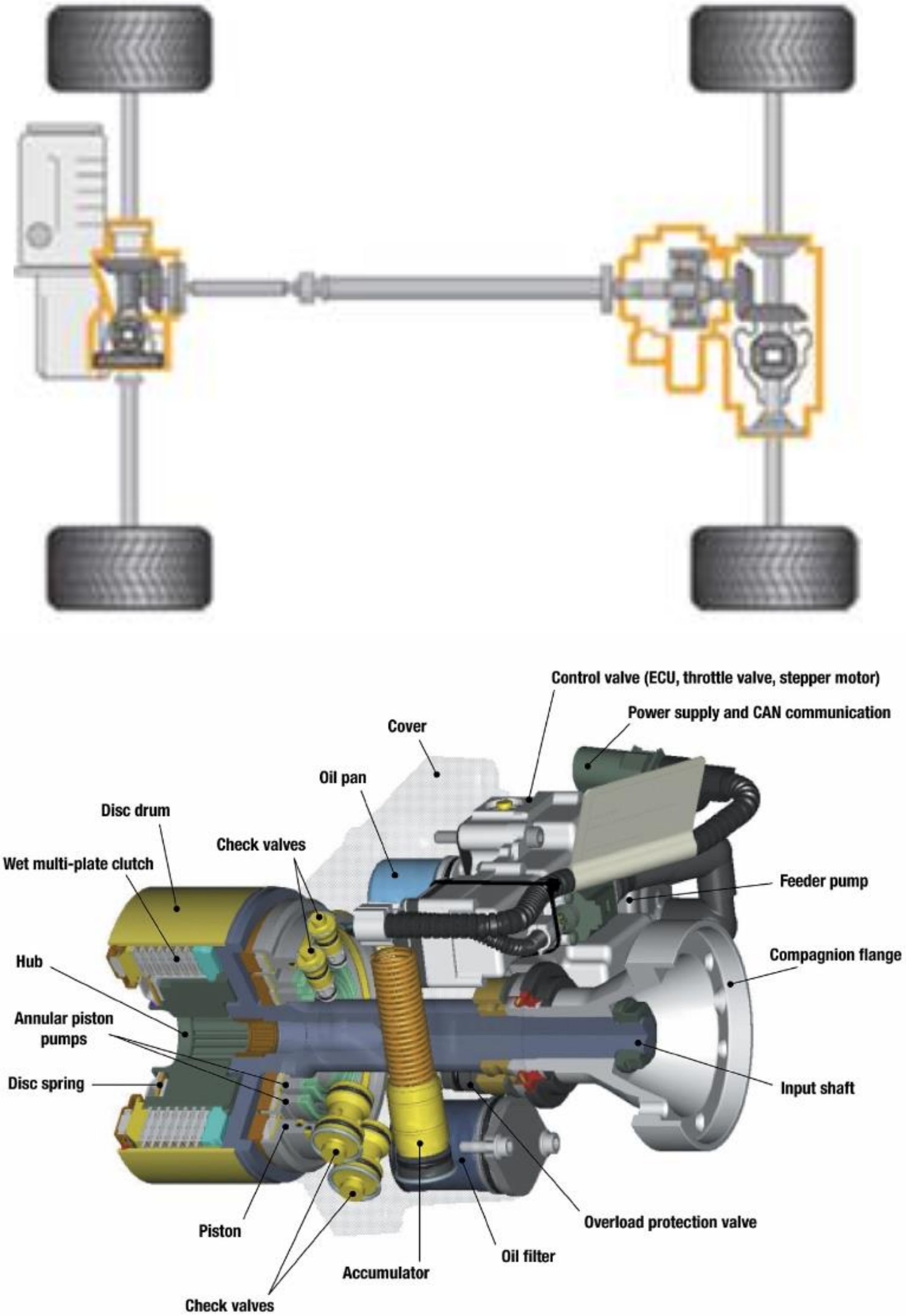

Figure 1. Illustration of the drive line. Highlighted areas are the rear and forward differentials and the AWD coupling [1].

2. Theoretical considerations

A viscous coupling is defined by torque transmission with the help of fluid friction. The viscous coupling is defined by shear stress of a permanent fluid film between two surfaces in relative motion. The shear stress is dependent on the velocity of the film fluid, by the dynamic viscosity [3] - Newton equation, eq. (1).

$$\tau = \eta \frac{\delta u}{\delta y} \tag{1}$$

Where $\tau -$ shear stres in the lubricant oil; η- dynamic viscosity; u- velocity; y-film fluid thickness;

For the simulation, the model is based on 3D model, computed in CAD program, using the specified dimensions. Also, the velocity is predefined for Δω= 100 rad/s, (ω1-ω2).

The fluid friction torque is calculated regarding the minimum radius and maximum radius of the interior and exterior dimension of the coupling (Ri= 38 mm and Ro= 53.7 mm) [3].

$$\mathrm{M} = \mathrm{z}\pi\eta(\omega_{1-}\omega_2)\frac{\mathrm{Ro}^4-\mathrm{Ri}^4}{2\mathrm{h}} \tag{2}$$

Where: M- torque friction, z-number of disks, η-dynamic viscosity, ω-angular speed, Ri- inner radius, Ro-outer radius, h- film thickness;

The value calculated for torque is M= 90.7 Nm ;

The simulation for energy, momentum and force are done in CFD (computed fluid dynamics) . The film fluid is a hydraulic oil type, with the film dimension h=0.05 mm, with the fluid viscosity η=0.12 Pas. The disk is based on steel , with the thickness of 1 mm, the number of the disks are z=11 and the convective coefficient estimated (Vauto≥60 km/h) [3] is $\alpha_1 = 50\frac{\mathrm{W}}{\mathrm{m}^2}\mathrm{K}$.

Because of the geometry of the coupling, it is more convenient to use a cylindrical system of coordinates (rΘz). Each axis has a corresponding velocity, namely uΘ, ur and uz. We will presume that the velocity distribution in the oil films is linear, eq. (3) [4].

$$\mathrm{u}_{\theta}\,(\mathrm{r}) = \omega\mathrm{r}\frac{\mathrm{z}}{\mathrm{h}} \tag{3}$$

The temperature distribution within the oil film is governed by the transient energy equation [4], eq.(4) .

$$\rho\mathrm{c}\frac{\delta\mathrm{T}}{\delta\mathrm{t}} = \lambda(\frac{\delta^2\mathrm{T}}{\delta\mathrm{r}^2} + \frac{\delta^2\mathrm{T}}{\delta\mathrm{z}^2}) + \eta(\mathrm{T})\left(\frac{\delta\mathrm{u}_\theta}{\delta\mathrm{z}}\right)^2 \tag{4}$$

Where: ρ- density of the fluid; c- convective term; T- temperature of the fluid; r- radius of the coupling; u_{θ}- velocity; z- axis coordinate.

The equation is used for calculate the values of temperature field in the coupling presented in Figure 5.

3. Numerical simulation

For a numerical simulation a computed fluid dynamic is used (Fig 2.). Using a schematic figure (Fig.4) of the viscous coupling, a 2D model can be obtained using a CAD program (Catia V5 and Gambit-FluentInc.). Pre-processing require a 2D model (Fig 3.), using Catia V5 and GambitFluent Inc., regarding the dimensions. The boundary conditions are presented in Fig2, where the disks that are engaged by the central shaft with (Ro=53,7 mm) are considered moving walls and the disks that are engaged by the exterior shaft (Ri=38 mm) are considered stationary walls. The movement of the disks, are analyzed and presented in Fig5. The input torque is defined by the exterior (Ro) and the output torque is defined by the interior shaft (Ri) in Fig.2. In figure 3 is presented the assemble of the disks mounted on the shafts.

The difference between the temperature variation for the axial direction of the coupling (Figure 5), is maximum in the film fluid, because the heat flux is maximum in liquid state and the fluid (hydraulic oil) , has the physic property of thermal transfer. Where the difference is increasing linear but slowly, is because the heat flux is minimum in solid state (steel disks).

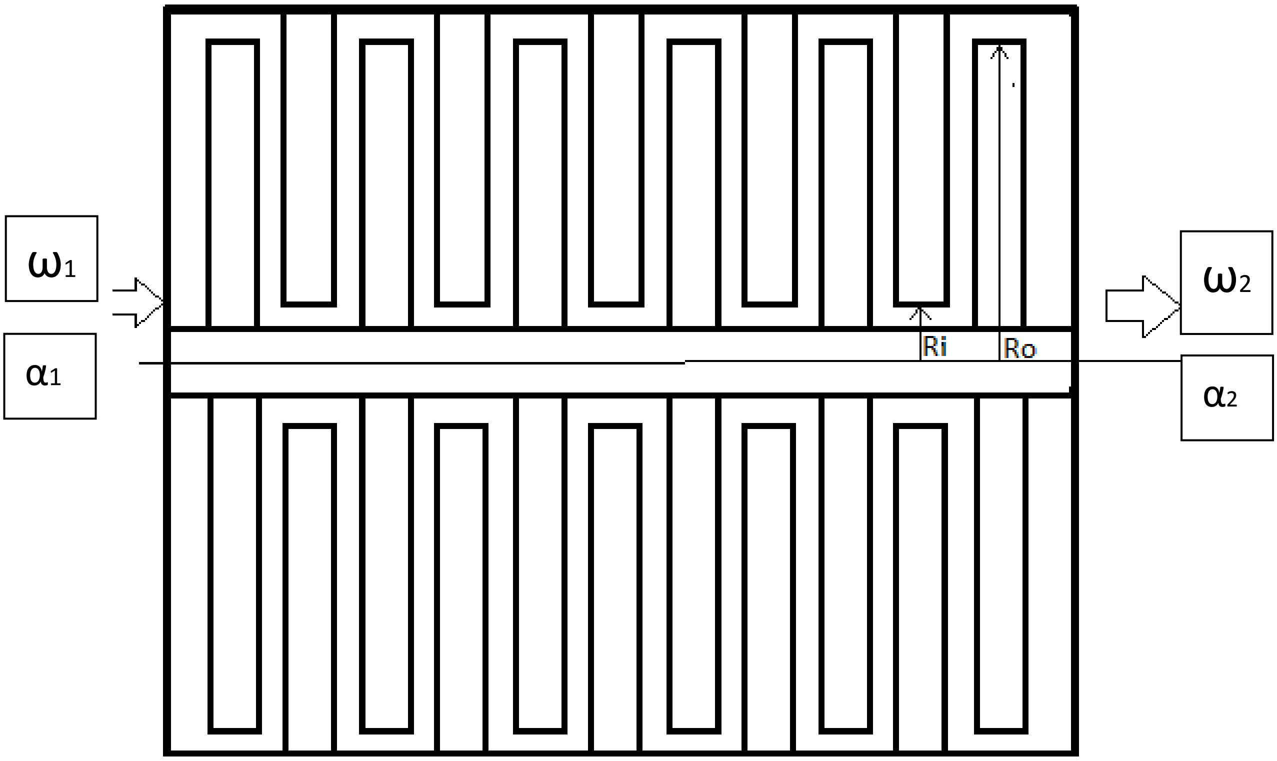

Figure 2. The model used for introducing the CFD software.

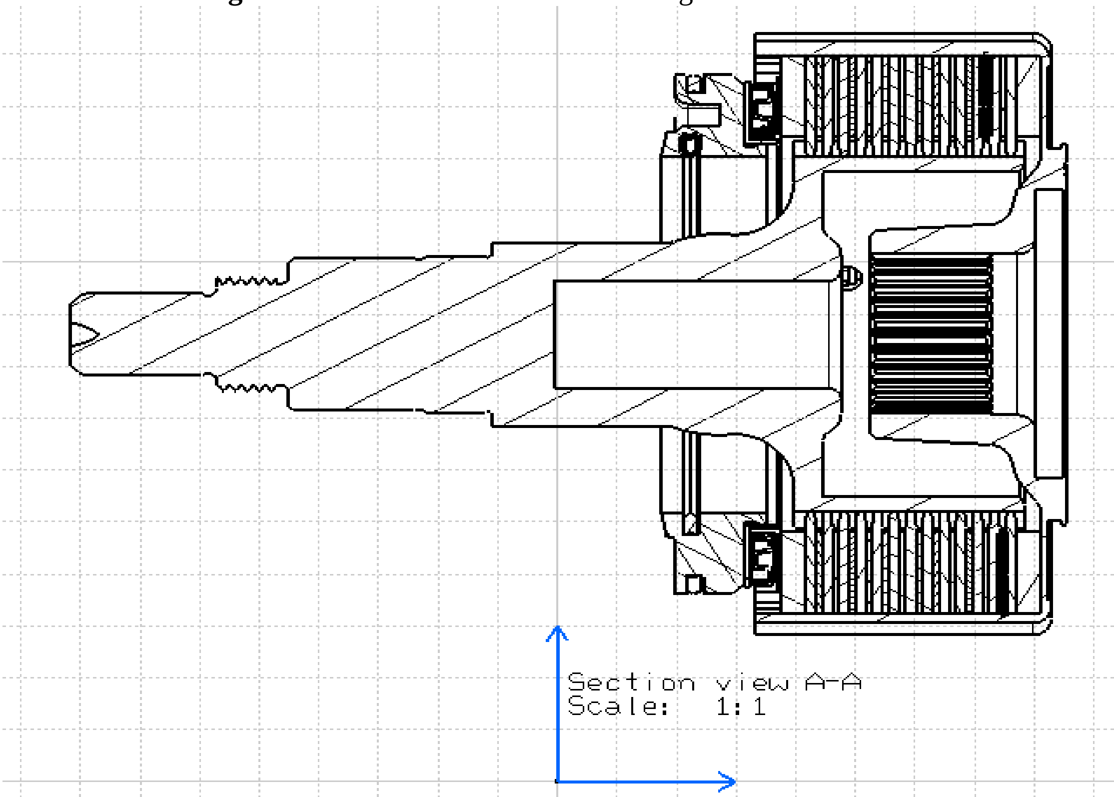

Figure 3. The 2D model for CAD.

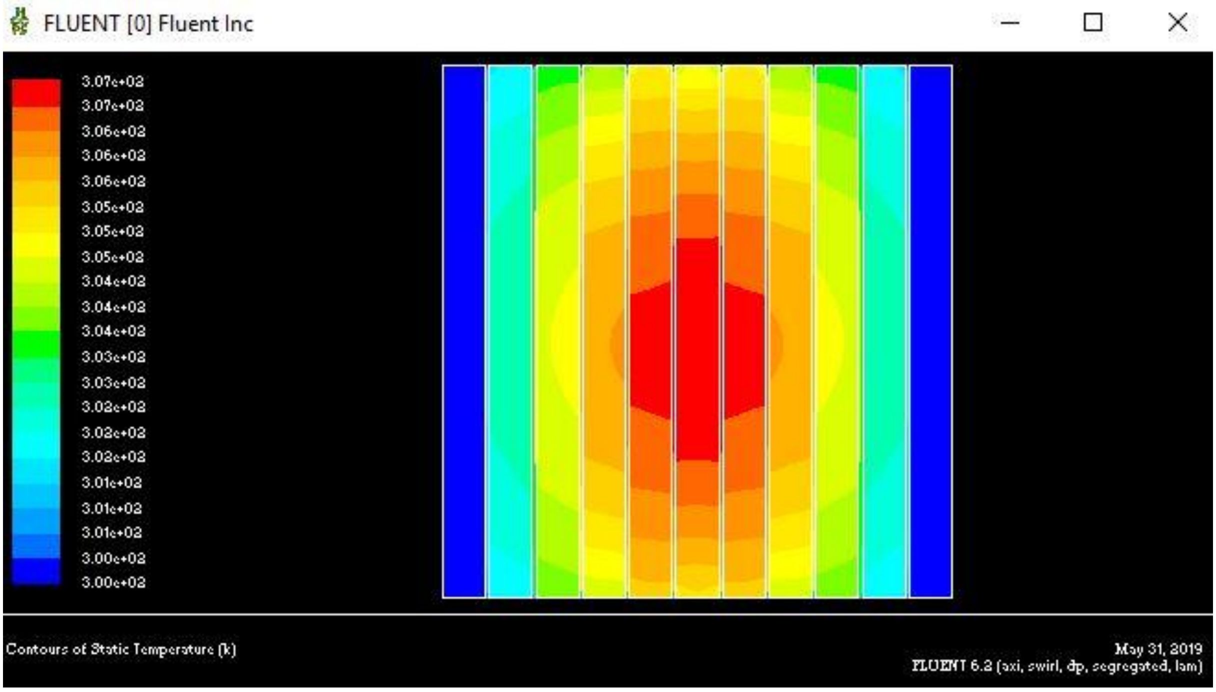

Figure 4. CFD simulation of the internal temperature distribution in the coupling.

The temperature difference is about 7 degrees Kelvin and the maximum value is obtained in the core of the coupling, because of the symmetry of the heat flux between the disks. We could improve the heat flux by increasing the convective coefficient α but this is limited by the vehicle structure.

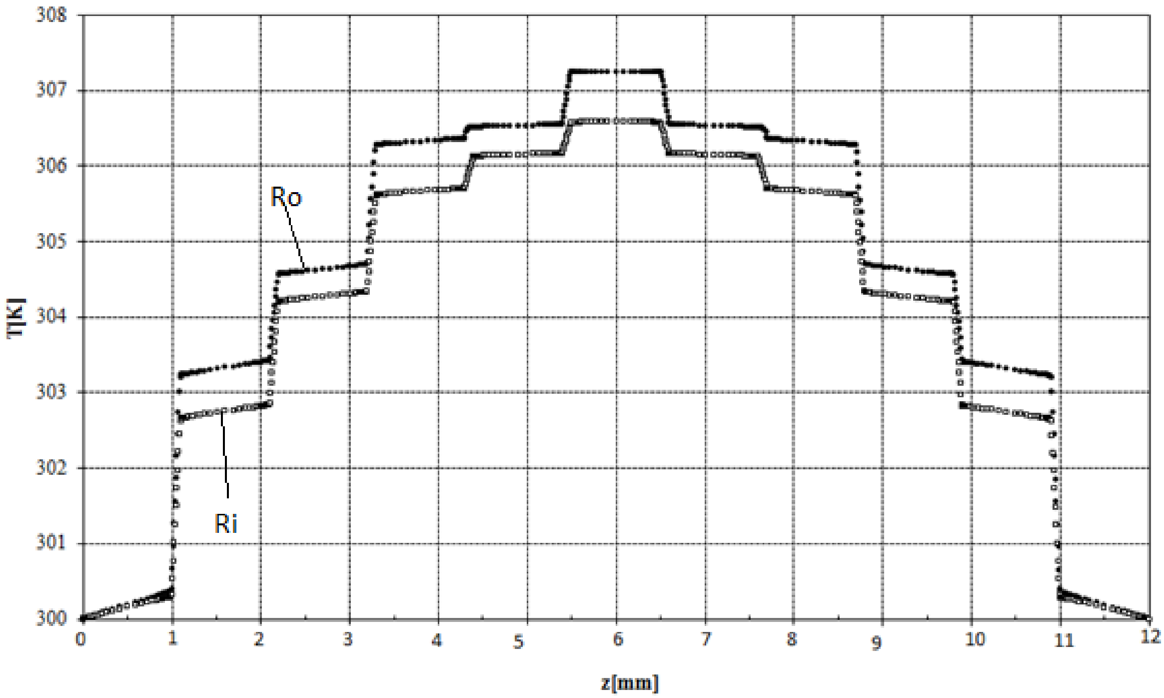

Figure 5. Temperature variation for the axial direction of the coupling.

Figure 5 presents the temperature difference between the disks, the first line is the temperature for the interior disk (Ri) and the second line is the temperature for the exterior disk (Ro).

4. Conclusions

In the automotive industry, especially in the mechanical departments, one of the issues regarding the innovations in this field, is the economically side. Real simulations and tests are very expensive, and it takes a lot of time preparing the models. The materials used, for the mechanical parts, are based on metals, improved by alloy them with other materials. A good way for testify and check all the dimensions and forces , used in mechanical engineering, is using a 3D model designed with a computed aided program, and a simulations with a computed aided engineering program.
Using CAD and CFD, we could obtained the results that we could improve with a real simulation, but we have a big step regarding the new prototype that we are studying.

As a mechanical part, the viscous coupling have a big problem in heat flux, because the core of the mechanical part is loaded with a lot of energy. This energy must be transferred to the exterior , for controlling the over heating situation, when a vehicle has issues in controlling hard terrain for example.

The temperature distribution for the axial direction of the coupling, after a short simulation, is rising very rapidly in the film fluid, as figure 5 is presented. The lower temperatures are simulated for the disks, because the solid state of a material, is heating slowly then the fluid state of a material.

5. References

[1] David B 2011, *Deriving and implementing a model of fifth generation Haldex AWD actuator* p 53
[2] Bulent Y 2002, *Viscous Heating Effects in Viscoelastic Flow between Rotating Parallel Disk Turkish J. Eng. Env. Sci.* p 511
[3] Adrian P 2011 , *Cuplaje cu frecare viscoasa* p 313
[4] Hamrock B.J., Schmid S.R., Jacobson Bo.O. 2004 , *Fundamentals of fluid film lubrication Second Edition* p 699