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Study between newtonian and viscoelastic lubricants using a computational fluid dynamics (CFD) as a tools

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Abstract

In this paper, we consider the study of the hydrodynamic lubrication using a New- tonian fluid and UCM model. The results show, that viscoelasticity displays differences with a Newtonian fluid, especially for the exhibition of a first normal stress difference.

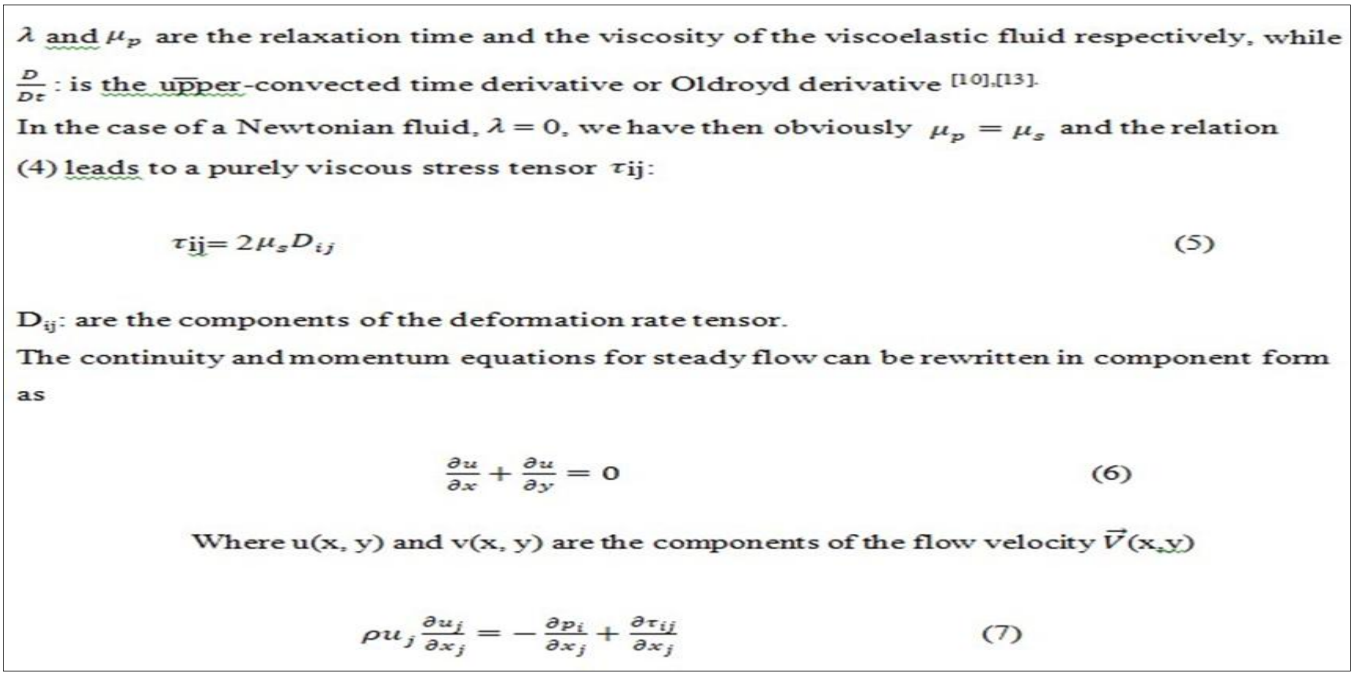
Keywords: Journal bearing, viscoelastic lubricant, UCM model

Introduction

In the classical hydrodynamic lubrication approach, lubricants are assumed to be have as Newtonian fluids. For many practical lubrication applications, the Newtonian fluid constitutive approximation is not a satisfactory engineering approach. Experiments have shown that the addition of small amounts of long chained polymer additives to a Newtonian fluid produces desirable lubricant properties. For Newtonian oil lubricants, the addition of polymers has modified the rheological properties in such a way that viscosity versus shear rate is not constant and introduced elastic effects. The vis- coelastic fluid effect on eccentric rotating cylinders is a long-standing and attractive subject in tribology. In the literature, numerous studies have been devoted to the visco- elastic flow between eccentric rotating cylinders, using different computational methods [1, 3, 10, 14, 15], in order to assess the lubricant viscoelasticity and/or lubrication performances. However, the effect of fluid viscoelasticity on the flow between eccentric rotating cylinders is not yet completely elucidated. The main challenge is to obtain numerical convergence for viscoelastic fluids in very small gaps problems. The ultimate objective of this study is to reveal viscoelastic effects on the flow between eccentric rotating cylinders and on the lubrication performances. The first specific objective of this study is to validate the code developed in C^{++}. The second specific objective is to calculate viscoelastic flows between eccentric cylinders using Fluent commercial Soft- ware. The different numerical method used by this software allows calculating 2D stationery flows, for moderate viscoelasticity.

Materials and Methods

One of the simplest viscoelastic fluid models available is the upper convected Max- well model incorporating a constant viscosity and a relaxation time. In this study, we restrict our attention to the UCM constitutive model characterized by a small relaxation time. The equations of motion and the constitutive equation for steady incompressible flow are- [2], respectively



λ and μ_p are the relaxation time and the viscosity of the viscoelastic fluid respectively, while
$\frac{D}{Dt}$: is the upper-convected time derivative or Oldroyd derivative [10],[13].
In the case of a Newtonian fluid, $\lambda = 0$, we have then obviously $\mu_p = \mu_s$ and the relation (4) leads to a purely viscous stress tensor τij:

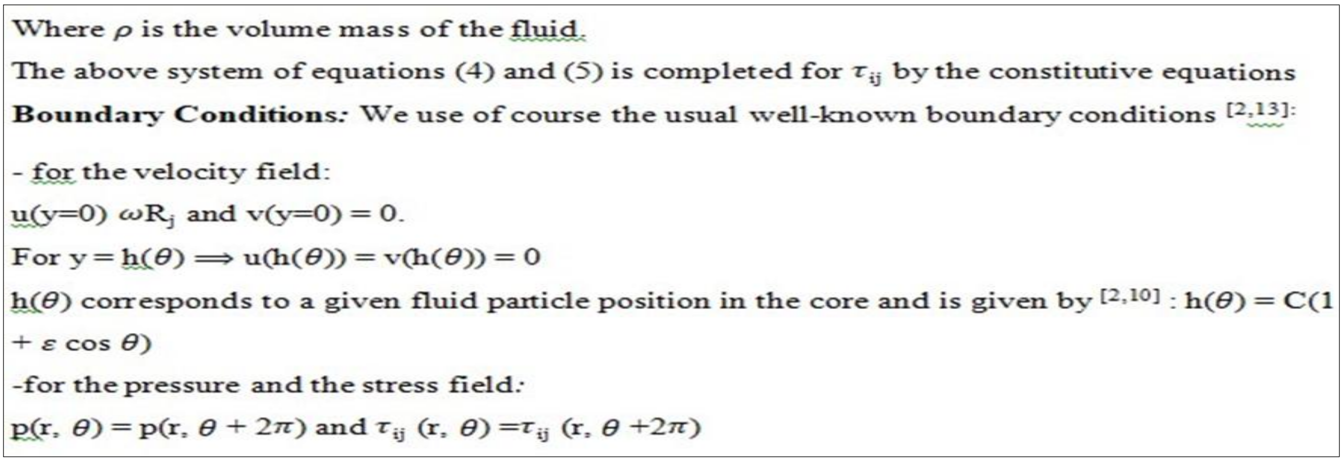
$$\tau ij = 2\mu_s D_{ij} \qquad (5)$$

D_{ij}: are the components of the deformation rate tensor.
The continuity and momentum equations for steady flow can be rewritten in component form as

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0 \qquad (6)$$

Where u(x, y) and v(x, y) are the components of the flow velocity $\vec{V}$(x,y)

$$\rho u_j \frac{\partial u_j}{\partial x_j} = -\frac{\partial p_i}{\partial x_j} + \frac{\partial \tau_{ij}}{\partial x_j} \qquad (7)$$



Where ρ is the volume mass of the fluid.

The above system of equations (4) and (5) is completed for τ_{ij} by the constitutive equations

Boundary Conditions: We use of course the usual well-known boundary conditions [2,13]:

- for the velocity field:

$u(y=0)\ \omega R_j$ and $v(y=0) = 0$.

For $y = h(\theta) \Longrightarrow u(h(\theta)) = v(h(\theta)) = 0$

$h(\theta)$ corresponds to a given fluid particle position in the core and is given by [2,10] : $h(\theta) = C(1 + \varepsilon \cos\theta)$

-for the pressure and the stress field:

$p(r, \theta) = p(r, \theta + 2\pi)$ and $\tau_{ij}(r, \theta) = \tau_{ij}(r, \theta + 2\pi)$

Numerical Procedure: The characteristics of this 2D flow, are numerically solved using the CFD package Fluent completed by UDFs and UDSs. The pre-processor used for the grid generation is Gambit. The particularity of the problem examined here (the clearance size is very small compared to the journal diameter) requires to divide the area into three zones, using the bi-exponent mesh for the very small gaps and exponent mesh for the two other zones, while UDFs and UDSs have been defined [13] to compute the sources terms of the momentum equation and the three components of stress: τ_{xx}, τ_{yy} and τ_{xy}. The nu- merical procedure to handle the present numerical analysis is given in details.

Results and Discussion

In this work, we first study the case where the relaxation time is very small. The motivation of this test is intended to compare the results with the analytical solution for the Newtonian fluid; which makes it possible to validate the numerical results by the use of the code developed in C^{++} and also to give an assurance to use this code in the numerical simulation of several more complicated lubrication problems. In the second stage, we study the effects of the relaxation time, viscosity, rotation speed and the relative eccentricity on the distribution of the pressure field, the stress field and the bearing load.

Results presents a comparision of the pressure distribution for the two fluids considered: Newtonian fluid and UCM fluid. We notice a superposition of the pressure distribution for the two fluids studied (Newtonian fluid through the numerical and analytical calculation and Maxwell's fluid through the numerical calculation) which thus seem identical. This is a consequence of the low value of the relaxation time λ=1.2x10^{-6}s which normally favors the elastic contribution. The numerical calculation is comparable with the analytical solution, these directly justify the efficiency of the calculation code developed in C^{++}. The evolution of the pressure along the sur- face of the journal for an eccentricity ε=0.6, a lubricant viscosity μ =0. 3Pa.s and a relaxation time λ=1.2x10^{-4}s for different rotation speeds ω. Note that the pressure in- creases with the rotational speed. The variation of the first difference of normal stresses (N1) along the surface of the journal for different journal rotational speeds. We notice that N1 strongly increases as a function of the evolution of the pressure along the surface of the journal for different viscosities μ. We clearly notice the effect of the viscosity μ on the pressure. In the is presented the evolution of the first difference of the normal stresses N1 along the surface of the journal for different viscosities μ of UCM fluid. We notice a significant increase in N1 as a function of μ. The effect of the relax- ation time on the pressure field. It can be seen that the pressure is weakly influenced by the relaxation time. We note that the effect of the vis- cosity of the lubricant on the pressure is very important comparable to the effect of the relaxation time. So, we conclude that the elastic effects on the pressure are less im- portant than the viscous effects. The profiles of the first difference of the normal stresses N1, along the surface of the journal for different relaxation times. We notice that for a low value of relaxation time (1.2x10^{-6} s) N1 is important. For a long relaxation time (1.2x10^{-3} s), the maximum value of N1 is of the order of 125 steps, this value is doubled almost 2.25 times more, compared to the previous relaxation time. The first difference of the normal stresses shows a very important viscoelastic effect for important values of the relaxation time. The evolution of the pressure along the surface of the journal for different eccentricities. Note the significant effect of the eccentricity on the pressure when ε tends to 1. presents the effect of rotational speed on the hydrodynamic force of the journal bearing. We note that this force varies very strongly as a function of ω where we observe that for a journal speed ω varying between 150 rad/s and 200 rad/s, the hydrodynamic force varies from 4000N to 5500N. The effect of rheological properties (viscosity μ of the fluid and relaxation time λ) on the hydrodynamic force. It should be noted that the hydrodynamic force varies greatly as a function of the viscosity μ of the fluid as well as with respect to the relaxation time λ presents the variation of the hydro- dynamic force as a function of the relative eccentricity ε. The curves are presented for two journal rotation speeds (20 rad/s and 40 rad/s). We notice that the force varies greatly as a function of ε. So that if we increase the rotation speed of the journal, eve- rything happens as if the curve is translated in the opposite direction to the eccentricity. We have shown that, the load capacity is increased with increasing rela- tive eccentricity for both, UCM model and Newtonian fluid. We observe large viscoelastic effects on load amplitude with UCM model.

Conclusion

The fluids considered are non-Newtonian, viscoelastic and modelled by an Upper Convective Maxwell (UCM) constitutive equation. The results point out the influence of UCM fluid on journal bearing lubrication for very small gaps. We find that viscoe- lasticity does indeed produce a measurable and beneficial effect on lubrication characteristics at the higher eccentricity ratios and that this effect correlates well with a char- acteristic relaxation time. In this paper, the UCM model including the static pressure, the first difference normal stresses and hydrodynamic forces in the journal surface generates significant viscoelastic effects. The results obtained by numerical simulation show that: The effect of viscoelasticity was also highlighted by the existence of the first differ- ence of normal stresses. The hydrodynamic force is greater in the case of a UCM type lubricant than that of a Newtonian fluid. The hydrodynamic force is influenced by the relaxation time and the viscosity of the fluid. We observed, from a numerical simulation, that the relaxation time does not influence the distribution of the pressure field along the journal, on the other hand this parameter strongly influences the stress field. The influences of the viscosity of the fluid, the rotational speed of the journal and the eccentricity appear clearly and explicitly on the fields of pressure, stresses and also on the hydrodynamic force. This result show that the viscoelasticity enhances the magni- tude of the pressure field on the journal surface. This means that viscoelastic lubricants affect the loading in the journal bearing system. The results obtained in this study are in good agreement with those attained by other researchers [1, 3, 6, 7, 9, 12].

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