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Elastohydrodynamics Lubrication for Bio-Based Lubricants in Elliptical Conjunction

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Abstract

This paper emphasizes on bio-based lubrication issue of elastohydrodynamic lubricants in mechanical part. The bio-based lubricant has a great potential as a substitute for conventional lubricant in industries. In this work, the elastohydrodynamic lubrication flows were investigated at the elliptical conjunctions by using bio-based lubricants and mineral oil. The computational fluid dynamic (CFD) software was used to determine the effect of lubricants and helps to verify the deformation of the pressure distribution at the conjunctions. The results show that at constant speed, the mineral oil exhibits higher value of dynamic pressure than the bio-based lubricant along X and Y axis between two mating surfaces. It is also found that the mineral oil carried more load compared to bio-based lubricant. Owing to the promising properties of lower dynamic pressure than the mineral oil, the bio-based lubricant exhibits significant behaviour in protecting the surfaces from wear and damage.

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1. Introduction

Many machine elements, lubricated by fluid film have surfaces that do not conform to each other, so small lubricated areas must then carry the load. The lubrication area of a non-conformal conjunction is typically three orders of magnitude less than that of a conformal conjunction. In general, the lubrication area between non-conformal surfaces enlarges considerably with increasing load, but it is still smaller than the lubrication area between conformal surfaces. Some examples of non-conformal surfaces are the concentrated load-supporting or load-transmitting contacts such as gear teeth, cams and followers, rolling-element bearings and others.

Elastohydrodynamic lubrication (EHL) is defined as the type of hydrodynamic lubrication where the pressure between contact surfaces is very high thus the contact surfaces deform elastically to an amount comparable to the film thickness. Unlike hydrodynamic lubrication where the expression for the film thickness can be determined a

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priori, in EHL problems the pressure distribution and the film thickness must be determined simultaneously. Although, there are generally two types of problems in EHL like line contact problems and point contact problems. In line contact EHL, the contact elements are assumed to be infinitely long in one direction and the contact takes place in an infinitely long strip. Meanwhile in point contact EHL; the contact takes place within a finite elliptical region [1].

1.1. Bio-based lubricant

The need for lubrication cannot be over-emphasized as far as its role in engineering is concerned. With the technological advancement, man in his guest to improve his standard of living continues to invent and produce new machines. When two metal parts are in contact, the amount of asperities and interaction within the contact area increases thereby causing; frictions which insist motion wear of the metal parts and generation of excessive heat. These friction, wear and excessive heat caused by the interaction between the surfaces of the moving parts of the machine has to be controlled by lubrication whose function is to reduce friction and wear, prevent oxidation and corrosion while acting as a coolant facilitating heat dissipation from the engine. A lubricant may be in gaseous, liquid, semi-solid (grease) or solid form. Lubrication is achieved when the surfaces in contact are separated by a continuous lubricant film.

Liquid lubricants have the highest application because they headily provide the separation of surfaces when correctly applied. Because of the importance and wide application of lubrication, coupled with the ever increasing world energy crisis, there is need to source out lubricants other than the computational ones obtained from mineral oils [4, 5].

Thus an alternative of producing a lubricant from bio-based material should be took into consideration. There is strong concern of awareness in biodegradable low-toxicity lubricants. Biodegradability is reached by using a suitable biodegradable base fluid, but low- toxicity requires an additivation that is environmentally friendly [2], too. However, the key aspects for any industrial application are technical performance and technical advantages proved in dedicated tests.

Therefore, in this project the effect of deformation on pressure distribution behavior in elastohydrodynamics lubrication in elliptical conjunction was investigated in order to clarify the best performance of lubricants.

2. Methodology

Computational Fluid Dynamic (CFD) is a numerical method for partial different equation (PDE) by representing the fluid flow with numbers. The equations is integrated by space and time to give the solution. There are some equations need to be concerned in order to run any simulation by using computational fluid dynamic (CFD). So, the important equation must be considered during the simulation is the continuity equation and the momentum equation.

2.1 Pre-Processing CFD

To solve this project and to run the simulation, we must start the process with pre-processing. Pre-processing is the process that includes building geometry, meshing and setting boundary type for the model to run in the simulation. In other word, pre-processing consists of data input through an operator friendly software. Later, these inputs can be read and process by solver.

2.2 Building Geometry

Generally, building geometry is a process of defining the geometry of the region on interest. This project used two dimensional structure or body. For this project, the model of this project is drawn as Fig.1a below. In fluent, before run the simulation, we must draw a tunnel. This tunnel will act as a boundary for the structure during the

(b)

simulation. That means, the fluent will just analyse the structure or body in the tunnel only. So, Fig.1b below also represents the tunnel for this project.

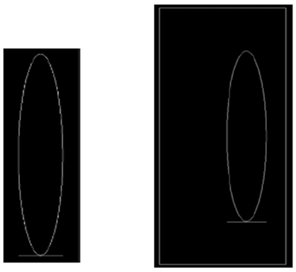

Fig.1. (a) Model and (b) tunnel was done in the Gambit for this project respectively

2.3 Meshing Process

In Fluent software, meshing process is one of the important part before conducting the simulation. Meshing process will ensured the result gained after the simulation is more accurate. Hence, the best size of meshing must be selected before run the simulation. All the meshing has been constructed in the Gambit. The meshing for this project is shown in Fig.2. Fluent can be divided into two parts where one part is draw one body or structure and another part is to run the simulation. Therefore, all the drawing was constructed in Gambit.

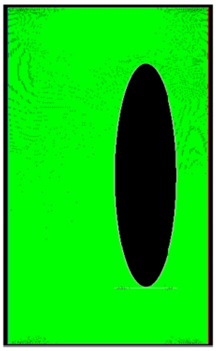

Fig. 2. The meshing was done in Gambit before export to Fluent

In Gambit, the size of meshing and the boundary condition has been set up before exporting the model into Fluent. These boundary conditions were wall, pressure inlet, outflow, pressure outlet and others. Table 1 shows the selected types of boundary condition for this project.

Table 1.Name and type for each boundary layer condition

Zone name/Label	Zone type	Position
Inlet	Pressure inlet	Tunnel inlet
Outlet	Pressure outlet	Tunnel outlet
Wall	Building/Structure	Building/Structure
Tunnel	Wall	Both tunnel side and top

2.4 Processing CFD

After the pre-processing stage has been completed, Fluent software was utilized in this project to simulate the result on the model. This section will be discussing about the specific parameters utilized in this project's.

Three types of numerical solution techniques can be applied in the solver as the calculation method. They are finite different, finite volume, finite element and spectral methods. In computational fluid dynamic (CFD), finite volume methods was applied. In Fluent, there are some steps that need to be done and set before starting the iteration such as;

- Read the mesh file
- Check the grid to make sure that there is no missing grid and error is zero
- Define the solver. For this part, segregated solvers with implicit formulation were chosen
- Define the viscous model can be used.
- Setup the boundary condition of the inlet velocity.
- Initialization
- Setup the monitor residual. From this monitor, the simulation can be monitored and the simulation convergence can be verified.
- Iterate. Start the simulation.

3. Result and Discussion

The entire experiment consists of two parts, where the two parts involve a type of lubricants which are mineral oil and biodegradable ester.

3.1. Comparison between mineral oil and bio-based lubricants (biodegradable ester) at two surfaces

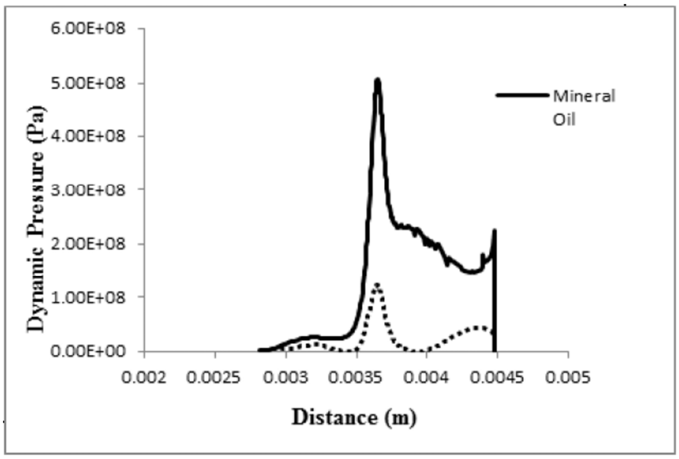

Fig. 3. Dynamic pressure distribution for X-axis

Fig. 3 shows the dynamic pressure distribution along X-axis between two surfaces for both lubricants. It is found that both lubricants have a similar peak of distance approximately at 0.0365m but the value of the maximum pressure for both lubricants was different. The mineral oil represents the highest value of dynamic pressure at 0.5GPa compare to the bio based lubricants 0.12GPa. Consequently, mineral oil will be able to withstand the loading of the part in contact than the bio-based lubricants.

According to Barus (1893) and Roelands (1966) formula, viscosity is proportional to the pressure. In the other word, when the pressure increases, viscosity also can increase. Based on the figure above, the different pressure was observed for both lubricants were due to the variation of viscosity. In this study, viscosity for mineral oil is

1.1063×10-4 kg/ms (99.4cSt) while for bio-based lubricants is 8.3475×10-5 kg/ms (75cSt).The pressure spike formed at 0.0045m for mineral oil while the bio-based was at 0.0043m. It is prove that the pressure spike for mineral oil was higher than the bio-based lubricants.

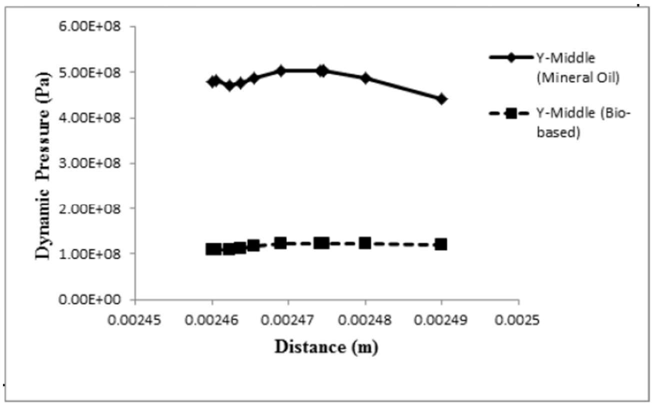

Fig.4 .Dynamic Pressure distribution for Y-axis

Fig.4 represents the dynamics pressure distribution along Y-axis for mineral oil and bio based lubricants. It is clearly observed the dynamic pressure for mineral oil was highest than bio-based where the maximum pressure for both lubricants is 0.5GPa, 84.7MPa respectively. This variation is due to the density for both lubricants where the density for mineral oil is higher than bio-based. In this study, the density for mineral oil is 925 kg/m3 while for bio-based is 870 kg/m3.

According to Hamrock et al. (1987), in elasto-hydrodynamic lubrication, when the rate of pressure increase is extremely high, typically 1013 Pa/s, the lubricant under these conditions will not have time to crystallize but will be compressed to an amorphous solid. Physically, this means that as the lubricant is compressed, the distance between the molecules of the lubricants becomes smaller and smaller.

These exists a points where the molecules are not free to move and any further compression will result in deformation of the molecules. The pressure where this first starts to occur is the solidification pressure, which varies considerably for the different lubricants. Besides that, based to Dowson and Higginson (1966) formula, the density is also proportional to the pressure.

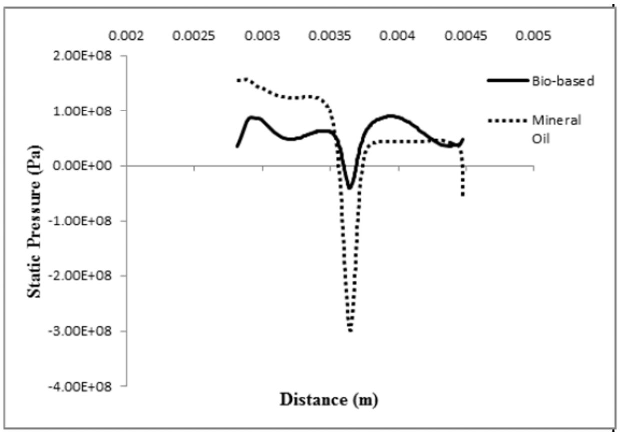

Fig.5. Static pressure between two surfaces

Based on the Fig.5 the static pressure between two surfaces can be determined for both lubricants. According to the graph, both lubricants have a similar spot of distance approximately at 0.03660m but the value of the maximum pressure for both lubricants was totally different. The bio-based lubricant shows the highest value at -40MPa while the static pressure for mineral oil was -0.3GPa.

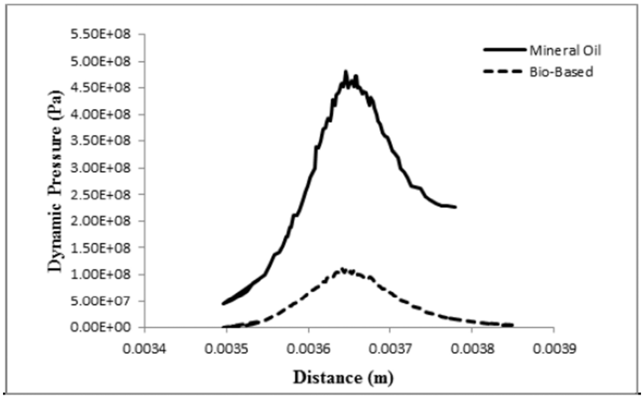

Fig.6. Dynamic pressure distribution for X-axis at the surfaces

Fig.6 shows the different of dynamic pressure distribution for X-axis at the surfaces for both lubricants. The maximum pressure for mineral oil and bio-based was 0.48GPa, 0.11GPa respectively. Even though mineral oil has a higher pressure than bio- based but in an area of surfaces between two contacts, it is show that the mineral oil is not a good lubricant due to its higher pressure would causes a serious wear and tear at the surfaces. Thus in this case, bio-based lubricant is suggested the best lubricants to protect the surfaces from wear and damage.

4. Conclusion

The following major conclusions can be drawn from the present study:

- At a constant speed, the mineral oil has the highest value of dynamics pressure than the bio-based lubricant along X and Y axis between two surfaces. Therefore, mineral oil will be able to carry more load than bio-based lubricant.
- The bio-based lubricant is promising to protect the surfaces from wear and damage in comparison with the mineral oil due to lower value of dynamics pressure.
- Mineral oil shows the highest value than the bio-based lubricant under static pressure condition.
- The peak pressure location moves closer to the inlet between the surfaces.

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