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The Study of Tribological Properties in Conjunction with a Radial Piston Motor and How its Knowledge can be Utilised to Improve Efficiency of the Motor and Thence the System

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ABSTRACT

The hydraulic motor is an area of exploration of paramount importance, but it does not depend on the viscosity of the hydraulic fluid alone. At low speeds and high torque conditions, hydraulic motors operate in the boundary regime and, thereby causing surface interactions of lubricant additives to have an effect on the friction and thus the system efficiency.

This is of importance because they can be used to delve into research and development of fluids that can improve motor efficiency whilst revealing the need for an effective additive package so as to ensure that the other properties of the fluid remain intact as it attempts to attain improved motor efficiency.

Thus this study investigates the study of tribological properties in conjunction with a radial piston motor and how its knowledge can be utilized to improve the efficiency of the motor and thence the system.

INTRODUCTION

Hydraulic motors serve the function of converting fluid power pump energy into rotary mechanical power [1]. The uses of hydraulic fluid power are diverse and it is hence used in a myriad of industrial applications such as, but not limited to, aviation, construction, mining, transportation, die casting, skid steers, cement mixture, paving machines, plastic injection molding, rock drills, etc. Such is the scope of hydraulic motors owing to its potential of providing high torque output; torque being the function of a hydraulic motor's displacement and the hydraulic system pressure (Figure 1).

Considering this massive scale of usage, one must also comprehend that the aforesaid industries earnestly strive for cost minimisation and mainly turn towards cutting down energy costs when it comes to the fulfilment of keeping costs low. Understandably, given the volume and extent of hydraulic pump-and thence motor-use, energy consumption is remarkably high. The US department of energy reported that fluid power and its applications accounted for around 2%-3% of the United States' energy consumption.

A significant amount of research is devoted towards the type of lubricating fluid that can be used to lubricate moving parts of hydraulic pumps and motors, how to improve effectiveness and longevity of said lubricating liquids, and design-related solutions such as minimising areas of contact between moving surfaces in contact in order to reduce friction and other design solutions such as ones which address motor leakage flow. Saving of energy is associated with power (the quotient of work done by time). It is also notable to state that the efficiency is strongly reduced at very low rotational speeds and at the starting moment [2].

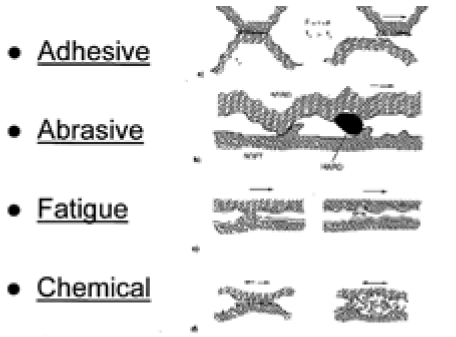

Figure 1. Types of wear.

Thus, keeping all that is established so far in mind, this article will focus on culminating various tribological aspects of a radial piston motor such as boundary film formation on the surfaces in contact (owing to the liquids utilized during operation), friction, and surface topography in hydraulic motors. For this exploration, the investigation will be carried out with a radial piston hydraulic motor.

Tribology revolves around adhesion, friction, wear and lubrication of solids in contact.

Wear is a process of material removal in which particles of different diameters and sizes are removed from the surfaces in contact i.e. interacting surfaces. Wear is a cause of limiting the life of a component owing to increased friction, loss of dimension or complete seizure of the motion [3]. Wear can be broadly classified into the following types: adhesive, fatigue, tribochemical and abrasive. These are visually distinguished in Figure 2.

Tribology in a Radial Piston Hydraulic Motor

The radial piston motor comprises a rotating cylinder block along with stationary housing that has a wavy formed cam ring attached [4]. The port plate is responsible for distributing the hydraulic oil to the cylinders and is calibrated according to timing that the cylinder will have high pressure on one side of the cam (working stroke) and low pressure on the other side (return stroke).

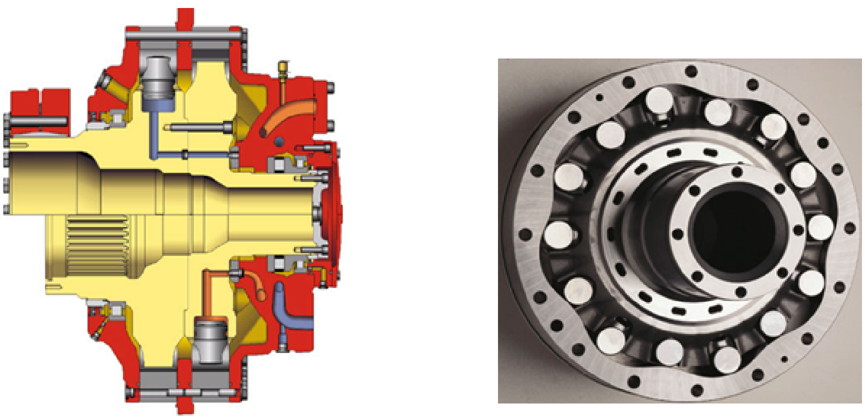

Figure 2. Radial piston motor (schematic (left) and real-life cross).

A tangential force that is transmitted through the cylinder block to the cam ring via the piston-cylinder, the piston-roller, and the roller-cam ring interface is exerted by the angle between the cam ring and the cylinder. When the hydraulic pressure increases, during heavy load operations, the aforementioned rolling and sliding surfaces will be heavily loaded which creates high demands for the toughness of the functional surfaces in play [5].

The cam ring's shape is specifically designed in such a way that the summation of the tangential forces from all the constituting pistons will give an even torque in any angular position of the shaft [6].

A circular groove which lies in the piston's interface to the roller-is connected to the pressurized oil in the cylinder and is responsible for providing hydrostatic lift [7].

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During low-speed operations and at initiation, there will be in the piston assembly-boundary lubrication of the sliding interfaces, which leads to relatively high frictional losses [8]. However, once the shaft begins to rotate at 'lift-off speeds', there will be hydrodynamic lubrication coming into play, thereby leading to very low frictional losses (Figure 3).

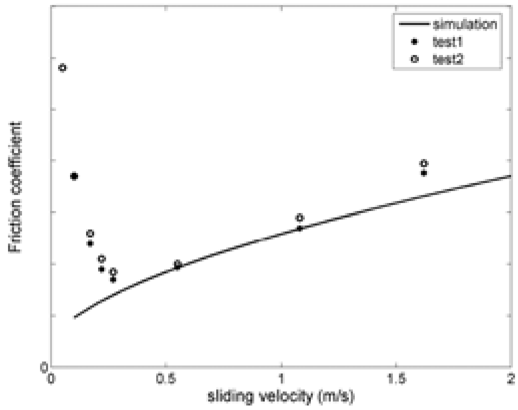

Figure 3. The friction coefficient in the roller piston interface, measured in the piston test rig.

The friction coefficient in the piston-roller interface as a function of speed is displayed in Figure 3, both calculated according to and measured in a piston test rig which allows us to isolate the roller -piston interface from two pistons. The maximum sliding speed in the test was half of maximum motor speed and the fluid viscosity was 40 cSt. The shape in this figure can be recognized as a Stribeck curve[1]. It can be observed that there is a significant difference in friction coefficients between the starting and at full film lubrication. It can also be noted that, especially for low fluid viscosity, the transition speed from mixed to full film lubrication-which is the sliding speed at minimum friction coefficient-is relatively high [9].

This implies that mixed lubrication can occur at high speeds if fluid viscosity is low. It can also be observed that the friction coefficient rises at high viscosities which are commensurate to the viscous losses in the lubricating film.

It is well known that seizure in hydraulic motors mostly occurs at high pressure and speed when, simultaneously, the hydraulic fluid viscosity is low. This picture shows a piston (and its slipper) that is used in a radial piston hydraulic motor (Figure 4). Earlier research in this area of the efficiency of hydraulic motors has focussed on frictional losses at low speeds and motor leakage flow. These models generally assume iso-viscous Newtonian fluid behaviour and have focused on controlling leakage path geometry through manufacturing or active surface control (Table 1).

Testing Fluids

The preliminary part of this study constitutes of exploring how fluids of different components and elements. For understanding what this article is attempting to unravel, the physical properties of films become a significant aspect but the composition of said films can also affect the properties in question. (Only select aspects of this table and the details of the fluids will be focused upon for the sake of relevance to this particular article.) The table below shows that Fluid A is a mineral oil infused with a sulphur phosphorous ashless anti-wear additive, which is the same for fluid B and fluid D.

A heightened level of phosphorous is noticed in fluid D owing to the addition of the friction modifier. The elevated levels of sulphur in fluid a and fluid D are because of the unreactive sulphur present in the base oil.

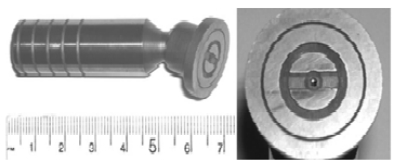

Figure 4. Piston and slipper assembly.

Table 1. Details about the hydraulic fluids utilized.

Fluid A	Fuid B	Fluid C	Fluid D	
Base oil Antiwear Additive	Group I Paraffinic Ashleess Sulfur-phosphorus	Group III paraffinic Ashless sulfur-phosphorus	Group III paraffinic Zinc dialkydithiophosphate	Group I paraffinic Ashless sulfur-phosphorus
Friction modifier	—	—	—	Alkyl phosphate
Kinematic Viscosity at 40°C (mm^2/s	46.5	43.9	43.9	46.5
Density, g/cm^3 at 15°C	0.878	0.847	0.847	0.878
P (ppm)	57	65	344	479
S (ppm)	4800	99	676	3900
Zn	2	7	433	8

METHODS

Mini Traction Machine: The Mini-Traction Machine (MTM) is a multi-purpose instrument for measuring friction and traction properties of lubricated and unlubricated surface contacts, under a wide range of rolling and sliding conditions. The MTM allows us to investigate friction and traction using a variety of materials, geometrical contacts, oil temperatures and contact pressures.

One of the main uses of the MTM is to measure friction between lubricated steel surfaces, under conditions typically found in internal combustion engines.

The MTM has great flexibility, so it can be used to investigate lubricated contacts in many other applications, such as transmission fluids, gear oils, bearings, and shock absorbers. 1.01.

A mini traction machine was utilised to produce stribeck curves (defined above) with an applied load of 50 N at 125 degrees centigrade.

Tribometer

A tribometer is an instrument that measures tribological quantities, such as coefficient of friction, friction force, and wear volume, between two surfaces in contact. A tribotester is the general name given to a machine or device used to perform tests and simulations of wear, friction, and lubrication which are the subject of the study of tribology.

With regard to this report, the tribometer enables the measurement of boundary lubrication regime friction coefficients. Specifically, a ball on a disc tribometer was utilised. This tribometer consists of a stationary pin and a rotating disc. The pin is loaded by a dead weight or actively controlled systems. The pin can have different shapes, flat, triangular, or spherical.

In this exploration, a steel ball was attached to a shaft and three polished plates were clamped to a self-aligning base. The rotation of the ball was set at 10 rpm along with a load of 12 N. The temperature of the fluid was at 100-degree centigrade. The measure of friction was made throughout the test and both ball and plate were retained for the measure of wear and tribofilm formation.

Microscopy

Images of the plates from the tribotesting were captured using a high-resolution microscope. A scanning electron microscope was utilised as well to obtain images of the scar. A ThermoElectron Nanotrace Detector was used to perform Energy-Dispersive X-Ray Spectroscopy (EDX); this allows us to carry out chemical analysis of tribofilm.

So far, the rheological effects of the fluids utilised are explored and tested. Another area of exploration, that is part of this article, is exploring the frictional aspects of the piston and its contact surface in the motor.

Embossing

Embossing refers to the creation of an impression of some kind of design, decoration, lettering or pattern on another surface like paper, cloth, metal, and even leather, to make a relief. In regular printing or an engraving, plates are pressed

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against the surface to leave an imprint. In embossing, however, the pressing raises the surfaces adding a new dimension to the object. A diamond tool was used to create the surface textures on the piston contact surface (Figure 5).

After embossing, mild polishing is carried out to remove any protruding ridges that may have been created along the ridges during embossing (Figure 6).

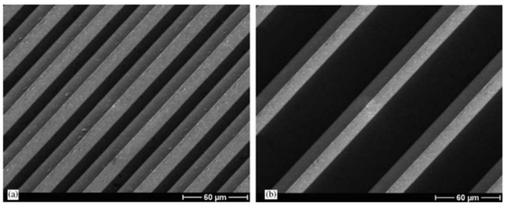

Figure 5. (a): Diamond embossing tool surfaces with ridge spacing of 30 micrometres; (b): 60 micrometres.

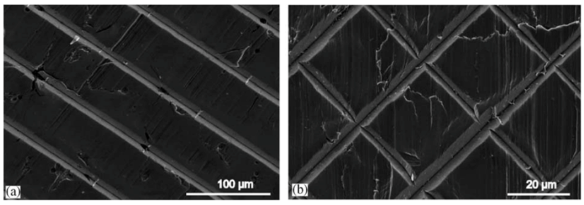

Figure 6. Textured piston sample before testing (a): parallel groove; (b): mesh pattern groove.

Tribotesting

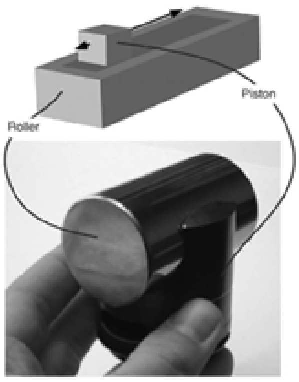

Figure 7. Roller piston assembly.

Tribotesting is testing friction using tribometers. The set up utilised is represented by the figure below. In order to make sure that the contact between the surfaces is flat and parallel, the holders were designed to self-adjust. For the test, standard mineral hydraulic oil was applied at 40 degrees centigrade (Figure 7).

Hydraulic Motor Efficiency

Torque is generated in a radial piston by running a shaft-mounted piston block by a cam ring in an epitrochoidal orbit. The measurements of the motor efficiency were carried out by utilising a dynamometer which comprises a pressure compensated radial piston pump [10]. The resistive load is provided by an electric load motor. In this test, the torque output of the hydraulic motor is measured for one revolution at 1 rpm at constant differential pressure (Figure 8).

It contains basic components such as direction control valve (screw controlled, solenoid return), an actuator line, relief valve, electric motor, etc (Figure 9).

- Test Motor Specifications:
- Radial Piston Motor
- Displacement (cc): 330
- Maximum Speed (rpm): 200
- Maximum Pressure (psi): 6525

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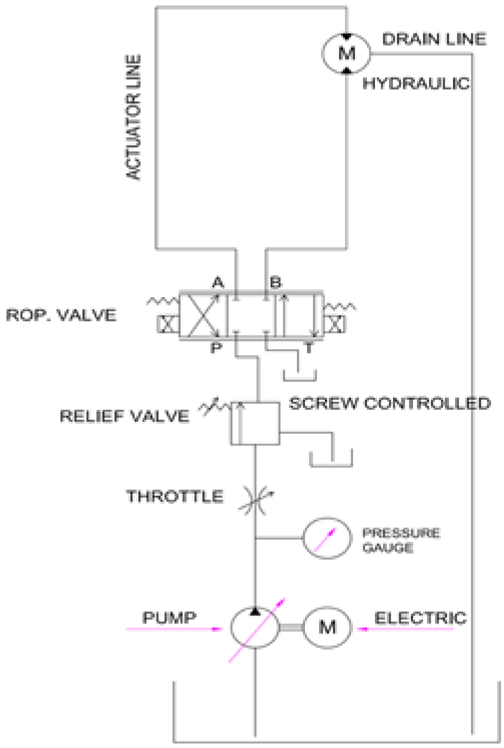

Figure 8. Simple hydraulic circuit.

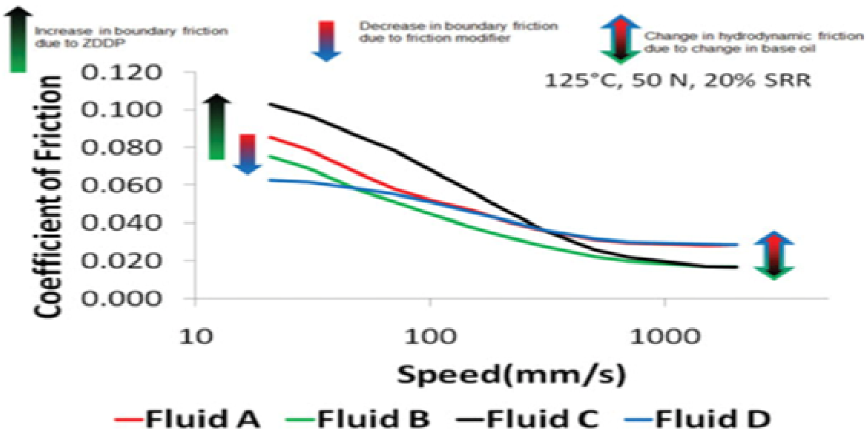

Figure 9. Stribeck curves of the fluids tested.

RESULTS AND DISCUSSION

In order to compare the fluids and the change in their coefficients of friction, Stribeck curves of the four fluids were plotted as shown in the graph that follows. It can be observed that fluid A and fluid D have higher friction than fluid b and fluid c. At lower speeds we can observe that A has lower friction than fluid d which can be attributed to due to the addition of friction modifier in fluid d. Moreover, at lower speeds, it can also be observed that the friction in c is higher than b and this can be attributed to the ZDDP in fluid c which forms a rougher film.

This diagram shows the efficiencies of radial piston motors with four different fluids. It is also evident, by analyzing the graph, that the friction modifier improved the mean mechanical efficiency by around 10%. We can also note that mechanical efficiency shows a general upward trend as pressure increases (Figure 10).

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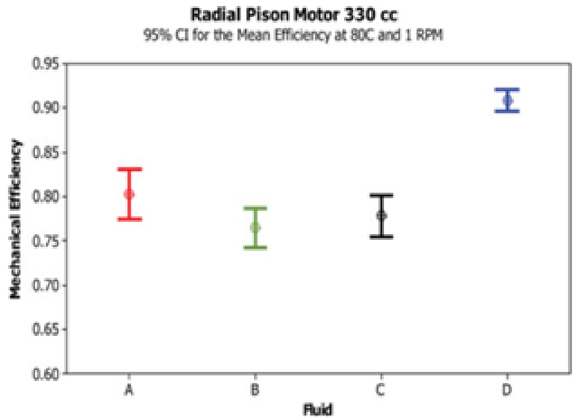

Figure 10. 1 rpm efficiency results for 330 cc radial piston motor at 80 degrees centigrade.

This graph displays friction fluctuation as a function of a number of strokes. (Logarithmic scale utilized for ease of data interpretation) The difference in the level of friction diminished after 1000 cycles (Figure 11). One must, however, consider the fact that 1000 cycles are minimal when we take into actual industrial operations into account. Although the difference between friction levels of the textures was less, the extent to which they minimized variations of friction was significant (Figure 11). The mesh pattern, especially, significantly reduced friction variation. Microscopical investigations reveal severe modifications of the surface owing to plastic deformation on the surface layer. This implies that one the reason friction variation is minimal is because of reduction in the contact area owing to wear.

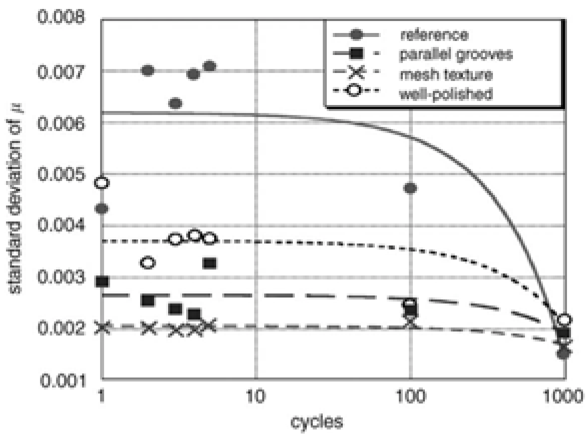

Figure 11. Friction fluctuation as a function of number of strokes.

FURTHER SCOPE/CONCLUSION

Research on the effect of improving the efficiency of hydraulic motors, such as this one allows governments and companies to operate at more optimal rates, monetarily and functionally. Further research, to positively and impactfully complement what has been presented here, should be the exploration of reducing friction by exploring tribological properties of different motors such as geroler motor, bent axis motor, axial piston motor, etc.

Furthermore, tribofilm formation on the aforesaid surfaces could be closely studied in order to create more versatile and efficient hydraulic fluids as cheaply as possible.

Such research promotes optimal use of energy: indeed a significant facet, relevant today more than ever before, keeping in mind the energy needs of the world of the 21st century and the depletion of fossil fuel along with, needless to mention, climate change.

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