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A study on the influence of surface topography on the low-speed tribological performance of port plates in axial piston pumps

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ABSTRACT

Axial piston pumps are widely used under severe conditions because they are able to operate highly efficiently at high pressure and various ranges of speed. However, pump efficiency is relatively low at low speed because of insufficient lubrication. The contact between the port plate and cylinder barrel is critically important because insufficient lubrication from this pair causes rapid wear and high friction loss which significantly reduces pump efficiency. Ring-on-disc testing was conducted to investigate the friction and wear behaviours of the port plate–cylinder barrel contact. Four types of surface finishing processes were used: coarse grinding, fine grinding, polishing, and laser texturing. A confocal laser scanning microscope and energy dispersive spectroscopy were used to examine the surface. Results indicate that the polished surfaces have the best tribological performance. Finely ground surfaces have lower wear but higher friction than coarsely ground surfaces. The number and size of the brass particles transferred to the steel surface are related to the surface topography. Laser textured surfaces have the highest friction and wear. Brass particles aggregate inside micro-dimples. Increasing contact pressure does not change the wear mechanism but increases abrasion.

1. Introduction

Hydraulic pumps are key components of fluid power systems. Although electric motor technology has developed rapidly, hydraulic pumps are still widely used in some industrial applications due to their high torque output (high power–mass density) and flexible arrangement. Axial piston pumps in particular are compact and are able to operate at high pressure and high overall efficiency [1,2]. Because axial piston pumps usually operate under severe conditions, the tribological parts are crucial. The interface between the port plate and cylinder barrel is important in an axial piston pump as most of the frictional loss is generated by these two elements [3].

Many studies have been carried out to assess the friction and wear mechanisms of the port plate/cylinder barrel interface. Most of them have focused on dynamics behaviours in order to improve the design of the port plate. They have used both experimental [4,5] and theoretical methods [6–8]. The dynamic characteristics of the port plate/cylinder are very complicated because they depend on many parameters, such as pressure, rotation speed, flow rate, and temperature. Some researchers have investigated the problem by focusing on some specific parameters by using typical tribology methods. Yang et al. [9] compared the wear behaviours of engineering plastics to that of Al_2O_3 ceramics using a block-on-ring machine with a focus on selecting materials for a water hydraulic pump.

Recently, low-speed efficiency due to insufficient lubrication has drawn considerable attention. The contact between the port plate and the cylinder barrel is crucial because the mechanical efficiency of the whole pump depends heavily on these two components particularly at low speeds. Michael et al. [10] investigated the problem by examining the hydraulic fluids. They concluded that formulating a fluid with low static and boundary friction coefficients and the smallest changes in viscosity at increased temperature and pressure could improve start-up efficiency. The research group in Korea Aerospace University reported their achievements by applying coatings in order to improve the low-speed efficiency of a piston pump. They applied duplex TiN [3], PVD TiN [11], CrSiN thin film [12], and Cr–X–N (X=Zr, Si) coating [13] to the surface of the cylinder barrel and measured the friction and wear using a ring-to-disc tribometer. Results showed that the coefficient of friction had been reduced and the low-speed efficiency increased considerably.

A review of precious works has indicated two methods of improving the contact between the port plate and the cylinder

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barrel: the first is to improve the properties of the hydraulic fluids and the other is to improve the materials. However, the influence of the surface topography has rarely been mentioned. From a tribological perspective, the influence of the surface topography is critical when a full film lubrication is not reached [14,15]. This is the situation for the lubrication between the port plate and the cylinder barrel at low speeds. Research on the surface topography has already succeeded in improving many industrial applications, such as bearings [16] and gears [17,18]. Particularly, sliding honing has been widely used in finishing the cylinder liner surface in an internal combustion engine, which is a variant of plateau honing and is characterised by reducing the plateau and valley roughness [19,20]. By using this technique, the productivity and consistency of liner surface finish can be improved, which reduces friction loss, oil consumption, and emissions. However, the surface topography of the hydraulic components has not yet been systematically investigated from a tribology perspective.

The motivation of the present work is to study the influence of the surface topography on the friction and wear behaviours of the port plate/cylinder barrel at low speeds. Several types of surface topography are achieved by coarse grinding, fine grinding, and coarse polishing. Laser texturing technology is also used to generate micro-dimples on the surface because surface texturing reportedly decreases the friction and wear in some cases [21–23]. In the current study, brass served as the port plate material and 38CrMoAl and 42CrMo as the cylinder barrel materials. The coefficient of friction and wear rate are measured using a ring-on-disc tribometer and further discussed from different perspectives.

2. Experimental details

2.1. Contact between the port plate and cylinder barrel

Fig. 1 illustrates a hydraulic axial piston pump consisting a driven shaft, a swash plate, a cylinder barrel, a port plate, a spring and several pistons. The main driven shaft rotates with the whole cylinder barrel. Because a swash plate limits the displacement of pistons, each piston moves back and forth inside the piston bore. The reciprocating movement of the piston periodically changes the volume of the piston bore suctioning and discharging oil through a port plate which is fixed to the pump body. The friction torque, T_f, between the port plate and cylinder barrel takes a large part of the friction loss in a pump which can be determined as follows:

$$T_f = \mu \cdot r \cdot (F_p + F_x - F_s) \tag{1}$$

$$F_p = \sum_{i=1}^{n} A \cdot p_i \tag{2}$$

$$F_s = p_s \cdot A_p \tag{3}$$

Here, μ is the coefficient of friction between the port plate and cylinder barrel; r is the moment arm of the force with regard to the shaft; F_p is the pressing force, which is determined by the pressure of the cylinder chamber, $_{pi}$; A is the area of each piston hole; N is the number of pistons; F_x is the spring force which can be measured through the displacement of the spring; F_s is the separating force, which is determined by the oil film pressure, p_s, between the port plate and cylinder barrel, and A_p, the effective area of the port plate, which depends on the port plate geometry. $_{pi}$ varies periodically depending on the rotation angle of the cylinder barrel θ_s, port plate geometry, rotation speed and the discharge pressure [11]. Of all these parameters, μ is the one that can only be obtained experimentally; that has also been reported in previous works [3,11–13].

It can be found out that the cylinder barrel and port plate contact is a sliding contact. The pressure distribution on a port plate varies depending on the port plate geometry and working pressure. Wang [24] numerically calculated the pressure distribution of a port plate with oil outlet pressure at 25 MPa. He found that the pressure ranged from 2 MPa to 25 MPa on the suction part of the port plate. The face of cylinder barrels and port plates are usually made of a soft material and a hard material in order to have most of the wear on the soft material. Copper (usually brass, red copper or bronze) is used as the soft material while steel (usually 38CrMoAl, 42CrMo or ductile iron) is used as the hard material.

2.2. Test equipment

The coefficient of friction between the port plate and the cylinder barrel was measured using an end-face friction tester MMU-10 which was also known as a ring-on-disc tribometer [25]. The upper specimen (cylinder barrel) was mounted on the main shaft which was driven by a servo motor. The lower specimen (port plate) was held stationary. The rotating speed range of the main shaft is 0–3000 rpm. The force was applied to the lower specimen by a load cell through a hydraulic cylinder which raises the normal force to contact surfaces between the port plate and the cylinder barrel. The maximum applied load was 10 kN. The upper specimen and the lower specimen were sealed in an oil box in which oil flowed in and out. The oil box was connected to an oil tank by pipes and a filter. The flow rate of the oil from the oil tank was controlled by a pump. In this way, the rig creates a sliding contact which can measure the coefficient of friction and wear rate between the port plate and cylinder barrel.

A schematic plot of the tribometer is shown in Fig. 2. The friction torque was measured by a torque wheel and the temperature of the lubricant was measured by a temperature sensor. The friction coefficient μ was calculated using the readings from the torque wheel T, the radius of the torque wheel r and the load cell F_N, as given by Eq. (4). A computer was used to acquire data

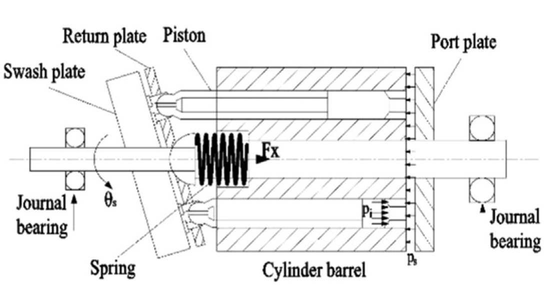

Fig. 1. A schematic of an axial piston pump.

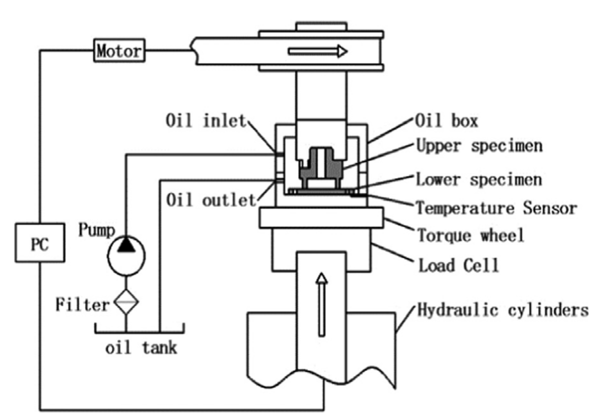

Fig. 2. Schematic of the end-face friction tester.