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STUDY OF LUBRICATION CONDITIONS IN SLIPPER-SWASHPLATE CONTACT IN WATER HYDRAULIC AXIAL PISTON PUMP TEST RIG

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ABSTRACT

In water hydraulic systems, requirements for better energy efficiency call for the development of variable displacement axial piston pumps. Most axial piston units utilizing water as pressure medium lack the possibility of adjusting the swash plate tilt angle because of difficulties in constructing robust water compatible swash plate pivot bearings. Without smooth enough adjustment motion, the lubrication conditions between the swash plate and the piston slipper pads become disturbed and loss of fluid film may lead to early pump failure.

This study reports on measurements made with a test rig built for investigating tribological phenomena in variable displacement axial piston pumps. In the tests, the effects of changing the swash plate tilt angle were measured in a test setup with constant high pressure which loaded the piston. Lubricating film thickness and lateral force acting on the piston were measured together with changes in these quantities in response to changes in swash plate tilt angle.

KEY WORDS

Water hydraulics, Axial piston pump, Slipper-Swashplate contact

NOMENCLATURE

F_{piston} : total force acting in piston axis direction [N]
F_{sp} : force perpendicular to swashplate [N]
β : swashplate angle [deg]

INTRODUCTION

Modern water hydraulics should provide reliable fluid power components that operate with pure water and thus represent an environmentally friendly alternative to the oil hydraulics. Compared to mineral oil, water has lower viscosity and lower viscosity-pressure coefficient which makes good lubrication more difficult to achieve. The kinematic viscosity of oil is approximately 30 times that of water at representative operating temperatures. Consequently, clearances for sealing surfaces must be much smaller than for oil hydraulics to obtain sufficient volumetric efficiency. However, smaller clearances increase risk for direct contact between sliding surfaces, higher friction and wear or component failure. [1]

In [2] water hydraulic pumps on the market are explored. Of the several different water hydraulic pumps that are on the market at the moment, most of them are oil lubricated piston pumps and only a few of the pumps are totally water lubricated. Water lubricated pumps are usually axial piston pumps with fixed swashplate angle.

To increase the overall efficiency of the system, variable displacement axial piston units are widely used basic components in oil hydraulics nowadays. Axial piston type units are very competitive also in modern water hydraulic pumps and motors. In mobile machines most of the units are axial piston design at the moment. However, there are not commercial variable axial piston pumps or motors for water hydraulics which is a significant problem in certain applications. [3]

Lubrication conditions between the swashplate and the slipper pad have been studied in many researches. Most of the researches were made using oil as pressure medium. Research has also been made with water based fluids. Li, Donders and Kazama have studied lubricating conditions using water or HFA-fluid in axial piston pumps [4,5,6]. All of these articles discuss pumps with constant swashplate angle.

The main objective of this study was to measure the water film thickness between the swashplate and the slipper pad and to record the basic effects caused by the adjustment of the swashplate angle.

TEST CONDITIONS

The structure of the test rig in this study allows changing the angle of the swashplate during measurements. The test rig that was used in measurements is shown in Figure 1. More information about the test rig is presented in [2].

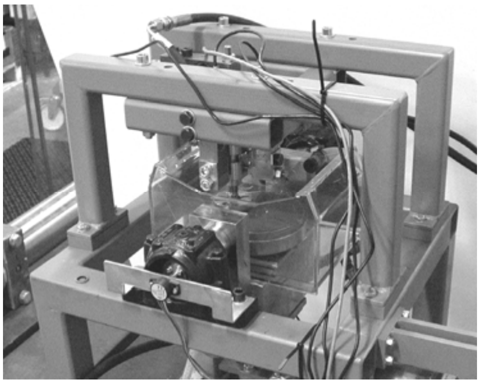

Figure 1 Test rig

The slipper pad is made of PEEK and the inner diameter of the sealing land is 9.90 mm and the outer diameter is 18.35 mm. The theoretical hydrostatic balance of the slipper is 0.729. Measured leakage for one piston-slipper pair is approximately 0.2 L/min with 10 MPa pressure difference. Surface roughness of the swashplate is R_a=0.22-0.24 µm.

Gap heights are measured outside of the slipper pad which makes changes of the water film more clear to see because of the geometric conditions. Measurements are made with three eddy current sensors with 1 mm measuring ranges (S1, S2, S3). Resolution of the sensors is 0.05 µm and static repeatability 0.1 µm. Dimensions of the test conditions are shown in Figure 2. Figure 2 also shows the locations of the sensors and the corresponding angular coordinates. The angular coordinate is used in reporting the results.

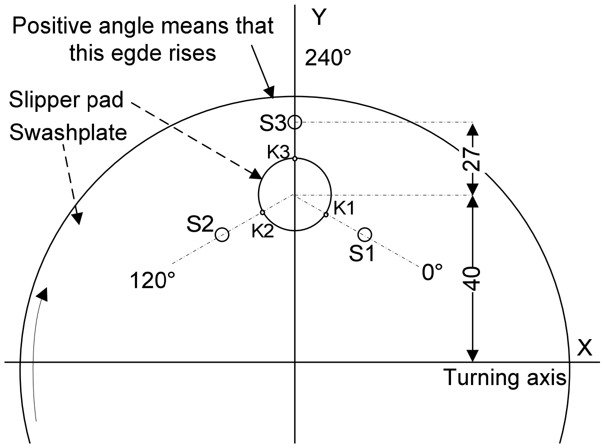

Figure 2 Dimensions of the test system and the slipper pad

Measured values are converted to the clearances between slipper pad and swashplate at points K1, K2, K3. With these points minimum gap height and location of the minimum gap can be calculated. Maximum gap located 180 degree clock wise from the minimum point.

EXPERIMENTAL RESULTS

The following figures show the computed gap between slipper pad and swashplate at the three clearance points (K1, K2, K3), at the center of the slipper (Av) and also the minimum value (Min). Figure 3 shows the reference measurements with 0 degree swashplate angle. The angular locations of the minimum and maximum values of the clearance during measurements are also plotted.

Measured gap heights can be compared to values computed assuming parallel gap flow [2]. With the present slipper dimensions and 10 MPa pressure difference, a leakage flow of 0.2 L/min corresponds to an average gap height of 7 µm.

$$F_{sp} = \frac{F_{piston}}{\cos(\beta)} \quad (1)$$

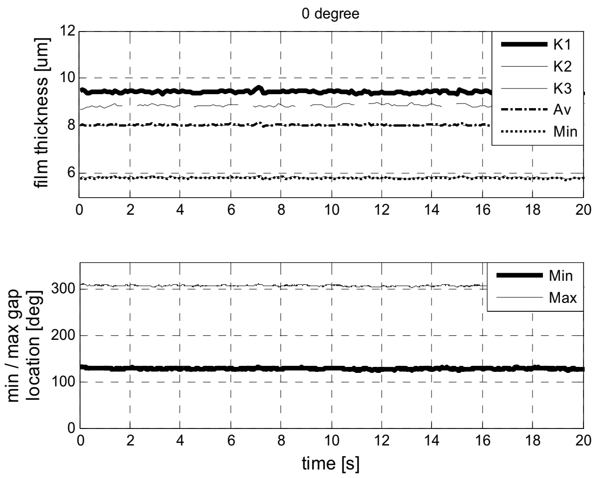

Figure 3 Gap heights of the slipper pad points with 1000 rpm, 0 degree swashplate angle and 10 MPa pressure difference

According to references [5] and [7] gap height is highest at inner edge and smallest at outer edge. Slipper is tilted backwards which means that gap height on the leading edge is higher than on the trailing edge. Measurements in this case show different kind of orientation as the Figure 3 shows. There could be some deformation at slipper pad or zero position is not exactly same as measured in 5 N load on dry circumstances. Minimum clearance is located about 129 degrees and maximum clearance located at 309 degrees (see Figure 2).

Orientation of the slipper pad is measured with four different constant swashplate angles: 0, 5, 10 and 15 degrees. Figure 4 shows the orientation of the slipper pad with 5, 10 and 15 degrees swashplate angle. Both measurements conditions are made in the following order: first adjustment of swashplate angle, then application of load pressure and finally setting the rotation speed.

Comparison between Figure 3 and curves at Figure 4 shows that there is not big difference at gap heights between different swashplate angles. Gap height changes are within 2 μm and at average gap height changes only under 1 μm. Also locations of the minimum and maximum points are almost same; difference is only a few degrees. That is obvious because contact between swashplate and slipper pad can carry only perpendicular load. Change at this perpendicular force is quite small. For example in our construction with 10 MPa, force change between 0 and 10 degrees angle is only 1.5 % (2084N → 2116 N) according to Eq. (1).

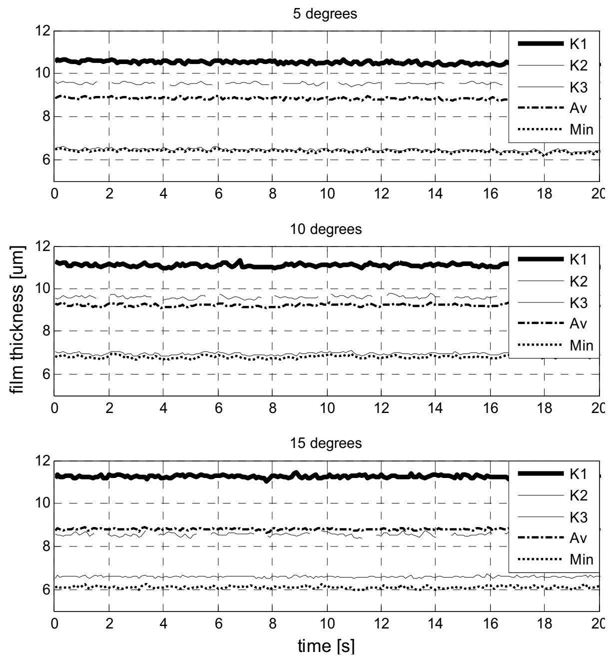

Figure 4 Gap heights of the slipper pad points with 1000 rpm, 5, 10 and 15 degrees swashplate angle and 10 MPa pressure difference

Situation is not exactly the same if 10 degrees is achieved during operation as Figure 5 and Figure 6 shows. Changes in gap heights are very smooth during turning process. Both for 0.2 MPa 10 MPa pressure orientation of the slipper pad is not exactly same before and after steps. Structure of the spherical joint is important for sliding conditions. Because of frictions of the spherical joint orientation of the slipper pad depends on turning direction and speed of the swashplate. In actual pumps the phenomenon is not significant because of low pressure area. It could be assumed that during the suction stroke orientation of the slipper pad is returned to the normal sliding position.

Figure 5 and Figure 6 shows the gap heights during swashplate turning with 0.2 MPa and with 10Mpa. Those figures also show that during step 0° to 10° average gap height reduces. During step to 10° to 0° gap height rises but overall changes are quite small. Friction force to X-direction is measured during swashplate change. Change of the friction force is about 30 N at 10 MPa pressure difference. Impact is of the same order as when pressure changes from 0.2 MPa to 10 MPa, which is about 40 N. Minimum and maximum gap height positions are almost same with both pressure levels, but location changes few degrees depending of swashplate angle.

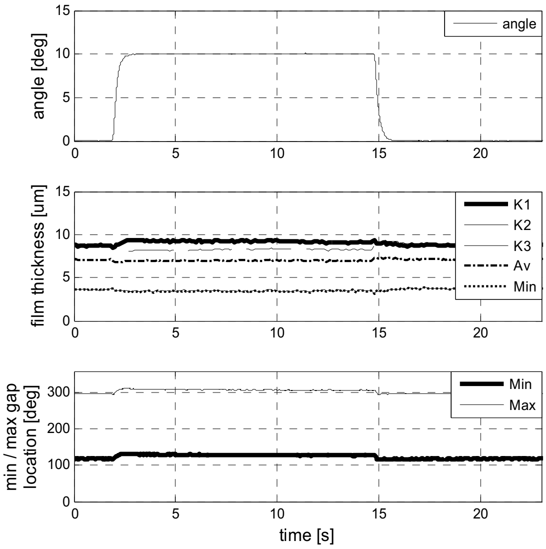

Figure 5 Gap heights during swashplate turning with 0.2 MPa load pressure. 1000 rpm

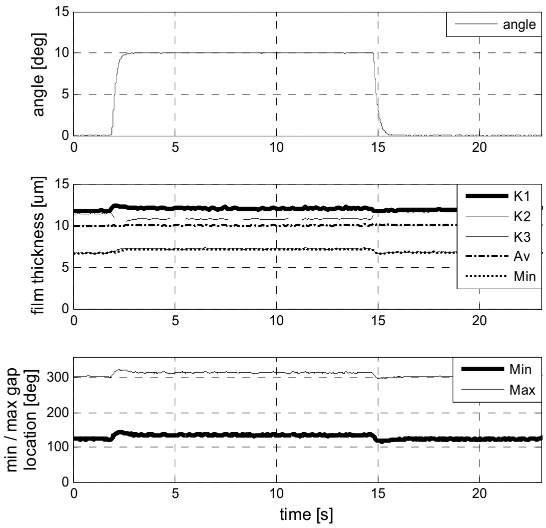

Figure 6 Gap heights during swashplate turning with 10 MPa load pressure. 1000 rpm

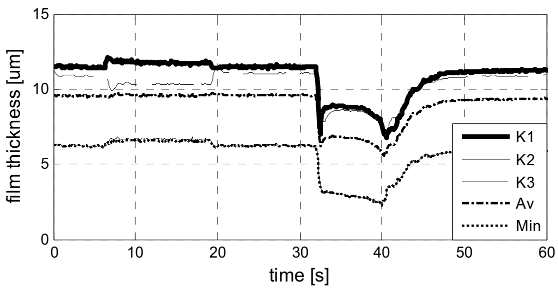

Figure 7 Gap heights during swashplate turning and pressure changes. 1000 rpm

Figure 7 shows changes during swashplate changes (from 10 degrees to 0 degree and back to 10 degrees) and after that during pressure changes from 10 MPa to 0.5 MPa and back to the 10 MPa. It could be seen that effect of pressure level is more significant than effect of the swashplate turning or effect of the swashplate angle.

CONCLUSION

In this paper experimental results on water film thickness measurements in an axial piston unit test rig were reported. It was shown how the swashplate angle affects the gap heights between swashplate and slipper pad. Constant angles in the range from 0 to 15 degrees have no big influence to the gap height or orientation of the slipper. Also effect of the 10 degrees step response of the swashplate angle is not significant for lubrication conditions. Pressure level of the pump is more important factor than swashplate angle.

Turning speed and turning direction of the swashplate under load pressure have an influence to the orientation of the slipper pad and more research in different conditions is needed to find that out. Also pressure cycle is interesting to research in future.

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