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SOFT EHL ANALYSIS OF A RECIPROCATING HYDRAULIC STEP SEAL

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ABSTRACT

A numerical soft EHL (elastohydrodynamic lubrication) model of a reciprocating hydraulic step seal has been used to analyze seal performance. The model consists of coupled steady state fluid mechanics, deformation mechanics, contact mechanics and thermal analyses, with an iterative computational procedure. Results for a typical step seal are compared with those of a double lip U-cup seal.

INTRODUCTION

The reciprocating rod seal plays a critical role in the operation of hydraulic actuators since it is relied on to prevent leakage of hydraulic fluid into the environment. There are many different types of rod seals, with the U-cup and the step seal being the most common.

Recent numerical analyses of U-cup seals, using a soft EHL model, has revealed that such seals operate with mixed lubrication in the sealing zone (interface between the rod and the seal) and seal roughness plays an important role [1,2] in determining seal behavior. A similar model is used in the present study to investigate the behavior of a step seal and compare its performance to that of a U-cup seal.

ANALYSIS

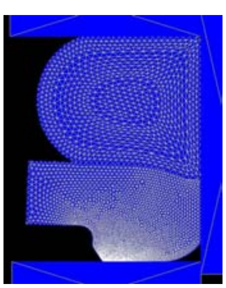

Fig. 1 Mounted and pressurized step seal

A typical step seal, mounted and pressurized, is shown in Fig. 1. The lower sealing element, adjacent to the rod, is PTFE (polytetrafluoroethylene), while the upper O-ring actuator is nitrile. The EHL model of this seal is similar to the model of a U-cup seal that is described in detail in [1]. The latter is comprised of coupled steady state fluid mechanics, deformation mechanics and contact mechanics analyses, with an iterative computational procedure. In the present study, a thermal analysis has also been included. It involves an analytical solution to the classical thermal conduction equation for a moving heat source, treating the rod as a semi-infinite body and neglecting the heat transferred into the seal. Heat generation through both viscous friction and contact friction is accounted for. The computed interface temperature is used to evaluate the fluid viscosity in the sealing zone.

RESULTS

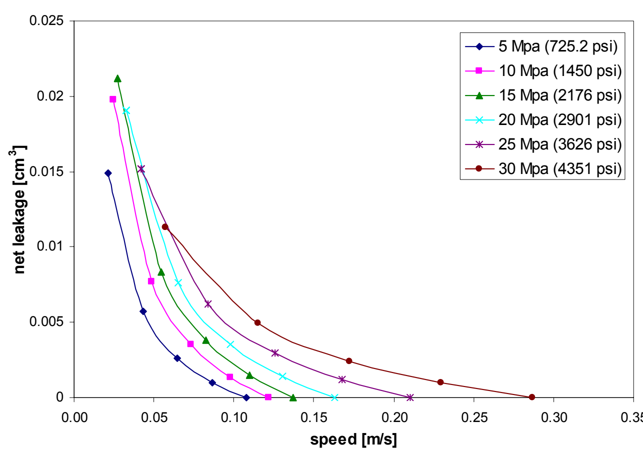

Fig. 2 Leakage per cycle vs. rod speed, various pressures, step seal

Figure 2 shows a plot of the computed net leakage per cycle vs. rod speed, for a fixed stroke length and for various sealed pressures during the instroke. As rod speed increases, the leakage decreases until a critical speed is reached, above which the net leakage is zero. At a given rod speed, the higher the sealed pressure, the higher the leakage.

A similar plot for various seal roughnesses is shown in Fig. 3. At a given rod speed, the higher the seal roughness, the higher the leakage.

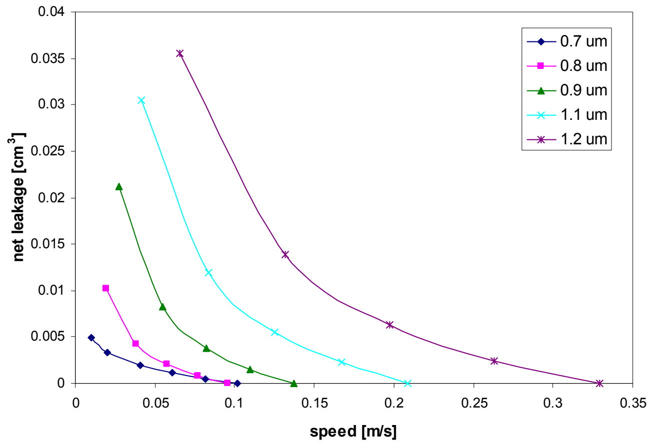

Fig. 3 Leakage vs. rod speed, various seal roughnesses, step seal

Figure 4 shows a plot of the critical rod speed vs. seal roughness for various sealed pressures. As expected from Figs. 2 and 3, the critical rod speed increases with roughness and sealed pressure.

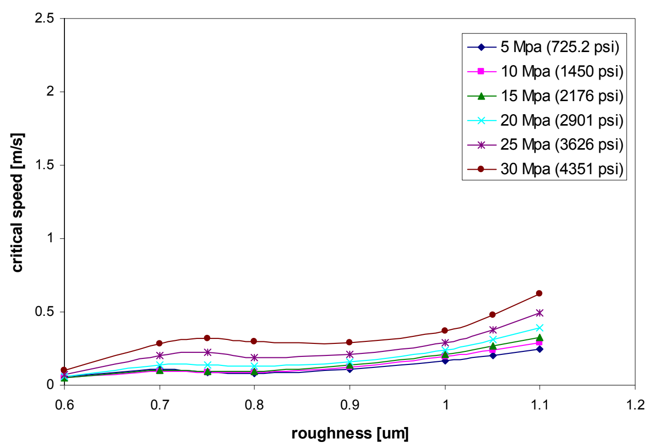

Fig. 4 Critical speed vs. roughness, step seal

The leakage vs. rod speed curves for a corresponding U-cup seal with a double lip are qualitatively similar to Figs. 2 and 3. The corresponding critical speed vs. roughness curve is shown in Fig. 5. Except at the lowest values of roughness, the critical speeds for the U-cup seal are significantly higher than those for the step seal at the same values of sealed pressure. Furthermore, for the U-cup seal results are shown for pressures only up to 13.8 MPa, above which the seal leaks regardless of rod speed. For the step seal, critical speeds are found for sealed pressures well beyond 13.8 MPa. Thus, the step seal exhibits superior sealing performance compared to the U-cup seal.

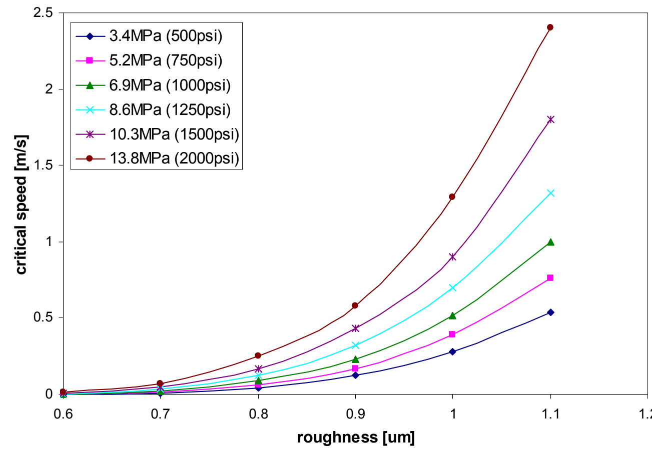

Fig. 5 Critical speed vs. roughness, U-cup seal

To understand why the step seal exhibits superior performance, the operation of the two seals at the same sealed pressure, 6.9 MPa, the same seal roughness, 0.7 microns, and the same rod speed, 0.46 m/s are compared. This operating point corresponds to zero leakage for both seals.

Figure 6 shows the nondimensionalized film thickness distribution, for the step seal. The film is thicker during the instroke than during the outstroke. This is a favorable characteristic because a thicker film allows more fluid to be drawn into the cylinder during the instroke, thereby reducing the possibility of leakage [1].

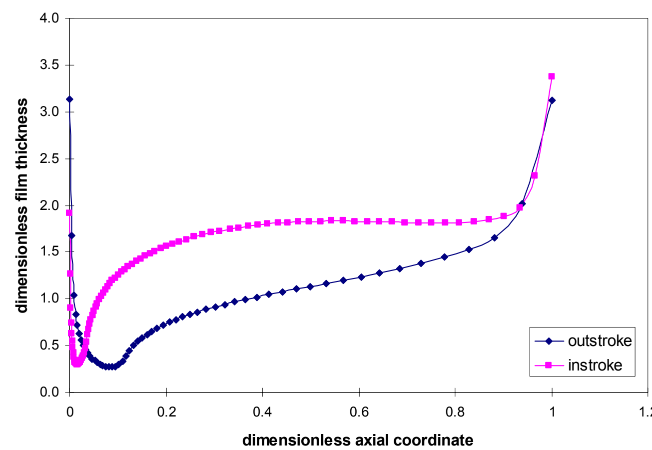

Fig. 6 Film thickness distributions, step seal

The corresponding film thickness distribution for the U-cup seal is shown in Fig. 7. For this seal, on the average the film thickness is smaller during the instroke than during the outstroke. This is an unfavorable characteristic.

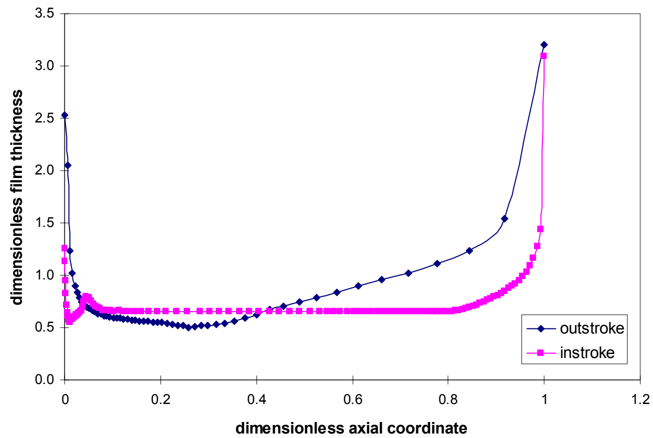

Fig. 7 Film thickness distributions, U-cup seal

Figures 8 and 9 shows the pressure distributions in the sealing zone for the two seals during the outstroke. From the fluid pressure curves it is seen that the flow is cavitated over almost the entire sealing zone for the step seal, and over a smaller portion of the sealing zone for the U-cup seal. Since cavitation is a favorable characteristic during the outstroke [1], the step seal is superior in this regard.

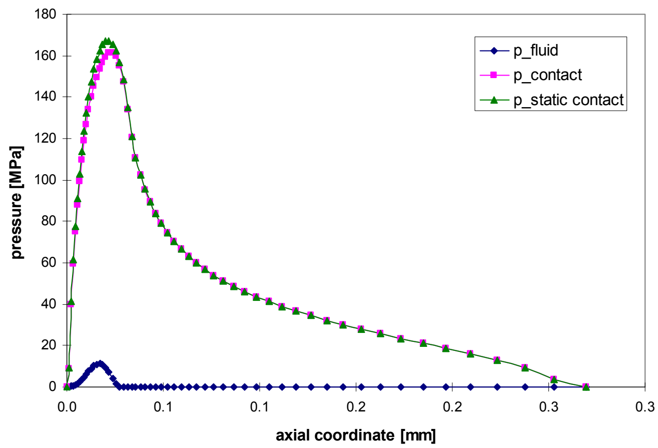

Fig. 8 Pressure distributions, outstroke, step seal

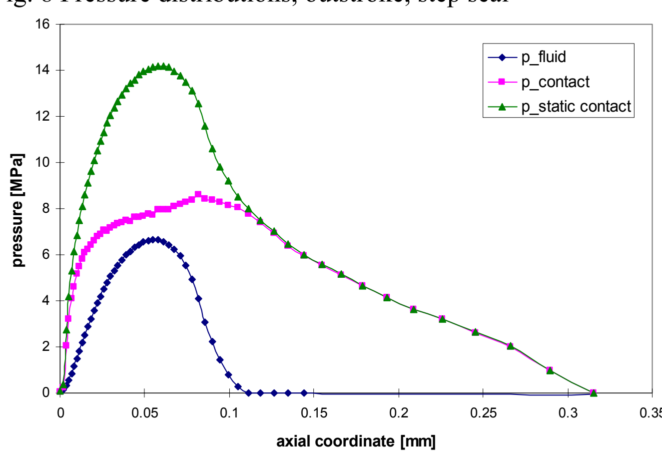

Fig. 9 Pressure distributions, outstroke, U-cup seal

Figures 10 and 11 show the pressure distributions for both seals during the instroke. No cavitation occurs for the step seal while some does occur for the U-cup seal. Since cavitation during the instroke is unfavorable [1], the step seal is again superior in this regard.

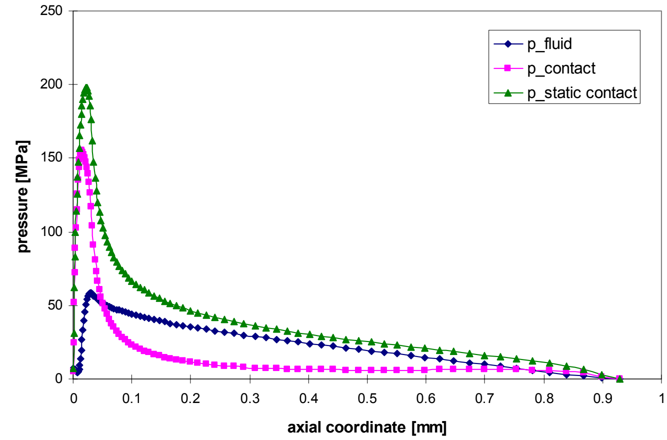

Fig. 10 Pressure distributions, instroke, step seal

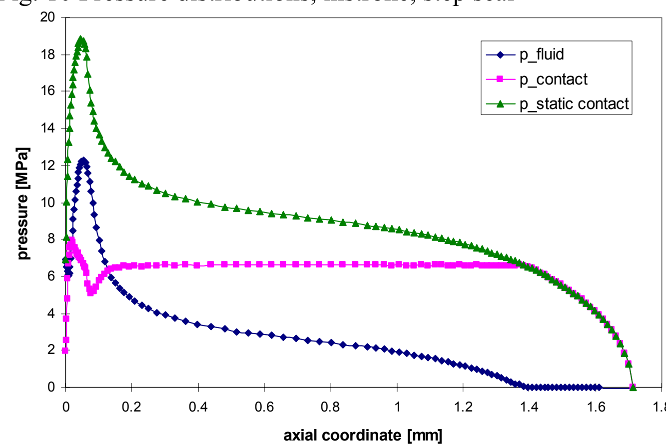

Fig. 11 Pressure distributions, instroke, U-cup seal

CONCLUSIONS

The results of this soft EHL analysis shows that the step seal exhibits superior sealing characteristics compared to an equivalent U-cup seal.

ACKNOWLEDGMENTS

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REFERENCES

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