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THE EFFECT OF THE RADIAL LIP SEAL GEOMETRY ON SEALING PERFORMANCE

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ABSTRACT
Radial lip seals are standard machine elements, which are often needed in industry, especially in machine design. It is known that sealing performance of the sealing elements are influenced by many factors. Some of these are; surface roughness, pressure, temperature and viscosity of fluid to be sealed. In this study, it was investigated how the geometry parameter would affect the sealing performance with examining characteristic of frictional torque at contact area. For the experiments 5 different seal models which include different lip geometry, were manufactured by SKF. Two parts of experiments were done and 18 specimens were used for these experiments. As a result, it was determined which geometrical parameters of lip geometry had a positive effect on the sealing performance and which had a negative effect. Because of this work, new seal models will emerge with optimization studies.
Keywords: Lip Seal, Lip geometry, sealing performance, PU (Polyurethane),

1. INTRODUCTION
In industry, there are many types of elastomers used for sealing materials. For instance, polyurethane (PU), fluoroelastomers (FKM), nitrile rubber (NBR) are the popular materials for sealing. Polyurethane (PU) was chosen as sealing material due to working temperature, high strength and high strain [1]. It is known that, sealing performance of seals are affected by many factors; they are surface roughness, temperature, viscosity of fluid to be sealed, pressure and geometry. Previous studies show that, the effect of geometric parameters of seals are found with numerical analysis [2].
Also the new radial seal design approaches by Kuiken J. [3] were quite useful. In this study, the effects on geometric changes in sealing performance of a shock absorbing lip were studied, then it was found that changing lip geometry affect contact pressure. In numerical analysis study, it has seen that, pre-loading and interference cause stress concentration on contact zone and then deformation occurs at this region. This causes considerable frictional torque on the contact zone [2]. In this study, for five different lip geometry was investigated to achieve most appropriate lip geometry under different operating conditions.

2. EXPERIMENTAL PROCEDURE
The test setup consists of 4 load cells and a cylindrical housing in which oil and seal are placed as shown in Figure 1. The shaft is connected to a motor by a belt pulley mechanism and the system is driven by a motor with a speed of 1500 rev/min. The seal is mounted to cylinder as an interference fit. The frictional force generated by the friction of the lip and the shaft mounted on the housing and the force is measured by 4 load cells and afterwards the friction torque is calculated.

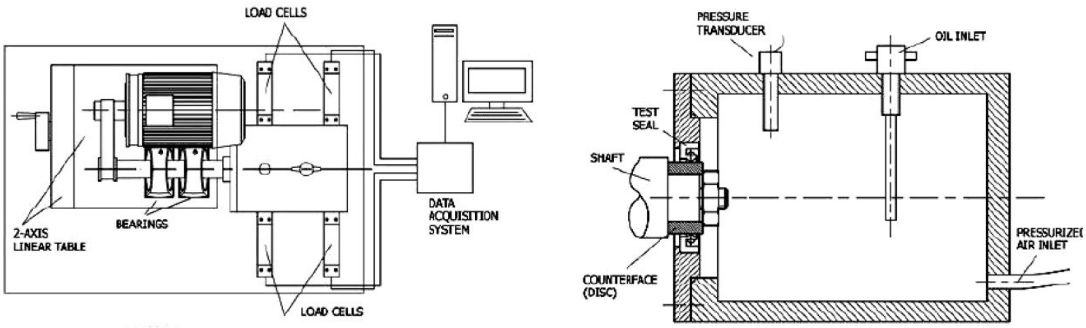

Figure 1. Schematic view of experimental setup

To adjust the experimental setup, the outer surfaces of the seal are lightly greased before radial lip seals are mounted on the seal housing. Since the greased seal are completely elastomeric, they are easily seated by hand and then mounted with a knob to complete the installation of the seal. Then the cylinder cover is connected to cylinder with 6 bolts. The shaft is then axially aligned with the inner diameter of the cylinder by means of an adjustable x-y table so that the shaft can be mounted to the cylinder. Before mounting the shaft and seal, the outer surface of the shaft and the seal are slightly lubricated. After the shaft is placed into the cylinder with the aid of the adjustable table, 1/4 of the shaft inside the cylinder is filled with oil so that it remains in the oil. The motor is mounted on a fixed plate with 4 bolts and the belt pulley is connected. After the pressure setting is made, the speed regulator is set to the desired speed and the experimental set-up was started. The friction forces on the seal during the test are measured by 4 load cells and the data collecting from the load cells to the data acquisition system. Data is transferred to the computer by the software program. Calibration of the data taken with the program should be done before starting the system. For this reason, measurements were taken with known moment values by using mechanism placed on the shaft and the calibration curve was introduced to the program by using the potential difference values read from the strain gauges and the applied torque values. Since the system showed excessive noise warnings, the insulation of the cables from the strain gauges and cable of the data collector was carefully re-insulated and noise-reduced and ready for testing. Since the noise cannot be completely recovered, the obtained data are reduced to actual measurement values by filtering. Frictional torque values were then obtained from the recorded friction force data.

3. EXPERIMENTAL RESULTS

In the experiment, 5 different model were manufactured and they compared with reference model (Table 1). For reference model, eccentricity is 0.3 mm and lip thickness is 1.3 mm.

Table 1. Models and parameters are designed for analysis

Model	Parameters	
	Eccentricity (e)	Lip thickness (d)
Ref. Model	0,3 mm	1,3 mm
Model 1	0,15 mm	1,3 mm
Model 2	0,6 mm	1,3 mm
Model 3	0,3 mm	1,6 mm
Model 4	0,3 mm	1,9 mm
Model 5	0,15 mm	1,6 mm

All model have same basic dimensions, they have 40 mm inner diameter and 62 mm outer diameter. In addition to that, experiments were carried out with two phases and 18 specimens were used. In the first phase, under constant speed and inner pressure, effect of geometrical parameters was examined and in second phase, under different speed and inner pressure, effect of operating conditions were examined. The experiment was carried out at 1 m/s speed and 0 bar inner pressure for a short period.

For the second phase of the experiment, to examine the effect of speed, pressure and lip geometry, frictional torque was measured for each condition and for each model but the other conditions remained constant. For the second phase, test conditions were determined as follows;

- The speed are chosen as 1, 3, and 5 m/s.
- The seals are tested under 0, 0.3, and 0.5 bar for a short period.

In first phase, all models were examined and frictional torque value of the contact area was calculated. As it seen at the Table 2, only decreasing eccentricity (model 1) decreases frictional torque at the contact area and the other models had negative effect on sealing performance.

Table 2. Experimental results for all models

Model No	*Ts (Nm)*
Ref. Model	*0,035*
Model 1	*0,0175*
Model 2	*0,063*
Model 3	*0,0532*
Model 4	*0,0434*
Model 5	*0,042*

In second phase, as seen in the Fig 2. and Fig 3., it has been observed that the increase in speed and pressure increases the friction torque as expected. When the results of the experiments are evaluated, it can be said that the increasing speed also increases the friction torque (Fig. 3) It has been observed that the increase of the pressure generally increases the friction torque in very small amounts (Fig. 4). For all models, it was observed that the lowest friction torque was obtained at the lowest speed and the model 1 where the eccentricity is reduced, has lowest friction moment in all models, It has been observed that in the studies carried out, especially in the experiments where the speed is increased, the temperature in the contact area increases considerably. It can be said that this increase has an effect on the results since it can change the characteristic of the material. For this reason, a mathematical model can be found in order to find the most appropriate value for the effect of eccentricity and lip thickness after studying the effect of temperature on results in future studies.

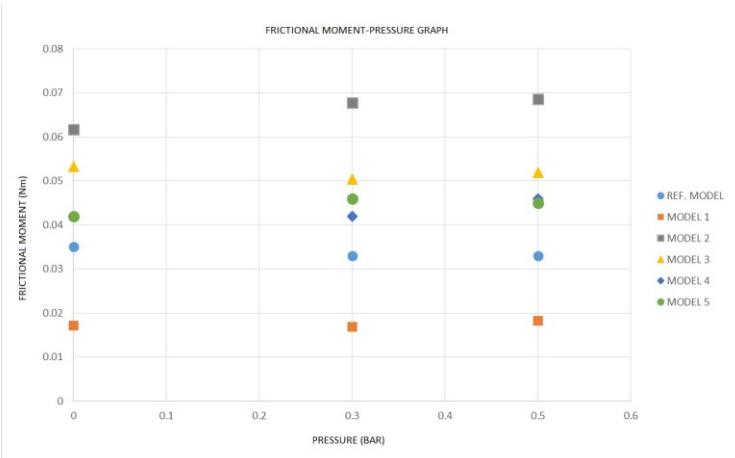

Figure 3. At constant speed, frictional torque and pressure relation of radial lip seal whose geometrical parameters are changed

When the results compare with the similar studies, literature support this study, H.OZPERK's study [4] showed that, when the increasing speed increases frictional torque firstly, but after that decreases due to rising temperature effect also increasing pressure causes frictional torque to increase. Also, when the D.BULUT's study [5] that she worked with polyurethane, similar results are found. In D.BULUT's study, author investigated effects of the radial force on frictional characteristics of polyurethane rotary shaft seals and she found that, for 40 mm inner diameter seal has 0,034 Nm frictional torque at 1 m/s and at 0,5 bar, but in this study at same conditions frictional torque was found 0,035 Nm. In addition to that, effect of speed and pressure similar with this study. These previous studies focused on effect of radial force, pressure and speed on frictional torque. Kuiken J.'s study [3] was about designing new seal with changing geometric parameters. In Kuiken study, author determined most effective geometric parameter of seal design then, with Taguchi method 6 new seal model created and examined. It was seen that in his study, eccentricity and lip thickness affected the result and effect of the lip thickness was greater than effect of eccentricity.

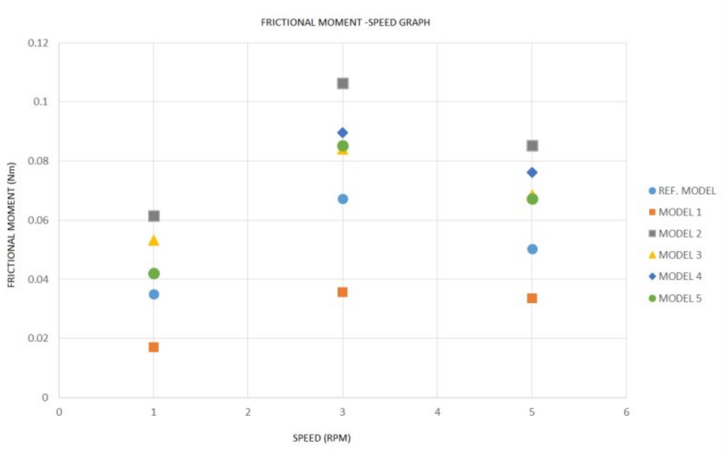

Figure 4. At constant pressure, frictional torque and speed relation of radial lip seal whose geometrical parameters are changed

4. CONCLUSION

In this study, the effects of the lip geometry on the sealing performance were determined and it was concentrated in to two parameters which are eccentricity (e) and lip thickness (d). It was found that decreasing eccentricity, decreases frictional torque but increasing eccentricity or changing lip thickness has negative effect on frictional torque. Also combining two parameter at a same model affect negatively. It was seen that advantages of the reducing eccentricity is lost because of increasing lip thickness, that's why model 4 and model 5 became worst model. In addition, increase of the pressure generally increases the friction torque in very small amounts and increase of motor shaft speed increases frictional torque up to certain value, after that a decrease is recorded. It can be said that increase in temperature has an effect on the results due to changing material characteristics.

5. ACKNOWLEDGMENTS

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