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Stuttgart, Germany
Sept.30 - Oct.1, 2026

Sealing the future –
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Tribology behaviour of U-cup type piston rod seals depending on used oil

Dr. Ing. Stefan Reichle, Dipl. Ing. Walter Igers, Dipl. Ing. Thomas Papatheodorou

In collaboration with various oil manufacturers, Parker Hannifin's Prädifa Technology Division determined the tribological behaviour of hydraulic rod seals—specifically using standard Parker U-cup seals of types B3 (with singe lip) and BS (with double lip) made from P5008 (thermoplastic polyurethane - TPU)—as a function of the lubricant used.

In this context, novel, friction-optimised lubricant variants were investigated and compared with commercially available mineral oils by means of standardised friction-force tests in screening tests. Furthermore, the breakaway friction behaviour of U-cup seals was determined as a function of standstill time, as was the stick–slip behaviour of the U-Cups under a wide range of operating conditions and on differently coated piston rod surfaces.

In the friction investigations carried out, the assessment criteria for the performance of the U-cup seal with the oils tested included the general friction in addition to stick–slip behaviour, as well the leakage, deformation and wear of the tested seals.

This contribution to the 23rd International Sealing Conference addresses several key aspects of the findings and presents the individual oils tested in detail.

1 Introduction

In an extensive test program, which last more than 3 years over a longer time period, the tribological behaviour of hydraulic piston rod seals type B3 and BS has been evaluated in standard friction tests according to the standard test procedure STP-11 at the physical laboratory of Parker Prädifa in Bietigheim-Bissingen. In these test series mainly mineral oil types of verying viscosities from different suppliers have been evaluated. The test oils were mainly delivered by the companies Exxon Mobil, Fuchs Lubritech and Afton Chemicals, but there were also some oils from other companies involved. All friction tests have been performed on hard chrome plated piston rods, but there were also some alternative rod treatments included to see, if there will be a similar or a different behaviour of the seals with the applied oil.

2 Test description

In the performed tests not only the friction behaviour of seals in general, was an issue, but also the stick-slip-behaviour of the seals themselves depending on applied pressure, oil temperature and rod velocity. In addition to that also the deformation, wear and leakage of the seals were analysed after the performed tests and their impact on the surface roughness quality of the used test rods.

2.1 Used test parameters

In the friction tests according to STP-11 following test parameters were used:

Pressures p:

- 0 MPa
- 5 MPa
- 10 MPa
- 15 MPa
- 20 MPa
- 25 MPa
- 30 MPa

Rod velocities v:

- 0,1 m/min
- 0,5 m/min
- 1 m/min
- 1,5 m/min
- 2 m/min
- 3 m/min
- 3,5 m/min
- 4 m/min

Temperatures T:

- 30 °C
- 60 °C
- 80 °C

Test seals:

- Parker B3 3646 P5008, 36x46x7,3
- Parker BS 3646 P5008, 36x46x7,3

Used test rods:

- Hard chrome plated test rods from different suppliers

The tests were performed mostly on hard chrome plated rods with a roughness Rz of max 1,2 µm and Rp of max. 0,3 µm. In each test series the friction of the seals was measured in new condition at the 3 oil test temperatures and at the pv-values mentioned above. Afterwards a short endurance test over 72 hours at a constant pressure and velocity was performed to age the seals. Then the friction tests were repeated to generate seal data in run-in condition of the seals.

2.1.1 Test procedure

At begin of each test, the test chambers (figure 1) have been cleaned from any wear debris of seals and oil, and the test rod has been reviewed regarding any damage. Any changes in surface roughness have been documented via surface roughness

measurement. Before each measurement, the test chamber has been heated up via heating elements to the required test temperature for the test.

The dimensions of each tested seal were documented before and after the performed friction tests. All tested seals have been reviewed regarding any profile changes or other physical defects after the performed tests. Profile cuts of each seal have been made after the test in scale 20:1. The stick-slip behaviour of each seal depending on applied pressure, temperature and velocity has been documented for further evaluation after the test.

In the test chamber 2 seals were installed (front-to-front) with pressure applied between the two test seals. As guiding elements PTFE band material of PS052 (PTFE filled with Bronze) was used.

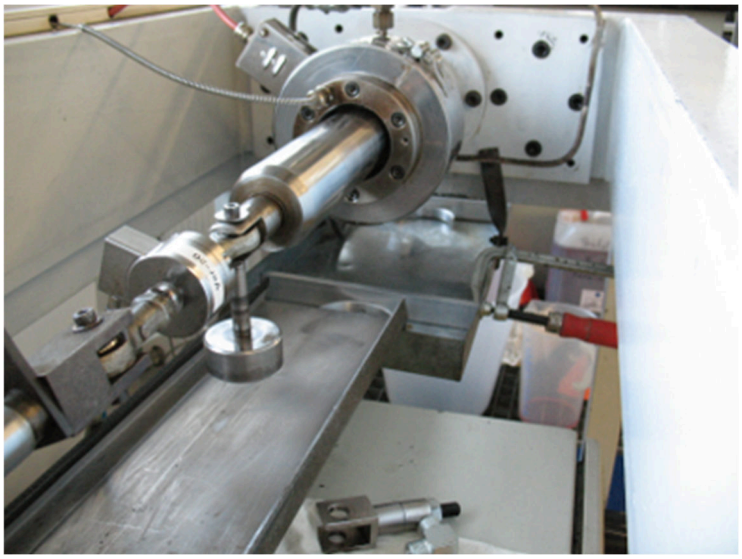

Figure 1: Hydraulic friction test stands 1

The test stand allows an easy change of the test oils due to the usage of a pneumatic-hydraulic pressure transducer which enables an easy cleaning of the complete system.

3 Test results

In the following chapters the results received with the U-cups seals and the tested oils will be described.

3.1 Seal behaviour

At all performed tests no early seal failures could be detected. All tested seals performed the applied test parameters without any problems. In most tests no leakage

at the tested seals could be detected, neither in the friction tests nor in the short endurance tests. One of the main parameters evaluated is the loss of prestress of the seals during the performed tests.

3.2 Loss of prestress

At the tested U-cup seals type B3 and BS, depending on the tested oil, a loss of pre-stress between 20 and 40% could be detected. Sometimes the B3-seals showed a higher loss of prestress at a specific oil and sometimes the BS-seals. There was no clear indication that the double lip U-cup seals type BS generate in general a higher deformation on the tested seal profiles. The loss of prestress is directly related to the loss of the radial height between the edges of the inner dynamic and outer static sealing lip of the tested seal profiles.

In the first test series with U-cups type B3 and BS the lowest loss of prestress could be detected with the oil no HI-41 of the Afton chemical oils (figure 2 and 3).

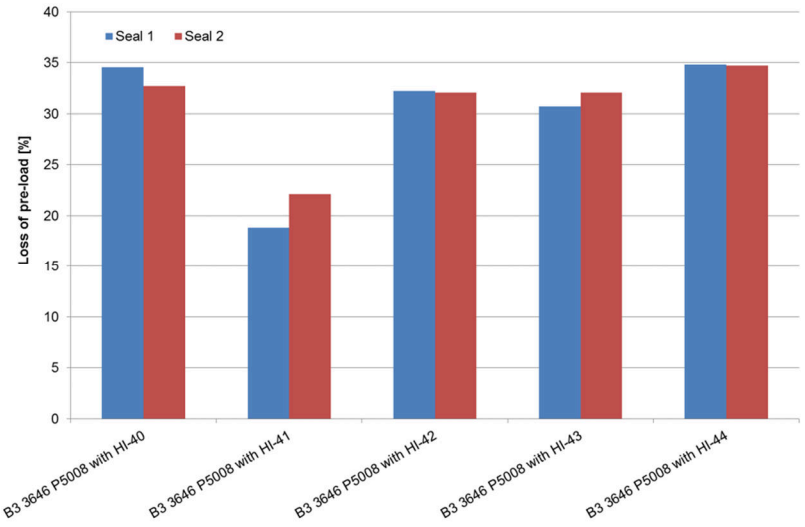

Figure 2: Loss of prestress with U-cups type B3 and HI-oils

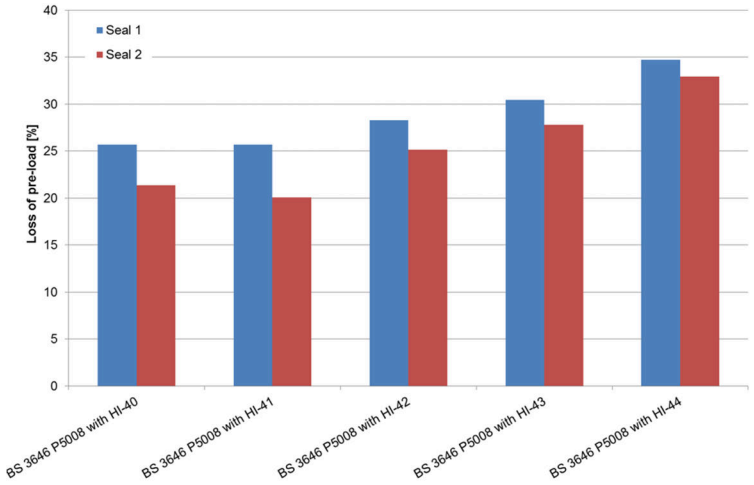

Figure 3: Loss of prestress with U-cups type BS and HI-oils

In the second test series with new delivered oils by AC, the picture regarding loss of prestress was not so clear anymore (figure 4). Depending on the tested oil sometimes the U-cup seals of type BS tend to a higher loss of prestress compared to the seals of type B3 and sometimes the B3 have the measured higher loss of prestress.

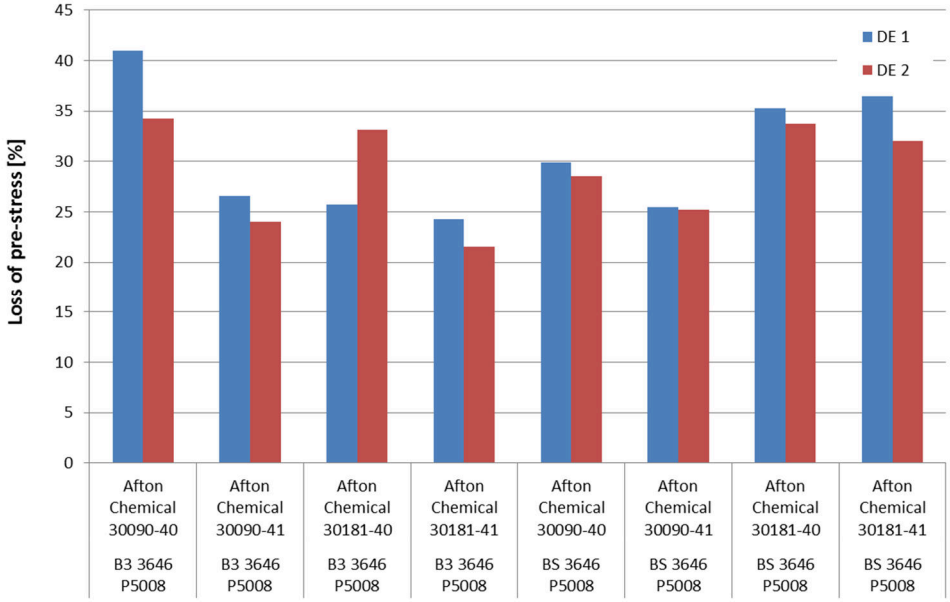

Figure 4: Loss of prestress with U-cups type B3 and BS and new AC-oils

In the test champaign with different oils from Exxon Mobil, it could be detected that the U-cups type BS showed a lower loss of prestress compared to the seals type B3 (figure 5).

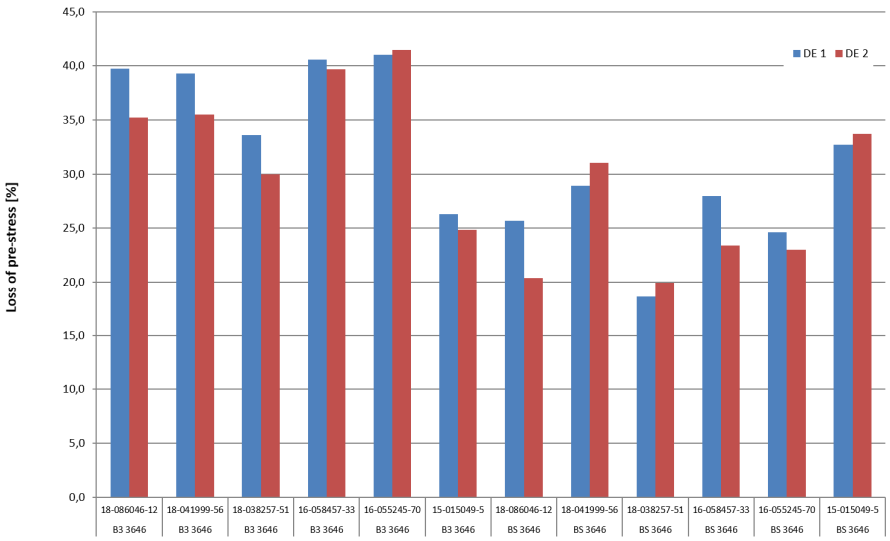

Figure 5: Loss of prestress with U-cups type B3 and BS with EM oils

3.3 Friction and stick-slip behaviour with AC oils

In the different test campaigns over the time, it could be detected that the friction of the tested seal profiles type B3 and BS variate depending on applied load and condition the seal itself (new or run-in condition). In general, it could be detected, that the friction of the seals is increasing with usage time due to the deformation and compression set of the test seals. More contact of the seal surface to the counter surface will create also more friction in the hydraulic system.

In figure 6 and 7 the measured friction values of U-cup seals type B3 in new and in a run-in condition at a pressure of 100 bar and an oil temperature of 60°C are displayed. In new condition the seals showed in 4 of the 5 tested AC oils an equal friction behaviour. The seals tested in oil HI-40 showed the highest friction values in new condition. After the short endurance test over 72 hours the seals tested in oil HI-44 generated the highest friction values on the hard chrome plated rod. At the tested B3 seals with oil HI44 also wear debris of the tested U-cups of polyurethane material could be detected on both sides of the stroke end. At a pressure of 300 bar and an oil temperature of 80°C, the received results were similar for the U-cups type B3 as shown in figure 8 and 9. The lowest values in new and in run-in condition could be determined with the oil HI-42. The results at run-in condition were impacted by slight leakage of seal no 1 in this test configuration.

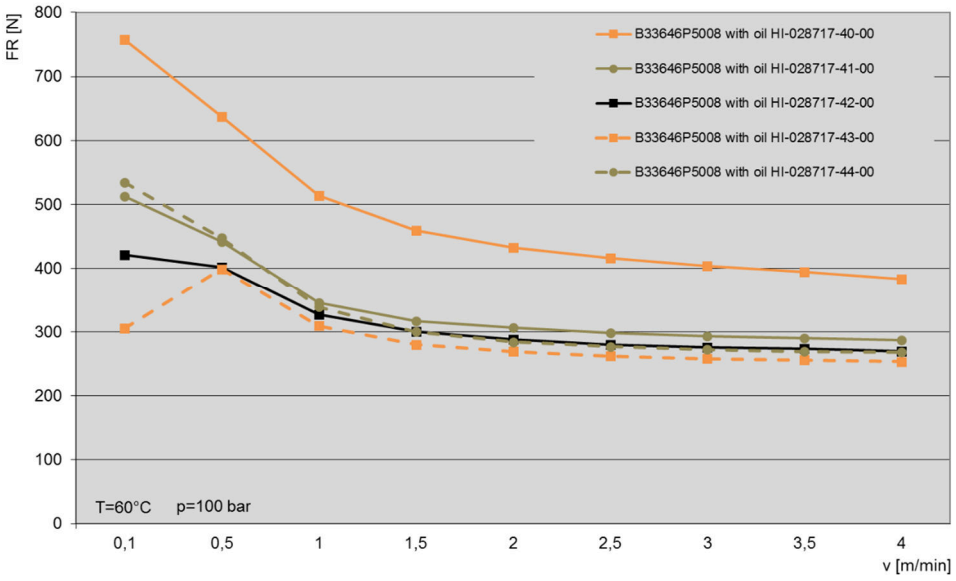

Figure 6: Friction of U-cups type B3 in new condition with AC oils

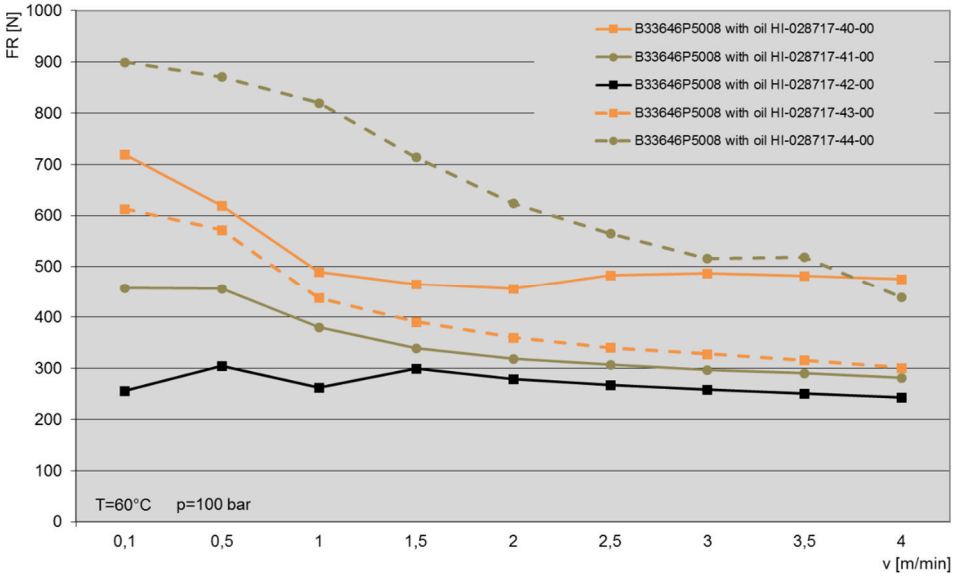

Figure 7: Friction of U-cups type B3 in run-in condition with AC oils

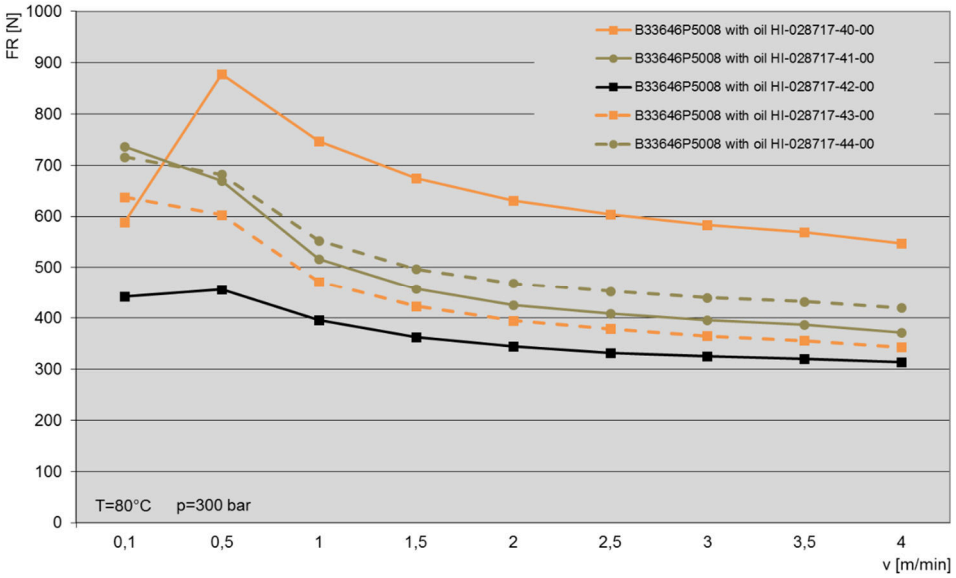

Figure 8: Friction of U-cups type B3 in new condition with AC oils (80°C)

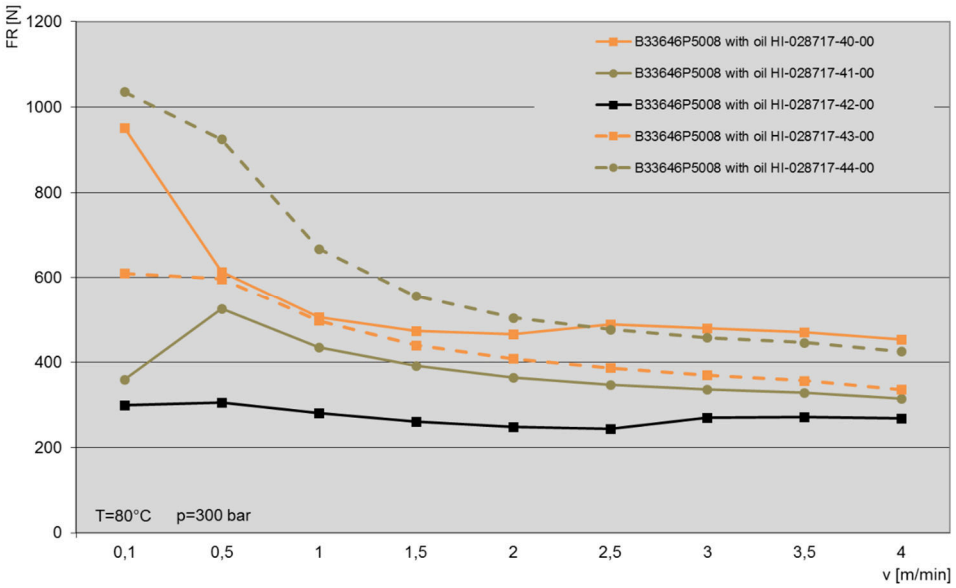

Figure 9: Friction of U-cups type B3 in run-in condition with AC oils (80°C)

At the tests with U-cup seals type BS and the AC oils, it could be detected that the seals tested in HI-44 show in general higher friction values compared to the other seals tested in the other 4 oils (figure 10 and 11).

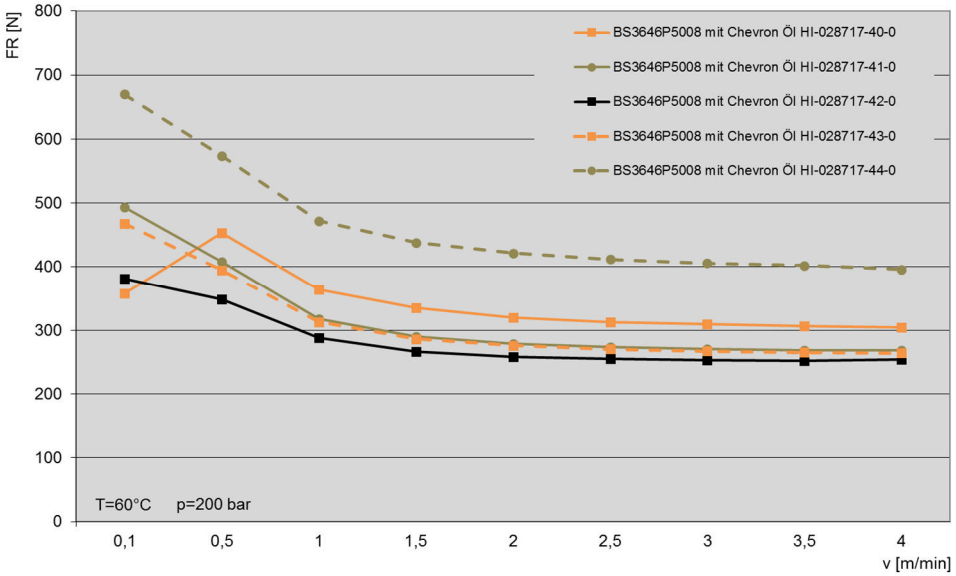

Figure 10: Friction of U-cups type BS in new condition with AC oils (at 60°C)

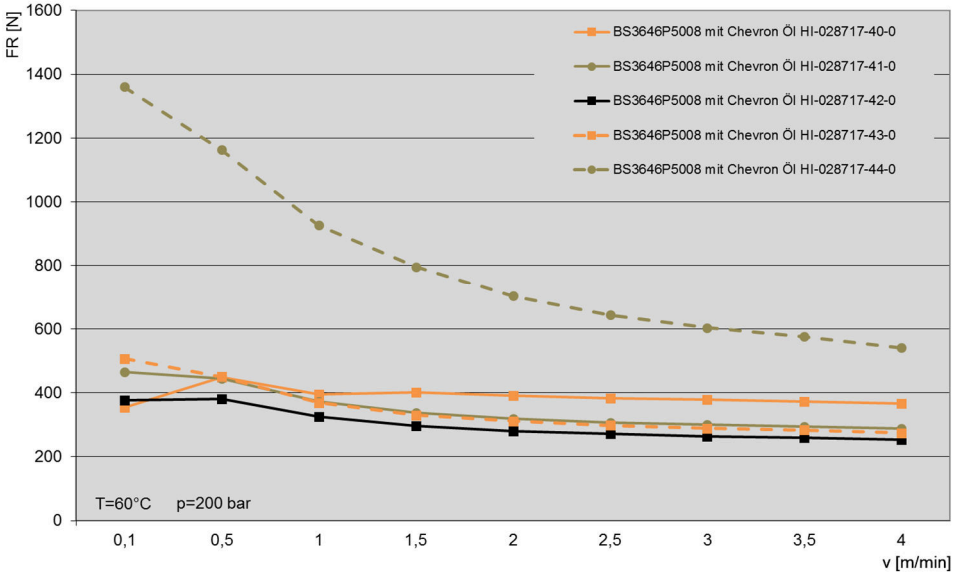

Figure 11: Friction of U-cups type BS in run-in condition with AC oils (at 60°C)

Although the U-cup seals tested in oil HI-40 show quite moderate friction values, it could be detected that this oil generated much more stick-slip in the run-in condition of the tested seals compared to the other test oils (figure 12 and 13).

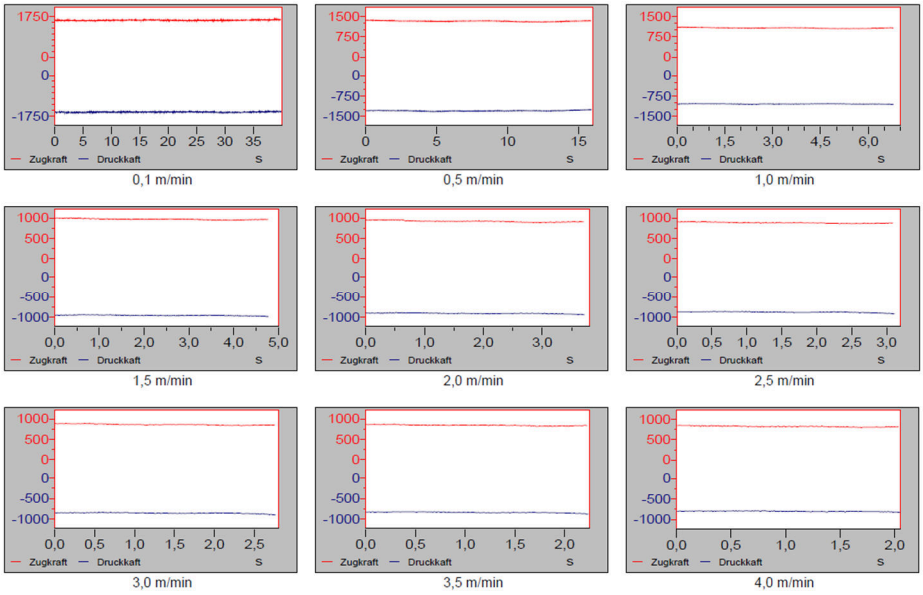

Figure 12: Friction curves of U-cups type B3 in new condition with AC oil HI-40

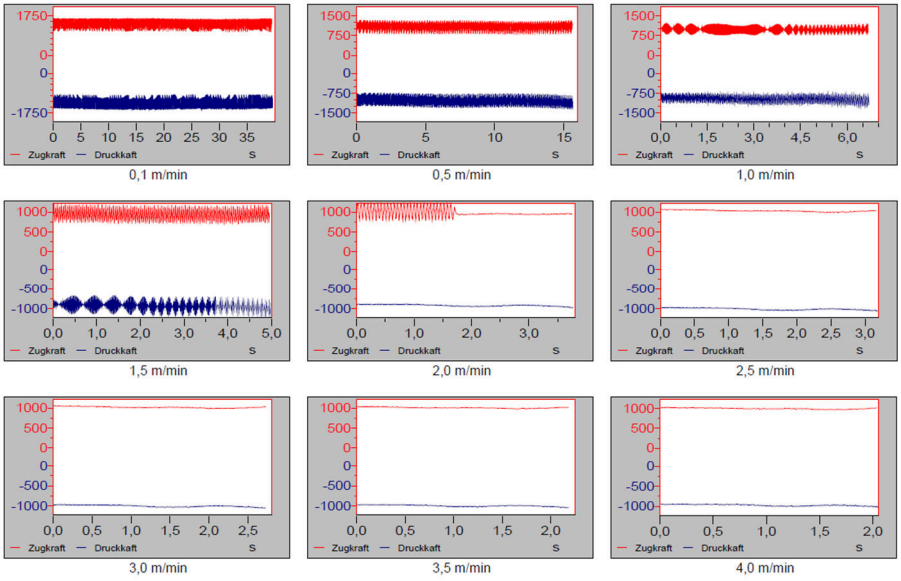

Figure 13: Friction curves of U-cups type B3 in run-in condition with AC oil HI-40

The lowest stick-slip effects could be detected with oil HI-028717-41-00. At the seals of type BS similar results could be detected in the performed tests but level of sound could be higher, and the generated frequency was different (see figure 14). In general, it could be detected, that stick-slip occurs mostly at the lower rod velocities in the performed tests.

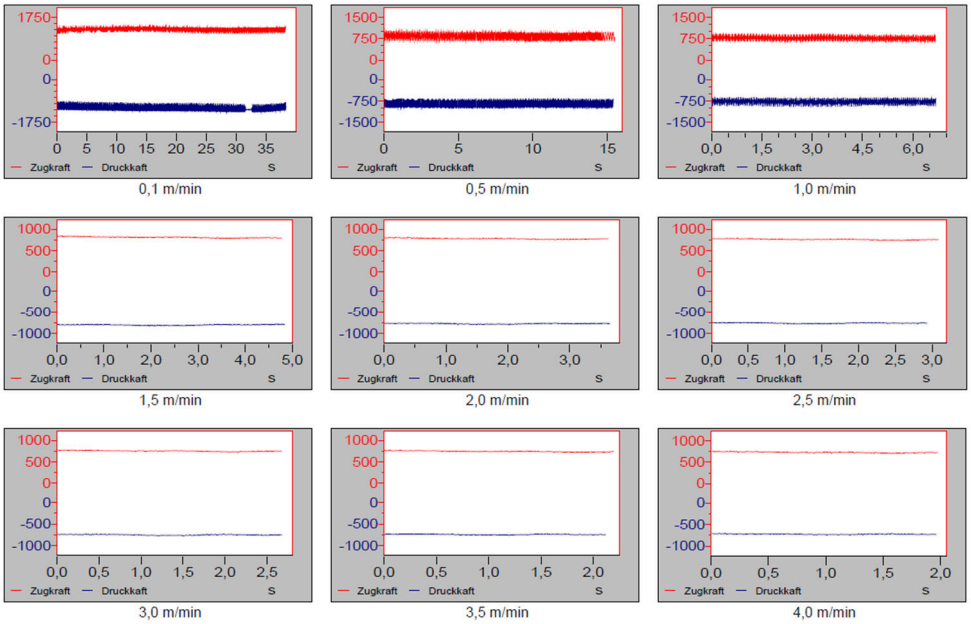

Figure 14: Friction curves of U-cups type B3 in run-in condition with AC oil HI-40

3.4 Friction and stick-slip behaviour with EM oils

At the tests with EM oils, a slightly different friction behaviour of the tested U-cup seals type B3 and BS could be detected. Seals which show quite a high friction level in new condition with a specific oil, generate lower friction values compared to the other oils after the run in condition (figure 15 to 18). Overall, the lowest friction values could be determined with the oils 18-086046-12 and 18-041999-56. But that does not necessarily mean, that these oils generate also the lowest stick-slip behaviour. With the U-cup seals type B3, it could be detected that the oil 18-086046-12 generates the highest values in stick-slip followed by the oil 18-038257-51. The lowest effects could be detected with oil 15-015049-5 at both U-cup seal types. The seals of type BS generated in general due to the secondary sealing lip in their profile slightly higher friction values compared to the seals type B3 in all tested oils. Seals which had in general more stick-slip, especially after the short endurance test run, had also a higher friction level in the performed friction tests. With the U-cups type BS the highest values in friction could be detected with the oil 15-015049-5 in run-in condition. In new condition the friction generation at U-cups type BS depends on applied pressure and velocity. Compared to the results retrieved with U-cup seals of

type BS, the differences in results were higher when testing the U-cups of type B3 in the different oils. It seems that not only the oil itself has an impact on the performance of the seals, but the tribology performance of the seal is also influenced by the design of the used seal in a specific application. Like the results with the U-cups type BS the highest values in friction could be detected at the U-cups of type B3 (with single lip) with the oil 15-015049-5 in run-in condition. In new condition the U-cups of type B3 created with the oil 16-055245-70 the highest friction values.

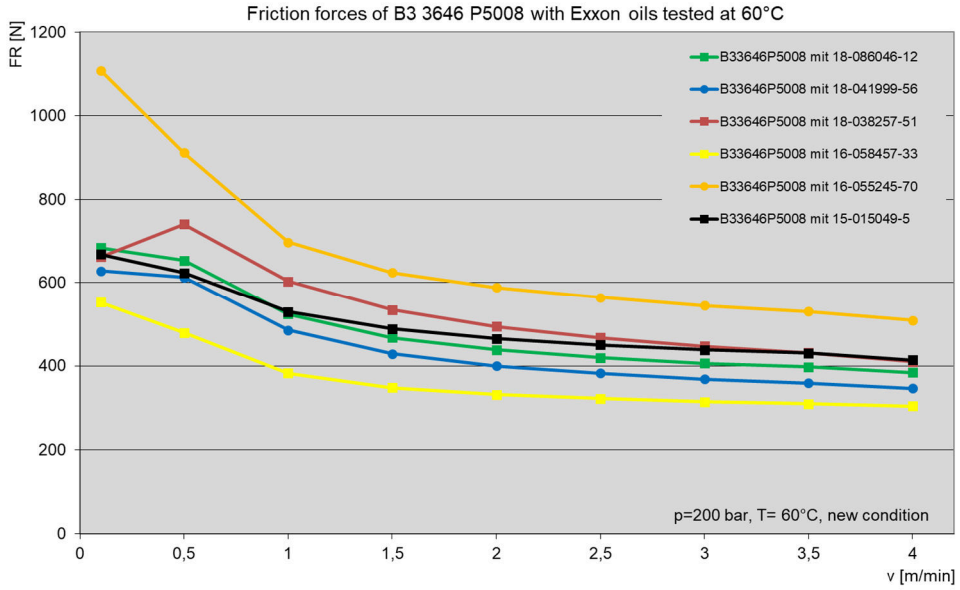

Figure 15: Friction of U-cups type B3 in new condition with EM oils (at 60°C)

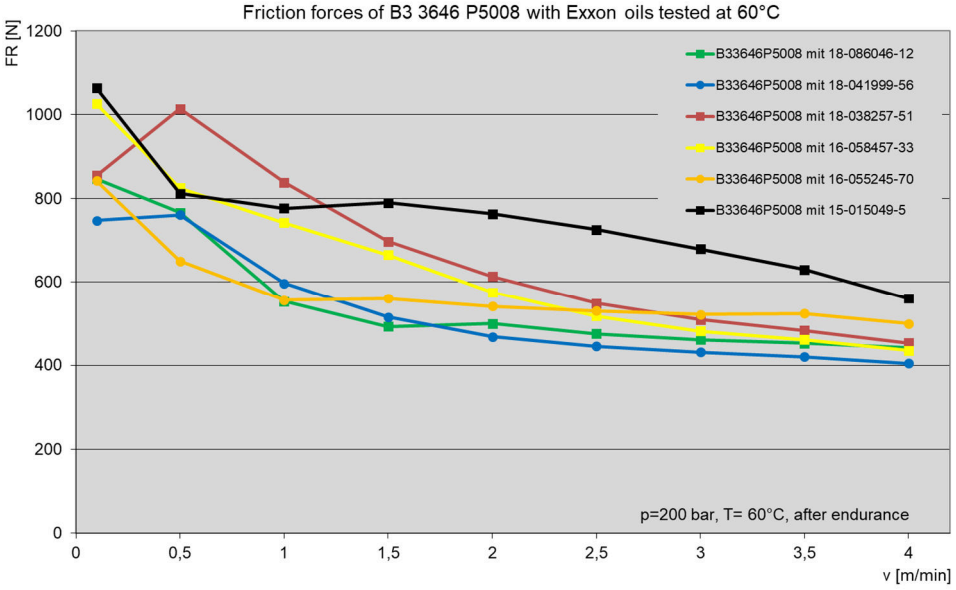

Figure 16: Friction of U-cups type B3 in run-in condition with EM oils (at 60°C)

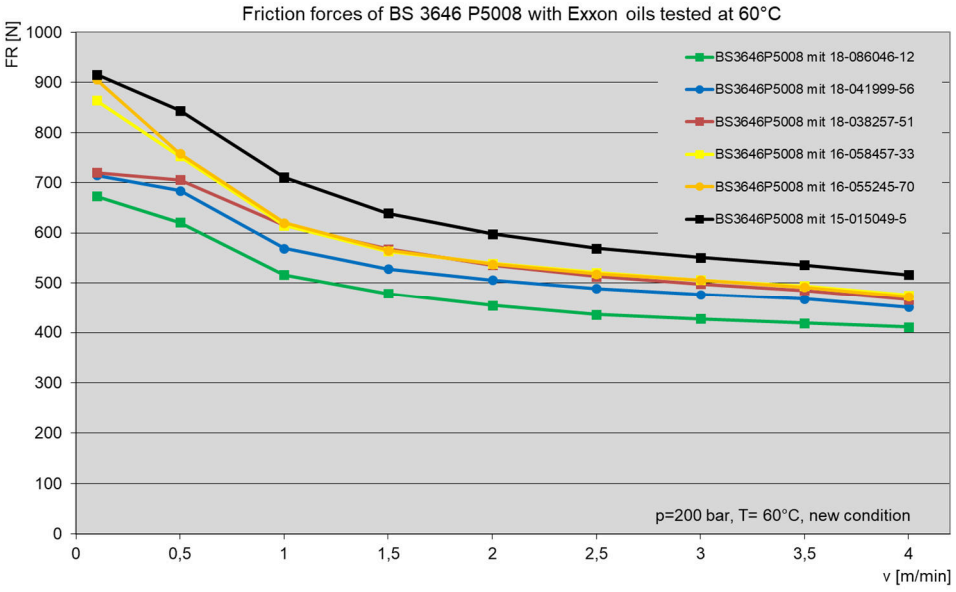

Figure 17: Friction of U-cups type BS in new condition with EM oils (at 60°C)

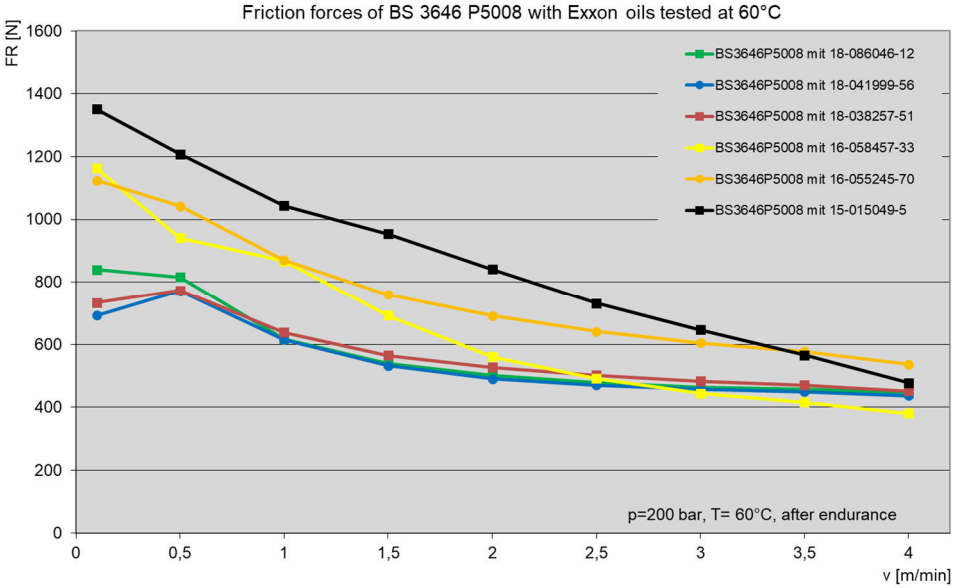

Figure 18: Friction of U-cups type BS in run-in condition with EM oils (at 60°C)

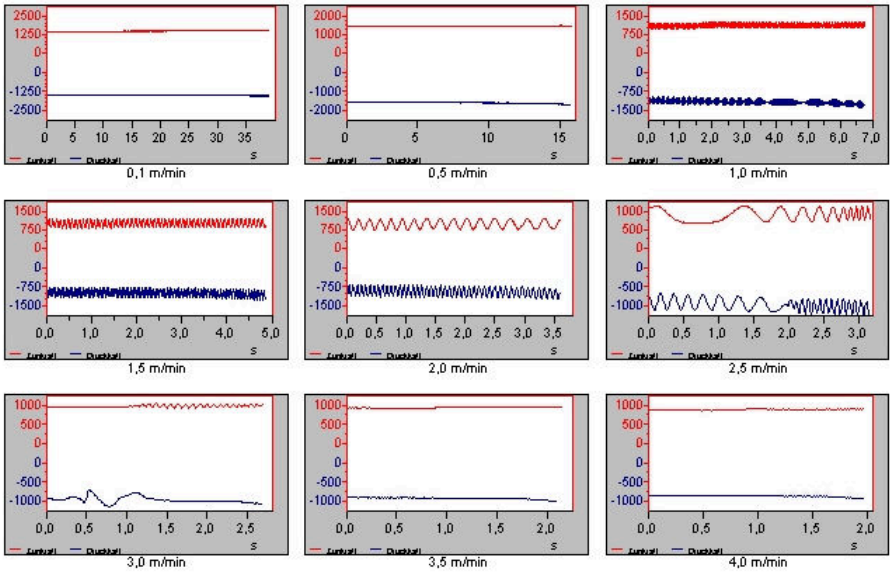

Figure 19: Stick-slip of U-cups type B3 at 100 bar and 80 °C in run-in condition with oil 18-086046-12

In comparison with the used standard oil Renolin MRX 46 from Fuchs Lubritech, the tested oils generated mostly the same behaviour regarding friction and stick-slip, depending on applied pressure and temperature on the tested U-cup seals type B3 and BS. The same behaviour could be detected also at other tested mineral oils of alternative suppliers.

4 Summary and Conclusion

The performed hydraulic friction tests show that the selection of an appropriate mineral oil can have a big impact on the stick-slip behaviour of piston rod seals type B3 and BS on hard chrome plated piston rods. But is should be always taken into consideration that a variation of the seal profile, the used material and the type of counter surface can result also into a different behaviour of the tribological system. Therefore, it is always recommended from Prädifa side to test the complete system in a real application before implementing in a serial production.

5 Acknowledgements

The publication has been generated in memory to our colleagues Thomas Braun and Eddy Vanswijgenhofen, who both passed to early away.

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