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# International Sealing Conference

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

Sealing the future –
Facing the challenges of tomorrow

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# Influence of surface quality of different nitride treated piston rods on the sealing behaviour of hydraulic piston rod seals

**Dipl. Ing. Thomas Papatheodorou, Dipl. Ing. Walter Igers**

In collaboration with several customers, in the context of specific customer issues, and involving various piston rod suppliers, Parker Hannifin's Prädifa Technology Division determined the tribological behaviour of hydraulic rod seals type U-cups and Slipper Seals on piston rod surfaces with different nitride treatments and surface roughness quality. The investigations were carried out under Parker's internally standardised test conditions and under test conditions specified by the different customers.

Using various screening tests, the influence of nitride treated piston rod surfaces on the seals operating behaviour regarding friction, leakage and wear was determined in short- and long-term endurance tests. In these tests also the roughness values on rods of the different nitride treatments were a variation parameter, which have been tested with different seal designs and materials. Furthermore, the changes at the piston rod surfaces were analysed and compared against the values of piston rods in new condition. This paper, presented at the 23rd International Sealing Conference, addresses some key aspects of the investigation results and presents the conclusions derived of the results throughout the performed sealing tests.

## 1 Introduction

In extensive test programs, the tribological behaviour of hydraulic piston rod seals type U-cup and Slipper seals have been evaluated in standard friction tests but also in endurance tests and under customer specific test parameters in their typical applications on different nitride treated piston rods. All friction tests have been performed according to the Parker test standard STP-11. The endurance tests on the ISO piston rod seal tester have been performed according to the Parker STP-10, which is following the rules of the ISO 7986 test standard. In addition, also tests under customer specific test procedures have been performed directly with the products, which the customers are using in their applications like hydraulic piston rod seals for convertible roofs but also seals of rubber and polyurethane materials for gas spring applications.

## 2 Test description

In the performed tests, not only the friction behaviour of seals in general was an issue to be evaluated, but also the wear and deformation behaviour of the seals under the applied load like oil temperature, pressure and rod velocity. In addition, the changes in surface roughness structure on the used piston rods were analysed after the tests and their impact on the surface roughness values, like Rz, Rp and others. In one of the performed test campaigns a specific customer question should be evaluated, like “Do nitride treated piston rods require to be polished twice before usage to generate a good sealing performance or is it enough to polish them only once to specific surface roughness values for the planed application?”

### *2.1 Test parameters*

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

Pressures p:

- From 0 bar to 300 bar in steps of 50 bar

Rod velocities v:

- On test rig 1:
  From 0,1 m/min to 4 m/min (0,01 m/s to 0,1 m/s)
- On test rig 2:
  From 0,01 m/s to 0,25 m/s

Temperatures T:

- 30, 60 and 80 °C

Tested seals:

- Parker B3 3646 P5008, 36x46x7,3
- Parker BS 3646 P5008, 36x46x7,3
- OD 0360 PS052 36x46,7x4,2
- HL 3646 P6030 36x46x4,2
- Gas spring seals for rod diameter 8 to 14 mm
- Seals for convertible roof cylinders with diameter 8 and 10 mm

Test rods:

- Several nitride treated piston rods with variation in polishing process from different rod suppliers

The friction tests were performed on different nitride treated piston rods with roughness values of Rz between 1 to max 4.5 µm and Rp between 0.3 to max 2.4 µm (table 1). In each test series the friction of the seals was measured in new condition at the 3 oil test temperatures and the pv-values mentioned above. Afterwards a short endurance test over 72 or 96 hours at a constant pressure and velocity was performed to age the seals and then the friction tests were performed again. This behaviour generates seal friction data in run-in modus of the seals.

Some of the tested piston rods used in the screening tests had quite high surface roughness values after the performed treatment process. The measured values were above the values given in the Parker catalogue for hydraulic piston rod seals.

Therefore, some of these rods were additional polished from the suppliers to reach roughness values in an area as used at standard hard chrome plated piston rods.

| No. | Treatment | Rz (new) | Rp (new) |
|---|---|---|---|
| LH1 | Tenifer Q | 1,18 | 0,45 |
| LH2 | Tenifer QP | 1,03 | 0,36 |
| LH3 | Tenifer QPQ | 1,19 | 0,35 |
| LH4 | Plasma | 4,45 | 3,38 |
| LH5 | Plasma Superfinish | 0,98 | 0,35 |
| LH6 | Plasma Superfinish | 0,96 | 0,35 |
| BC1 | CID 1 | 1,85 | 0,76 |
| BC3 | CID 3 | 1,62 | 0,7 |
| MP1 | NC Ox | 1,57 | 0,69 |

*Table 1: Selection of nitride treated piston rods used in the evaluation tests*

#### 2.1.1 Test procedure

At the beginning of each test, the test chambers (figure 1) have been cleaned from any wear debris of seals and oil from the previous test, and the piston rod has been reviewed regarding any damages. Any changes in surface roughness have been documented via a surface roughness measurement unit. Before each new test set-up, the test chamber has been heated up via heating elements to the required test temperature.

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

The typical set-up of the hydraulic friction seal tester 2 is displayed in figure 1. As guiding elements either PTFE band material of PS052 (PTFE filled with Bronze) or rings made of polyester fabric were used. The initial friction of these elements has been also evaluated before the seal tests have been performed.

The ISO hydraulic endurance seal tester consists of 6 test chambers where 2 seals or 2 complete sealing systems can be tested in each test chamber (figure 2). In addition, specific customer test set-ups were used to examine the seals under customer specific test requirements. Figure 3 shows the test set-up for seal testing in convertible roof applications and figures 4 and 5 show the test set-up for seals in gas spring applications. Figure 4 shows the set-up for testing of original gas springs while in figure 5 a similar test set-up is shown as it is used for hydraulic piston rods seal tests.

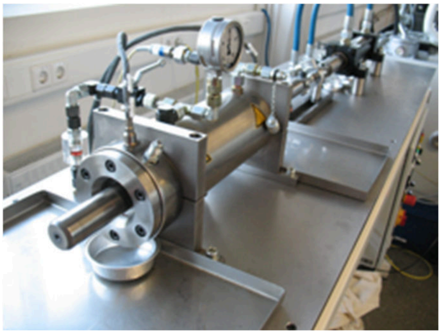

*Figure 1: Hydraulic friction test stand 2*

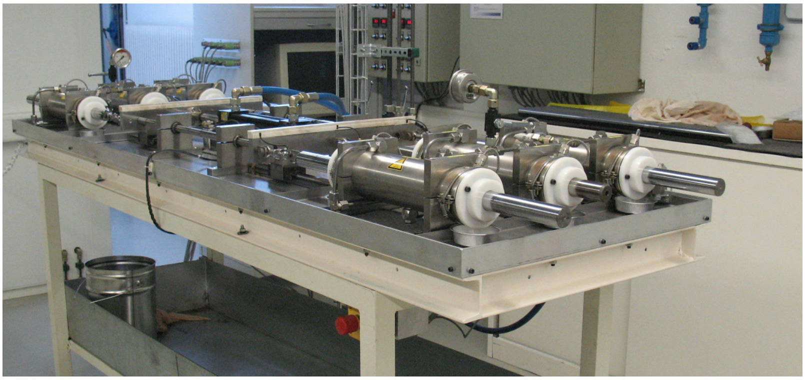

*Figure 2: Hydraulic ISO 7986 test stand*

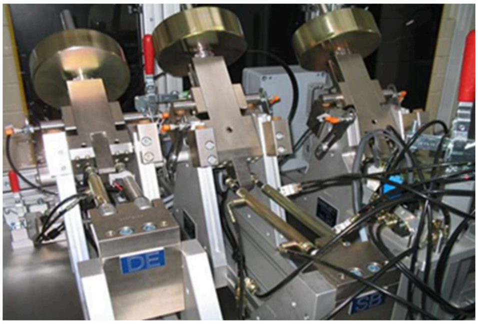

*Figure 3: seal testing in convertible roof applications*

*Figure 4: seal testing for gas spring applications*

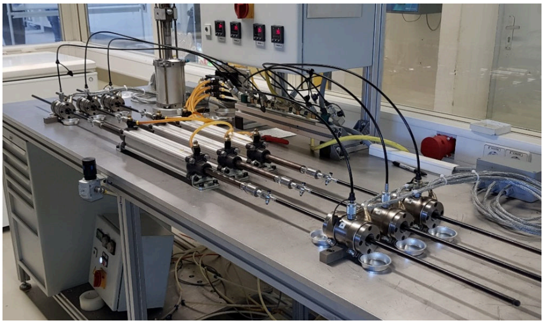

*Figure 5: gas spring seal testing in test chambers*

## 3 Test results

In the following chapters the results received with piston rod seals in different types of tests will be described and discussed.

### *3.1 Seal performance on friction seal tester*

In the first test campaign Parker piston rod seals of type B3, BS, HL and OD have been tested on different nitride treated piston rods of diameter 36 mm according to the Prädifa test standard STP-11. Depending on type of tested seal and piston rod configuration sometimes early seal failures could be detected during the short endurance tests due to high leakage rates although the seals did not fail completely throughout the friction tests after the short endurance test. It could be detected that the generated leakage values impact the measured friction values of the tested piston rod seals.

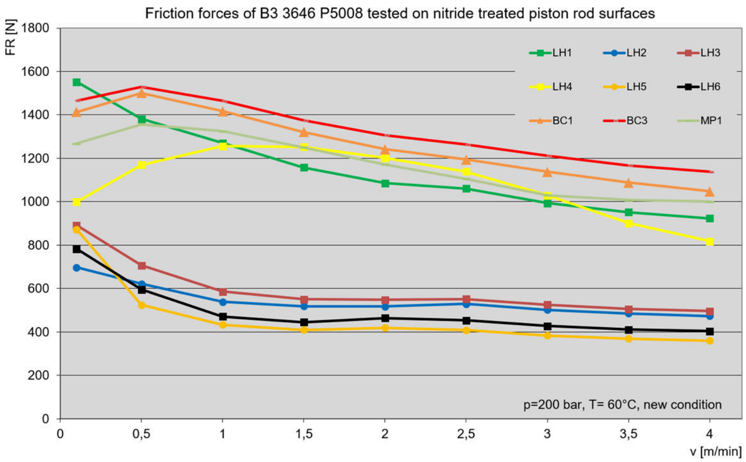


*Figure 6: B3 3646 P5008 on nitride treated piston rods in new condition*

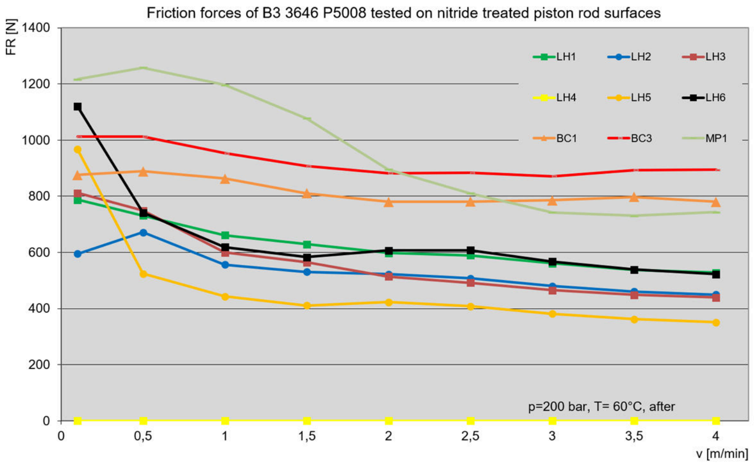


*Figure 7: B3 3646 P5008 on nitride treated piston rods in run-in condition*

Depending on rod surface condition the U-cups type B3 show in new condition a variation in the test results. Higher polished rod surfaces generate a lower measured friction for the tested seals (figure 6). In run-in condition most of the tested seals show a reduction in measured friction forces versus the values in new condition due to wear and deformation of the seals (figure 7). On hard chrome plated rods normally an increase in friction can be detected for such seals. A similar behaviour could be detected for the low friction U-cup seal type HL. Due to the lower pre-stress of these seals and the lower friction level in general the impact on the deformation and wear of these seals and therefore on the measured friction values in run-in modus was lower. At the tested piston rod seals made of PTFE-compounds a bigger impact of the Rp-values of the used nitride treated rods on the performance of the seals could be detected. As higher the Rp value of the tested piston rod is more wear at a Slipper seal will be generated.

### 3.2 Seal testing on endurance seal tester

All performed endurance tests at a test temperature of 65°C run without any bigger problems for over 1 million load cycles with tested piston rod seals of type B3, BS and HL.

On all tested B3 3646 U-cup seals made of P5008, only minimally visible axial running marks were observed. Except for one tested seal, no deeper axial scoring could be detected in the dynamic sealing surfaces of the test seals. In the area behind the sealing edges, a visible running zone was present on all seals.

All seals showed only minimal extrusion. After the endurance test, the sealing edges of the U-cup seals were still completely sharp-edged. The dimensional changes and preload losses were approximately at the same level for all test seals. The preload losses ranged from 17 to 28%. The radial height of the seals decreased by an average of approximately 0.3 mm.

The most notable aspect of this test was the pronounced leakage of seal DE 2.2 of the seal tested in test chamber 2. All other tested U-cup seals remained nearly leak-tight over the entire test duration or showed only minor leakage. For these seals, no significant leakage or oil-film formation could be observed at the stroke end position. The cause of the high leakage of seal 2.2 in PK2 was the deeper axial wear mark. This is presumably attributable to the high roughness Rz of piston rod no. 15. While 5 of the 6 tested piston rods were in the Rz range between 0.58 and 0.7 µm, rod No. 15 had an Rz value of 2.5 µm. After the endurance test, a slight decrease in the Rz value to 2.1 µm was observed on rod no. 15 in PK2, which means, that even a “soft” material can smooth down a counter surface under a high sealing contact pressure at the sealing edge.

In terms of friction behaviour, essentially the same friction-force trends were observed at all positions. As the test duration increased, the friction force of the test seals increased slightly. Due to the high leakage on the rod in test chamber 2, a pronounced decrease in friction force was observed there on the U-cup seals right at the beginning of the test and then throughout the entire running time.

At the tested U-cups type BS 3646 made of P5008 with double lip, also only minimally visible running marks were observed, except for the seals that had run in test chamber PK2. Hardly any deeper axial scoring could be detected in the dynamic sealing surface of the test seals. In the area behind the sealing edge, a visible running zone was present on all tested seals. All seals showed only minimal extrusion. After the endurance test, the sealing edges of the U-cup seals were still completely sharp-edged. The dimensional changes and preload losses were approximately at the same level for all test seals. The preload losses ranged from 11 to 34%, a bit higher compared to the U-cup seals type B3. The inner diameter of the tested seals increased by 0.14 to 0.25 mm over the running time of 1 million load cycles, although one seal tested in test chamber PK2 showed a significant increase of 0.65 mm.

In terms of friction behaviour, essentially the same friction-force trends were observed at all positions (figure 8). As the test duration increased, the friction force of the test seals increased slightly. Due to the high generated leakage on the rod in test chamber 2, a strong decrease in friction force over the entire running time could be observed there.

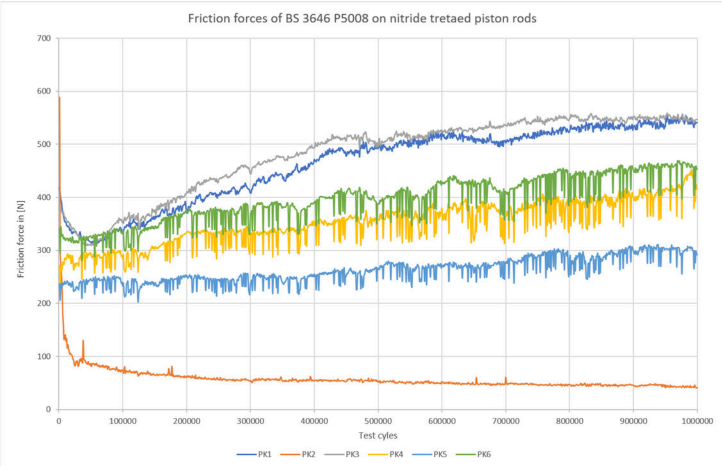


*Figure 8: Friction forces of BS 3646 P5008 on nitride treated piston rods over 1 Mio. cycles*

In the tests with Slipper seals type OD of PTFE-Bronze it could be detected that a nitride treated rod surface has a big impact on the back-pumping effect of the tested seals during the rod instroke under high pressure. Depending on the rod surface roughness high leakage values could be detected (figure 9).

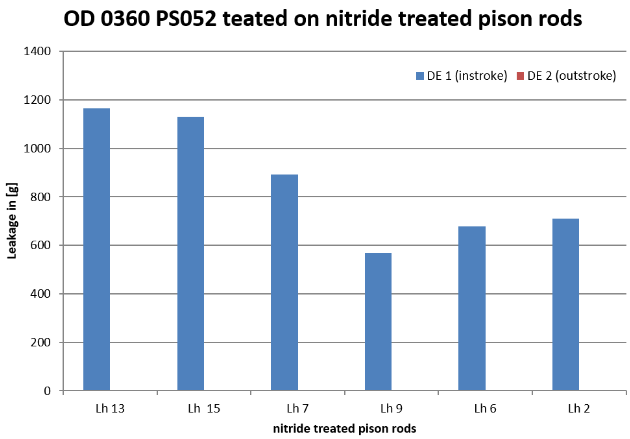


*Figure 9: Leakage of OD 0360 PS052 on nitride treated piston rods over 1 Mio. cycles*

### 3.3 Seal testing for convertible roof applications

In nearly all tests on custom rod seals made of P5001 for comfort hydraulics, increased wear behaviour was observed when using nitride treated piston rods. Furthermore, the investigations showed that as the service life of the rod increases, seal wear decreases significantly, although no changes in the roughness values are observed. In additional endurance tests with Parker standard rod seals, this phenomenon was to be investigated in more detail, with the aim of defining a characteristic value for the surface roughness of the rod that allows conclusions to be drawn about seal wear. The investigations were carried out on nitride treated piston rods from different suppliers as well as on available reference rods with hard chrome plating.

To investigate how repeated use of the same piston rod, and the possibly associated smoothing of the rod, affects seal wear, new rod seals were each subjected four consecutive times on the same piston rod to a standard short-duration endurance test, and the seal wear and rod wear were compared with each other. The test conditions were as follows:

| | | | |
|---|---|---|---|
| Test cycles: | 12.000 | | |
| Pressure: | 250 bar / 0 bar | | |
| Temperature: | 80°C | | |
| Tested seals: | GS 1016 P5008 | | |
| Tested piston rods: | nitride treated: | d10-S1 | Rznew 0.70 |
| | hard-chrome: | d10-H1 | Rznew 0.55 |
| Stroke length: | 200 mm | | |
| Rod velocity.: | 0.2 m/s | | |
| Test media: | Aral Vitamol 4004 | | |

In all endurance runs, after approximately 6,000 LW, a slightly moist rod was observed at the seal pressurized during retraction. Despite leakage, all test seals completed the full 12,000 LW. No significant wear could be detected on the seals pressurized during extension (DE pushing). The following explanations are therefore limited to the seals pressurized during retraction (DE pulling).

The new nitride treated rod produces increased sealing-surface abrasion, particularly at the back of the seal, compared with the rod that has been used multiple times. As service life increases, sealing-surface abrasion decreases, but becomes distributed more over the entire length up to the dynamic sealing edge. In the sealing surface, small material flaps form at an abrasion edge, which moves toward the dynamic sealing edge as the rod's service life increases (figure 10).

When using the hard-chrome rod, the seals pressurized in the pulling direction show wear in the form of sealing-surface abrasion. However, no dependence of the abrasion behaviour on the piston rod running time is evident (figure 11).

On nitride treated rods, wear and loss of preload are significantly higher in the new condition than on a used rod, although the roughness values are nearly identical.

Based on the sealing tests with U-cups of type GS following conclusions can be drawn regarding performance on nitride treated piston rods.

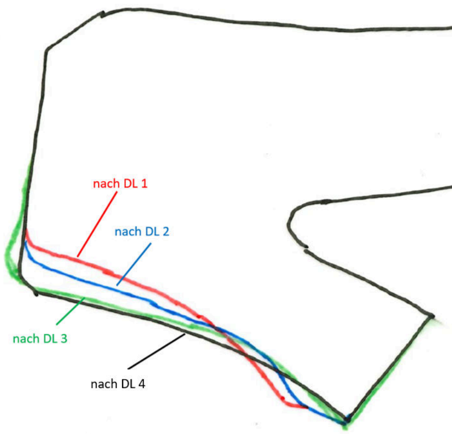


*Figure 10: Comparison of profile section GS 1016 P5008 on nitride rod S1 after 4 tests*

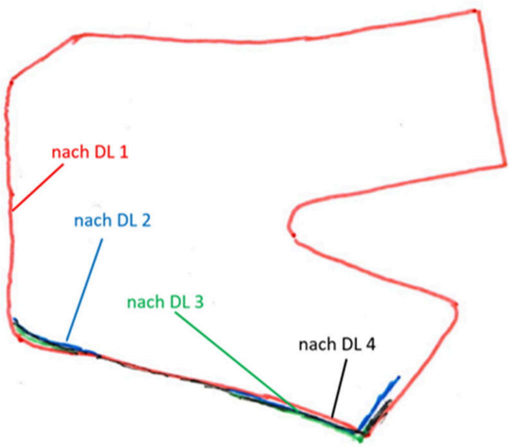


*Figure 11: Comparison of profile sections of GS 1016 P5008 on Hard chrome plated rod after 4 tests*

► After a certain running time on a nitride treated piston rod, no further reduction in the wear rate occurs for the tested U-cup seals.

- Nitride treated piston rods from different production batches and/or suppliers can lead to significantly different seal wear despite having the same roughness values.
- With the usual 2D roughness measurement parameters, it is not possible to detect differences in the rod surface between new and used rods that would explain the different wear behaviour. Even 3D measurements did not show significant differences between the different piston rods.
- Higher surface roughness of the piston rod leads to increased seal wear. The standard specification of a maximum limit value of Rz 1.6 appears to be too high for the nitride piston rods used, particularly since this has a direct effect on the Rp value of the piston rods.
- The tested hard-chrome rods produce less wear than nitride treated piston rods. Furthermore, the differences between seals with high and low tensile strength, as well as between the new and used condition of the rod, are absent or significantly less pronounced.
- In the tests, a reduction in rod speed tends into a result of reduced seal wear.

The increased wear on nitride treated piston rods compared with hard-chrome rods is also evident, in a somewhat less pronounced form, on standard seals made of P5008. Furthermore, after repeated use of a nitride treated piston rod, seal wear continuously decreases as a function of rod running time, although the roughness values do not change. This effect is not observed on hard-chrome plated rods.

In the comparison carried out with the hard-chrome plated rod, it should be considered that it has slightly lower roughness values than the nitride piston rod.

To further detail the described wear phenomenon on nitride treated piston rods, additional tests with other seals and further piston rods with different coatings and roughness levels are required. Since tactile roughness measurements cannot detect any deviations that would explain the different wear behaviour, other methods shall be included in such investigations for the future.

### *3.4 Seal testing for gas spring applications*

As part of several benchmarking tests, the gas spring seals type Y4 1011 Z5474 of NBR 85 Shore A were tested in endurance runs on nitride treated piston rods delivered by a customer and on different hard-chrome-plated piston rods.

For these investigations, a new test setup was implemented in the Parker PTD test field. In terms of appearance and function, the test setup corresponds to the test rig described in ISO 7986; however, the new test rig is used to test piston rod seals with a smaller inside diameter. The test chambers can be subjected either to constant pressure or to pressure cycling. Constant pressure was used in these endurance tests, as this more closely corresponds to the condition in a gas spring. The customer provided the information that the NBR seals withstand the temperature load of 100 °C quite well, but do not fully pass his internal tests. This result was confirmed in an initial endurance test. In further endurance tests, new seals were tested at different test temperatures under otherwise identical conditions.

The test with the gas spring seals of NBR ran without major issues over the duration of 1 million double strokes on the nitride treated piston rod surfaces. In one of the 12 seals tested, a light leakage of 0.71 g over the entire test duration was detected. No dripping leakage occurred in any of the other seals tested. A certain formation of a lubricating film was observed on the piston rod surfaces after the performed endurance test.

For the gas spring seals, preload losses of 42% to 53% occurred within this test duration. This also influenced the measured radial force loss. For the 12 seals, this loss was a maximum of 30%, meaning that all seals still exhibited sufficient radial force after the endurance test to ensure proper function.

The roughness values of the piston rod surface were slightly reduced by the tested seals because of surface smoothing. Before the start of the test, the measured Rz values for the nitride treated piston rods were approximately 0.815 µm. After the endurance test, the Rz values were approximately 0.778 µm. The peak heights Rp of the rod surface were also slightly smoothed or polished by the seals, from 0.301 to 0.300 µm.

Only minimal axial running marks can be observed on the dynamically run sealing surfaces. The sealing edges still appear sharp-edged on all seals examined. On seal no. 10, in addition to the fine axial running marks, a partial groove can be observed in one section of the circumference (figure 12). This also explains the light leakage detected for this sealing element during the endurance test. For the other seals tested, the formation of fine axial running marks had no negative impact on the leakage behaviour of the seals.

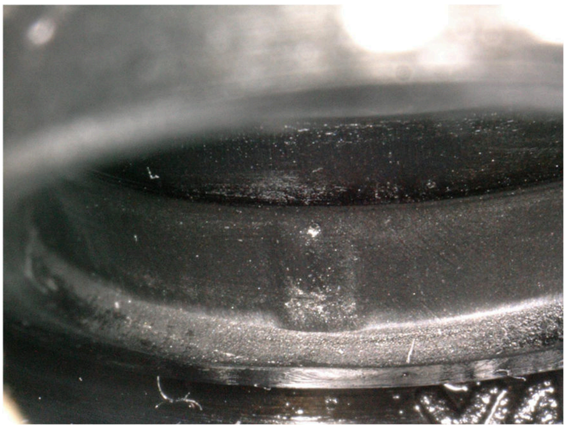

*Figure 12: Scratch on seal surface of Y4 1011Z5474 after performed endurance test*

The results achieved in the endurance tests over 1 Mio. cycles each with gas spring seals of NBR -materials on nitride treated piston rod surfaces confirmed the result communicated by the customer. At tests performed at temperatures of 50 to 80°C, the loss of preload and the change in radial force in the tested seals were moderate, so the seals withstood the endurance test without major issues.

## 4 Summary and Conclusions

The performed hydraulic seal tests on different nitride treated piston rods show that the selection of the roughness of the counter surface will have a big impact on the performance of the tested piston rod seals type B3/BS, HL and OD.

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 into a different behaviour of the tribological system. Therefore, Prädifa recommends always testing the complete system in a real application before implemented it in a serial product.

## 5 Acknowledgements

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

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