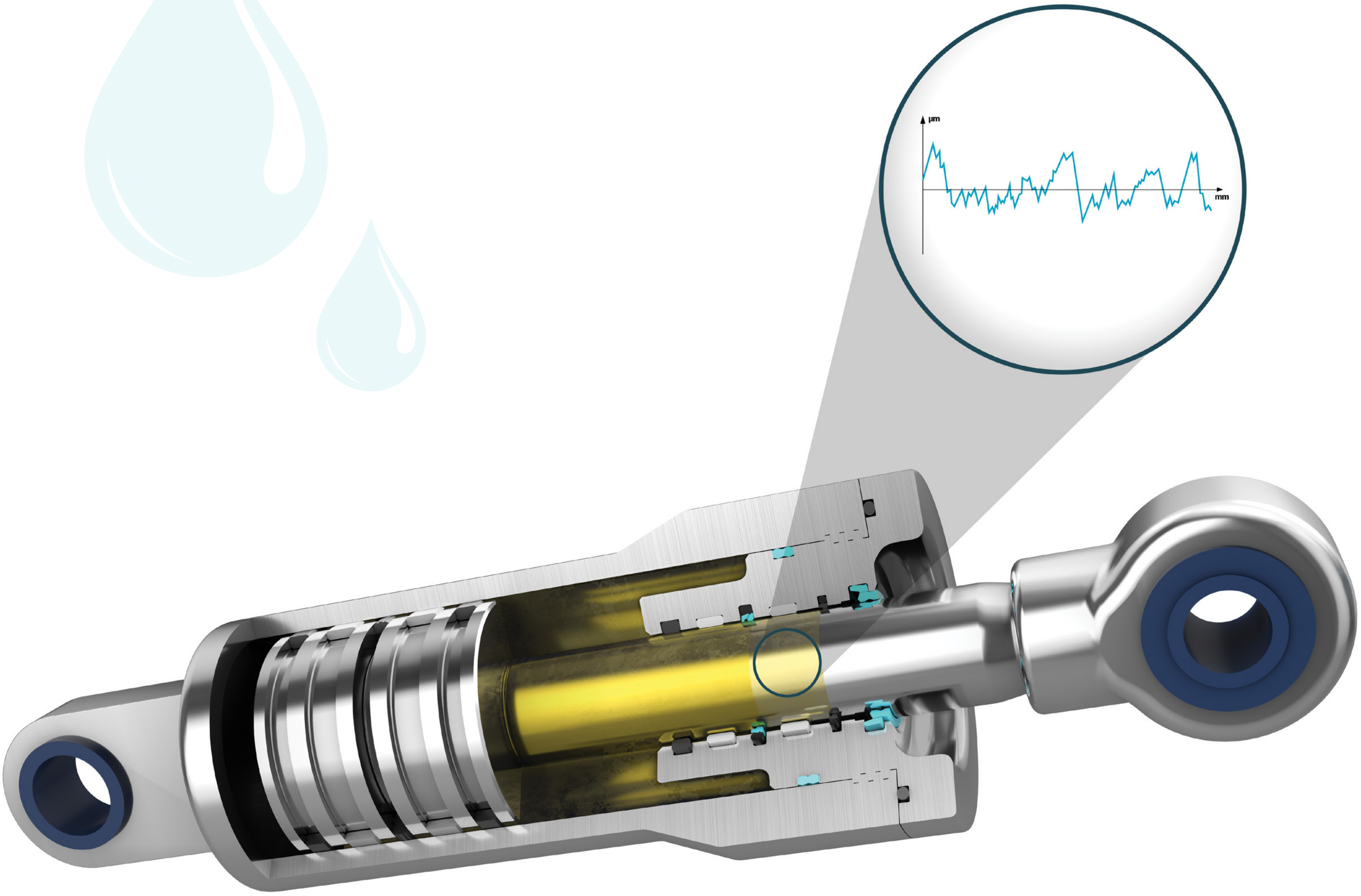
TRELLEBORG SEALING SOLUTIONS

An Introduction to Counter Surfaces



Introduction

A new approach is required for the definition of counter surfaces to ensure effective sealing in dynamic applications where chrome plating is replaced by alternative coatings.

—— **Authors: Dr.-Ing. Mandy Wilke, Holger Jordan,**

Traditionally piston rods in hydraulic systems were chrome plated to provide friction and surface finish characteristics. Under the REACH directive, Hexavalent Chromium (CR6) is a substance of high concern and must now be omitted from any hydraulic application, leading to the adoption of alternative coatings for the hydraulic system's piston rods.

To maximize the performance and system life in hydraulic systems, these should be designed to optimize a system's tribology, which is dependent on the interaction of a system's seals, hydraulic fluid and the finish of the mating surfaces. The lubrication within the hydraulic system is fundamentally affected by the surface finish of the mating surfaces. Their characteristics will determine the lubrication within the system and therefore the tribological environment.

Traditional two dimensional representations of the piston's surface finish were sufficient to describe chrome surfaces. The interaction between these, commonly used seals and hydraulic fluids, was well established. Currently, recommendations from seal suppliers for mating surface finishes in hydraulic systems, despite the use of alternative coatings, are still based on chrome.

However, the surface finish characteristics of alternative coatings differ significantly from chrome. This whitepaper proposes that to fully optimize the tribology effect within hydraulic systems where alternatives to chrome are used to coat the piston rod, more in-depth recommendations should be utilized.

Background

Hydraulic Systems

Hydraulic systems are used in a wide variety of applications, from aerospace landing gear to tractor implements, prosthetic limbs to wind turbines. The basic idea behind all of them, is that a force is applied at one point and transmitted to another point using an incompressible fluid, with the force usually being multiplied in the process.

The principle of hydraulics is founded on Pascal's Law, which states "A pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere."

Hydraulic Cylinder

Single- or double-acting, a hydraulic cylinder is a mechanism that converts energy stored in the hydraulic fluid into a force used to move the cylinder in a linear direction. As part of the complete hydraulic system, the cylinders initiate the pressure of the fluid, the flow of which is regulated by a hydraulic motor.

The hydraulic cylinder consists of a cylinder barrel, in which a piston connected to a piston rod moves back and forth. Coatings are usually applied to the piston rod to give it good friction characteristics, to minimize wear and maximize performance. So that seals achieve their optimum function, coatings are finished to roughness recommendations from seal suppliers.

Surface Roughness

Surface roughness is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness plays an important role in influencing how an object will interact with its environment.

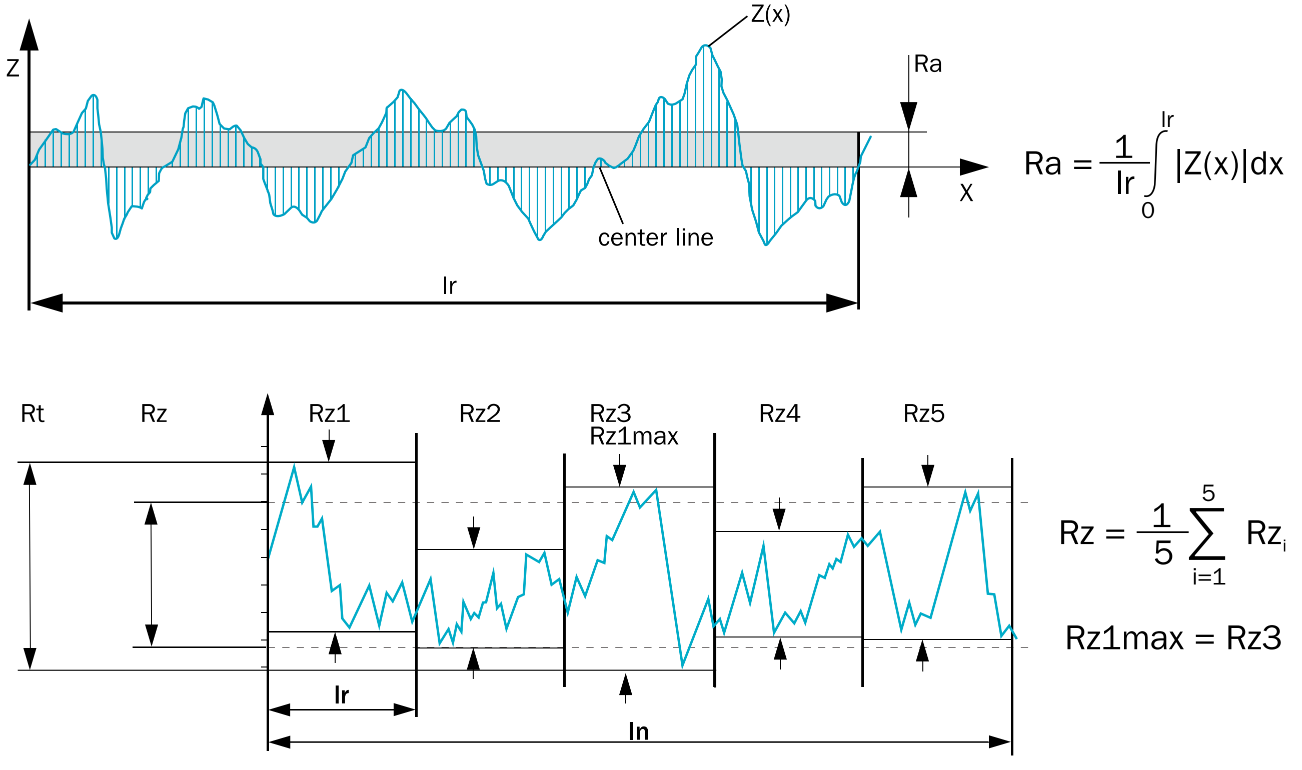
In dynamic hydraulic applications, the quality of a mating surface substantially determines the state of lubrication and wear in the contact area. This is a critical element of the tribology of the whole hydraulic system.

Common Surface Finish Recommendations

Generally, sealing suppliers provide surface finish recommendations using two-dimensional measures.

The most commonly used roughness parameter is the Ra. As described in ASME B46.1, Ra is the arithmetic average of all absolute values of the profile height deviations from the mean line, recorded within the evaluation length; the average of a set of individual measurements of a surfaces peaks and valleys.

In addition to the Ra, other two-dimensional measures are used, such as the Rz and Rz1max. Rz is calculated by measuring the vertical distance from the highest peak to the lowest valley within five sampling lengths, then averaging these distances. The Rz1max takes the largest of the five Rzi-values from the five sampling lengths over the total measured length. See Figure 1.



$$Ra = \frac{1}{lr}\int_0^{lr} |Z(x)|dx$$

$$Rz = \frac{1}{5}\sum_{i=1}^{5} Rz_i$$

$$Rz1max = Rz3$$

Figure 1: Two dimensional roughness parameters (Jenoptik)

Jenoptik: *Rauheitsmesssysteme von Jenoptik Oberflächenkenngrößen in der Praxis,* In: Leaflett 06/2013, 10037108.

Restriction on Chrome Coating

The most common coating used on hydraulic piston rods was chrome. This coating material is based on Hexavalent Chromium (CR6). The REACH (Registration, Evaluation, Authorisation and restriction of Chemicals) directive is aimed at providing a high level protection of both human health and the environment from potentially harmful chemicals. In 2017, it placed restrictions on the use of any coating or plating that utilized Hexavalent Chromium (CR6).

Hexavalent Chromium is the most toxic form of chromium. It is a known human carcinogen, and the toxic waste produced from the Hexavalent Chromium bath during electroplating is deemed a hazardous waste material. It is included in the list of chemicals that have been identified as substances of very high concern, the use of which is restricted and can only be used under strict authorization.

Alternative Coatings

Due to the requirement to eliminate Hexavalent Chromium (CR6) from hydraulic systems, alternative processes are now being used to coat the piston rod. Types of coatings include:

High-Velocity Oxygen-Fuel (HVOF)

HVOF is a thermal spray system utilizing the combustion of gases, such as hydrogen or a liquid fuel, such as kerosene. Fuel and oxygen mix and atomize within the combustion area.

The HVOF coating, generally of tungsten carbide, chromium carbide or nickel hard alloys, is characterized by a comparatively dense layer structure with layer thicknesses of about 0.1 mm to 0.3 mm, dependent on coating material.

Laser deposition welding or cladding

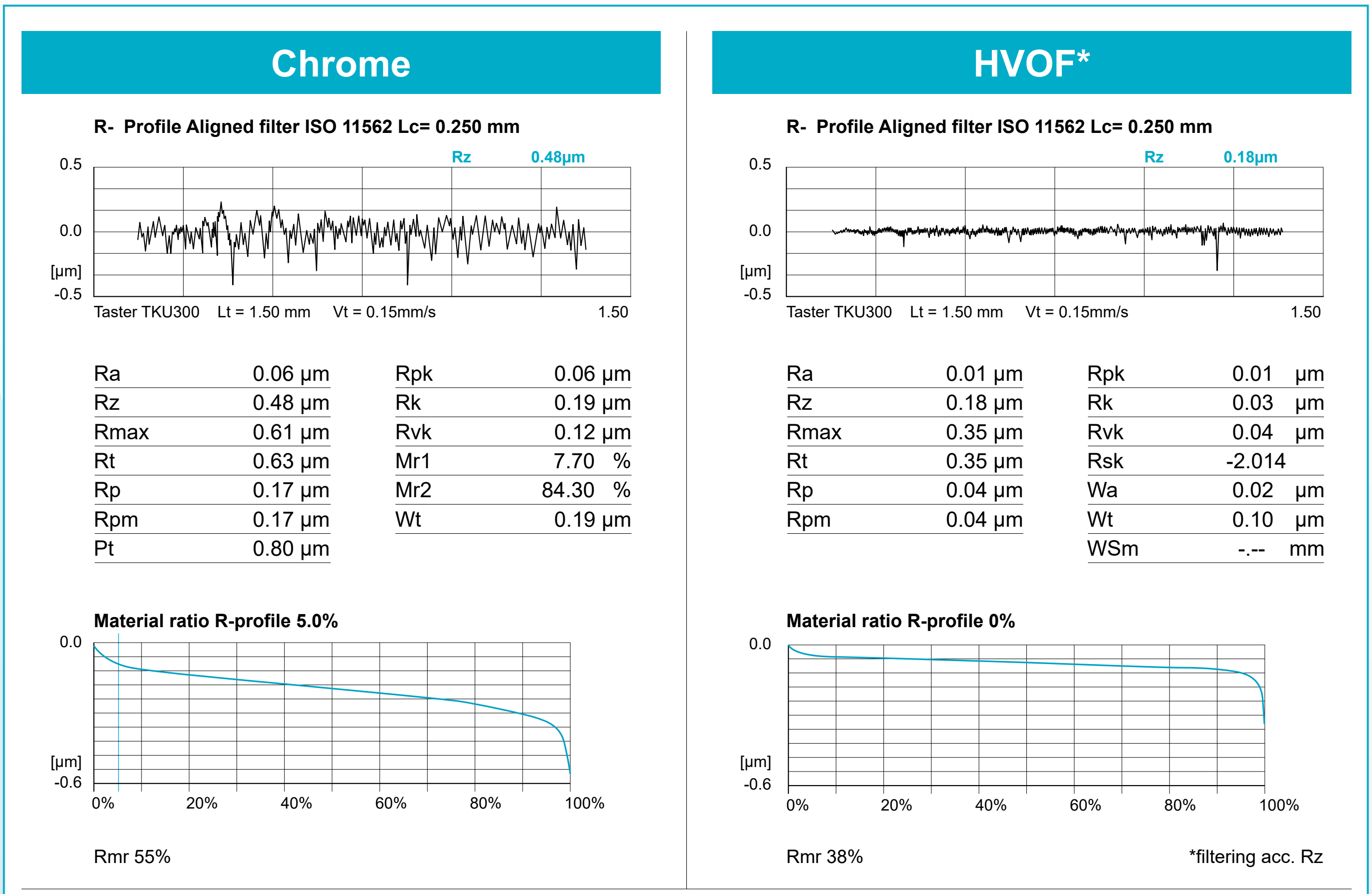
This coating technology achieves layer thicknesses of between 0.2 mm and 4 mm, or more, and usually uses nickel and cobalt-based alloys, steels and carbide blends as coating materials. These layers may be much softer compared to the HVOF layers and chrome layers, depending on the alloy used.

Tribology: The Key to Optimizing Sealing Performance

Surface recommendations based on chrome do not optimize performance with alternative coatings

Surface finish guidance from seal suppliers continues to be based on the surface finish characteristics used to describe conventional chromium layers. The surface finish achieved with chrome, though, cannot usually be achieved with alternative coatings using common coating methods.

The alternative coatings have a fundamentally different topography, as can be seen in Figure 2. Generally, the measures based on chrome can give a good recommendation for the height variations of a surface and can still be used successfully in many applications with alternative coatings.



Chrome

Ra	0.06 µm	Rpk	0.06 µm
Rz	0.48 µm	Rk	0.19 µm
Rmax	0.61 µm	Rvk	0.12 µm
Rt	0.63 µm	Mr1	7.70 %
Rp	0.17 µm	Mr2	84.30 %
Rpm	0.17 µm	Wt	0.19 µm
Pt	0.80 µm		

HVOF*

Ra	0.01 µm	Rpk	0.01 µm
Rz	0.18 µm	Rk	0.03 µm
Rmax	0.35 µm	Rvk	0.04 µm
Rt	0.35 µm	Rsk	-2.014
Rp	0.04 µm	Wa	0.02 µm
Rpm	0.04 µm	Wt	0.10 µm
		WSm	-.-- mm

Figure 2: Comparison of chromium layer (Cutting reference 5%) to HVOF layer (Cutting reference 0%)

However, the difference in surface topography of alternative coating methods leads to significant changes in film formation when compared to chrome.

If the surface finish recommendations used for chrome are used for alternative coatings, hydraulic systems may more quickly reach their performance limits in terms of wear.

Tribology

For hydraulic applications, seal integrity and service life of the system are always the main priorities. To truly optimize this in hydraulic systems, tribology needs to be taken into consideration.

Tribology is the science and engineering of interacting surfaces in relative motion and includes the study and application of the principles of friction, lubrication and wear. The functionality of tribological systems is known to depend on the proper tuning of the tribo-partners. Relative to hydraulic sealing systems, these are the seal, the hydraulic fluid and the mating surface. If the correct tuning is achieved, then friction and wear can be minimized, thereby maximizing the performance and the life of hydraulics.

Optimized tribology needs new measures

If tribology is to be optimized in hydraulic cylinders, the measures given as recommendations by seal suppliers are not sufficient, especially as these are still based on chrome. Due to the resulting differences in surfaces from varying coating technologies and in base materials, “a general definition” of roughness is unlikely to meet requirements to tune the tribology of a hydraulic system.

To optimize hydraulic systems with the latest coating technologies, statements and conclusions on the suitability of a surface should be made on the basis of further parameters, which result from the material ratio curve (Rmr), reduced peak height (Rpk), reduced valley depth (Rvk) and the core region (Rk).

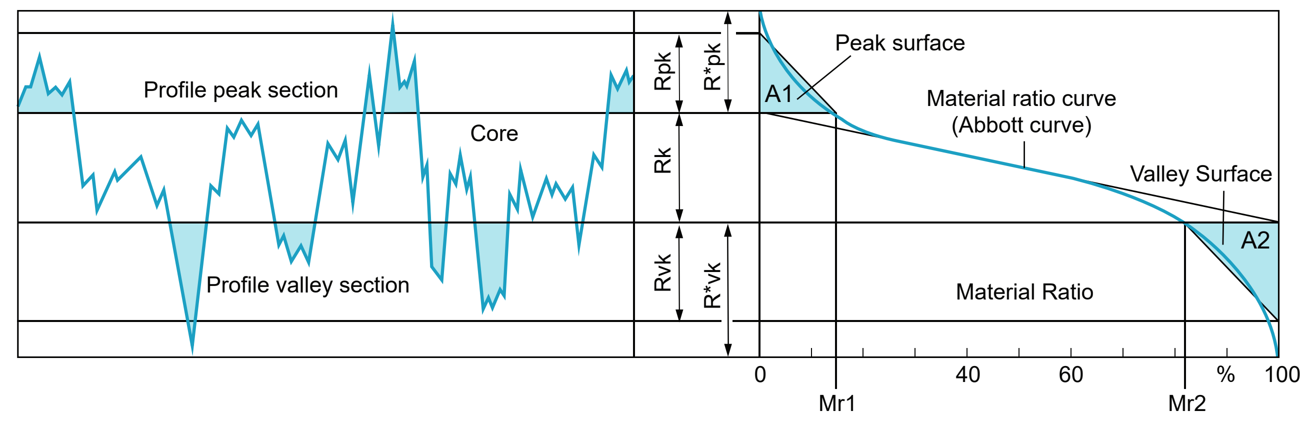


Figure 3: Definition of RK values (Jenoptik)

Jenoptik: *Rauheitsmesssysteme von Jenoptik Oberflächenkenngrößen in der Praxis,* In: Leaflett 06/2013, 10037108.

The characteristic values result from subdivision of the material component curve created from the filtered roughness profile and fall into three ranges.

- Rvk - Average depth of the grooves projecting from the core area into the material
- Rpk - Average height of the peaks protruding from the material
- Rk - Depth of the roughness kernel profile performance limits in terms of wear

Consideration of criteria beyond surface finish

Though measuring surface finish with parameters Rk, Rvk and Rpk provides a much more accurate way of describing mating surfaces, in addition, to truly optimized system tribology, the different coatings, piston manufacturing methods and piston type must also be taken into consideration.

This can be achieved by measuring with different depths of cut, with a cutting reference of 0%, 2% and 5%, which is considering the run-in behavior of the seal and mating surface.

For instance, when comparing HVOF to traditional chrome, the very hard layer of the HVOF coating measured at 0% does not show a change in roughness characteristics over time. Chromium layers, however, show smoothing of the peaks (Rpk) quite quickly, which is considered when measuring at a cutting reference of 5%.

A holistic analysis

Figure 4 attempts to bring this extended approach for describing mating surfaces in terms of coating, manufacturing process and distinction of piston rod and piston tube, together.

It extends the two-dimensional descriptions commonly used today, Ra and Rz, to Rpk and Rvk, with upper and lower limits to properly describe the topography of the various surfaces. It also includes Rmr at various percentage cutting references, dependent on coating type.

		Ra		Rz		Rpk		Rvk		Rmr*	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Rods, hard chrome	Mineral Oil / HFC PTFE Compound	0.05	0.3	0.6	2.0	0.05	0.30	0.05	0.8	50%	70%
	Mineral Oil / HFC Polyurethane (TPU)	0.05	0.4	0.6	2.0	0.05	0.40	0.05	0.8	50%	70%
Rods, Welded and Sprayed Overlays <45 HRC	Mineral Oil / HFC PTFE Compound, Polyurethane (TPU)	0.05	0.3	0.6	2.0	0.05	0.30	0.10	0.8	70%	90%
Rods, HVOF, Ceramic Welded and SprayedOverlays ≥45 HRC		0.05	0.2	0.3	1.5	0.03	0.15	0.05	0.3	70%	90%
Bores, Cylinders honed/grinded		0.05	0.4	0.6	2.5	0.05	0.40	0.10	1.4	50%	70%
Bores, Cylinders roller burnished		0.05	0.4	0.3	2.0	0.03	0.30	0.10	1.4	60%	90%
Bores, Single accumulators honed/grinded		0.05	0.3	0.6	2.0	0.05	0.30	0.10	1.0	50%	70%
Bores, Single accumulators roller burnished		0.05	0.3	0.6	2.0	0.05	0.20	0.10	1.0	60%	90%

*Rmr determined at cut depth C = 0,25 x Rz, relative to reference line Cref = 5 % for soft coatings and chrome
Cref = 2 % for nitrated and hardened Cref = 0 % for ceramic coating

Figure 4: Extended approach to the description of mating surface

Topography description based on test data

The basis for this extended specification comes from extensive dynamic tests on various seals at different loads that take into account determined surface characteristics. Investigations were carried out on rod and piston sealing systems with a wide variety of mating surfaces.

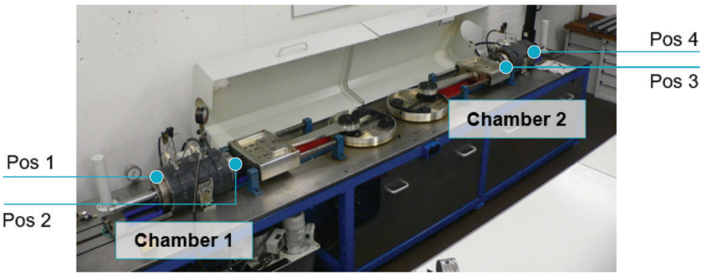
The basis for the characteristic values shown in Figure 4 are the leakage and wear behavior of polytetrafluoroethylene (PTFE), polyurethane (PUR) seals made of ultra-high molecular weight polyethylene (UHMWPE) and the wear behavior of the mating surface.

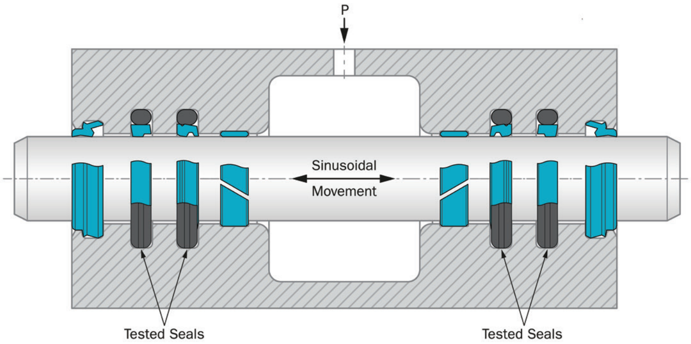
Lubricant optimized hydraulic sealing system

A practical example of optimizing hydraulic sealing is given below and utilizes the extended approach of describing surface finish. The piston rod in the hydraulic system was coated using laser deposition welding, otherwise known as cladding technology.

The traditional surface measurements of these piston rods have a comparatively open profile, with Rpk values between 0.17-0.26 µm and Rvk values of 0.35-0.71 µm, with the Rz values at the upper end of the recommendation and between 1 , 8 and 2 microns. The material ratio was between 71% and 83%.

Stroke Length	300mm
Pressure	0/30 MPa
Velocity	0.7 m/s
Temperature	50 °C
Cycles	1.000.000 DS
Diameter	50 mm
Rod	Laser Cladding
Medium	Shell Tellus 46 / HLP





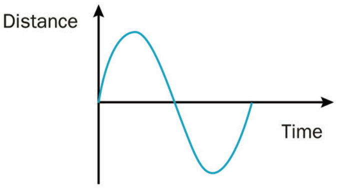


Figure 5: Endurance test bench and test parameters

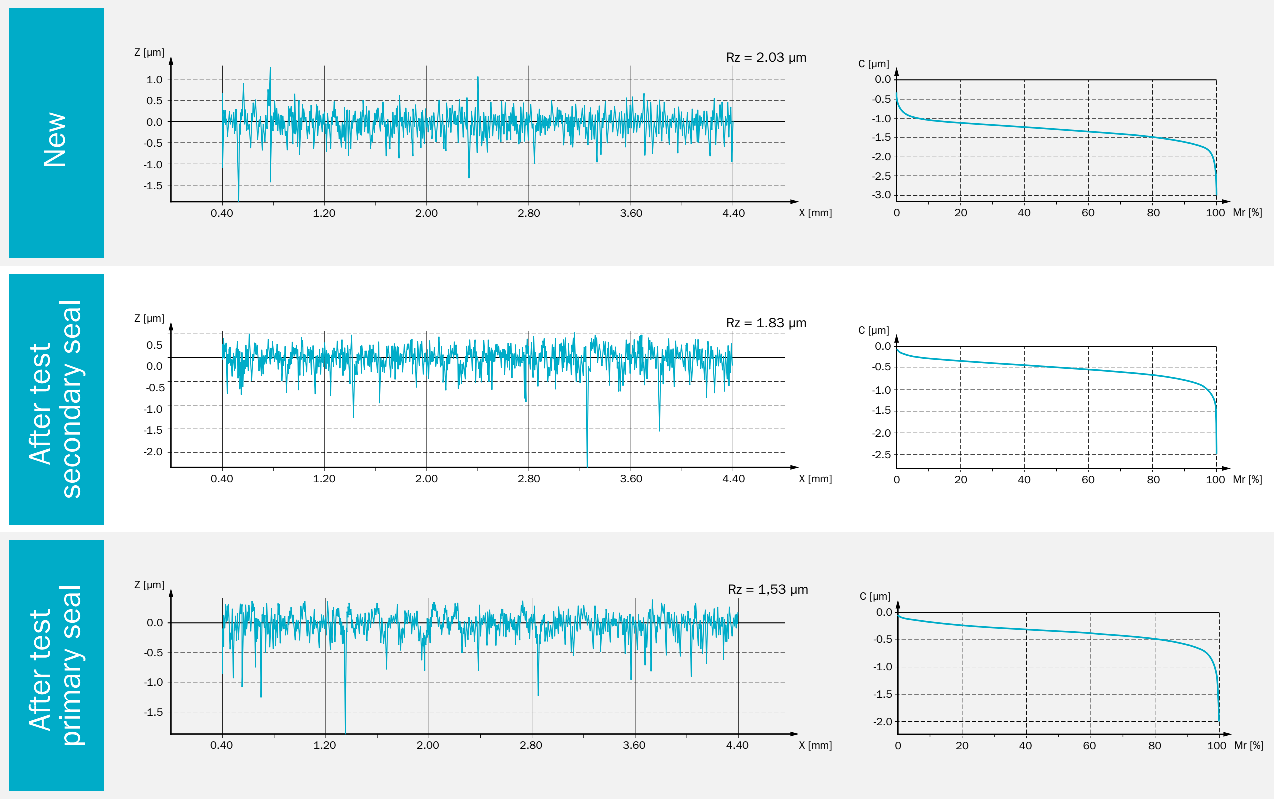


Figure 6: Surface measurements laser cladding with a cutting reference of 5%

By way of example, one of these surface measurements is shown in Figure 6. It gives measurements before and after the experiment, in which a lubrication film-optimized sealing system was used and compared, under the same experimental conditions Figure 5, with a sealing system without optimization of the lubricating film.

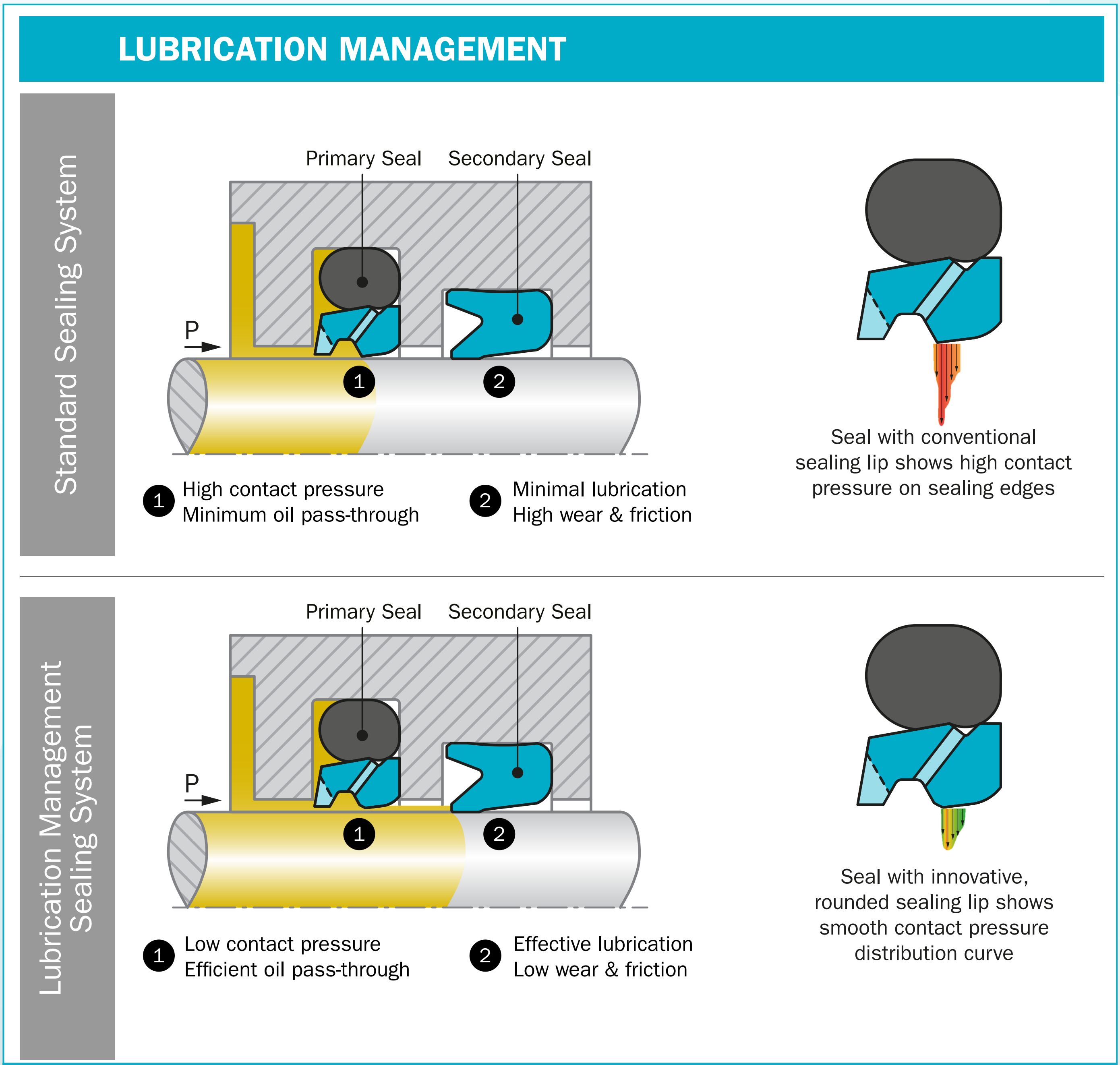


Figure 7: Mode of action of the lubricating film optimized sealing system

In the lubricant-optimized sealing system, the primary seal over the period of the test, shows a reduction in the Rz values by about 25%, calculated with three measurements on the circumference. This reduction in the Rz value can be explained by the low hardness of this layer and is a rather small change for this coating. This is also reflected in the change in Rpk values, which have been reduced by between 50% and 63%.

In comparison, the primary seal in the conventional sealing systems without optimization of the lubricating film, were smoothed in relation to the Rz by between 50% and 60%. This smoothing effect is described even more clearly by the Rpk, where the peaks have changed by between 67% and 84%.

The smoothing of the surface in the conventional sealing system is also mirrored in measurements of wear on the sealing elements, as determined by preload loss and friction.

These results can be extrapolated to propound that the hydraulic system employing Lubrication Management, Figure 7, will significantly extend the life of the hydraulic sealing system, and thereby the hydraulic system itself. Lubrication Management can only be achieved through an extended approach to surface finish analysis and a recommendation that allows the effective tuning of the tribology of the hydraulic system.

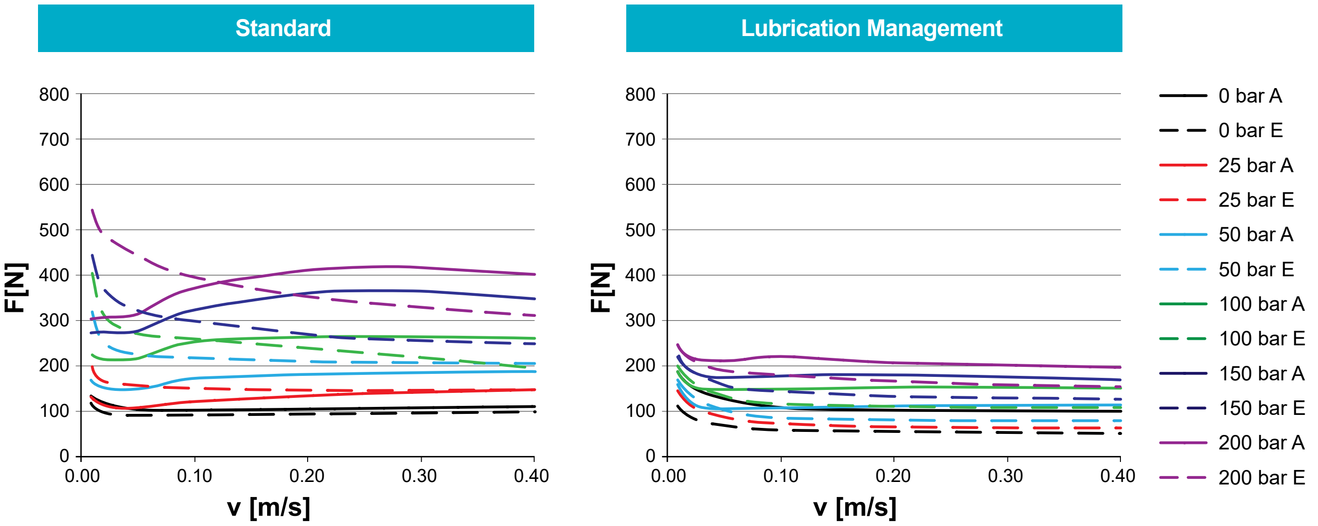


Figure 8: Comparison of sealing system with Lubrication Management to a standard sealing system

The friction is shown in direct comparison in Figure 8. The primary seal used was an O-Ring pre-stressed PTFE stepped gasket, with a polyurethane (PUR) sealing element as a secondary seal and a ultra-high molecular weight polyethylene (UHMWPE) scraper.

Figure 9 shows the minimal wear on these seals in the lubricant optimized sealing system.

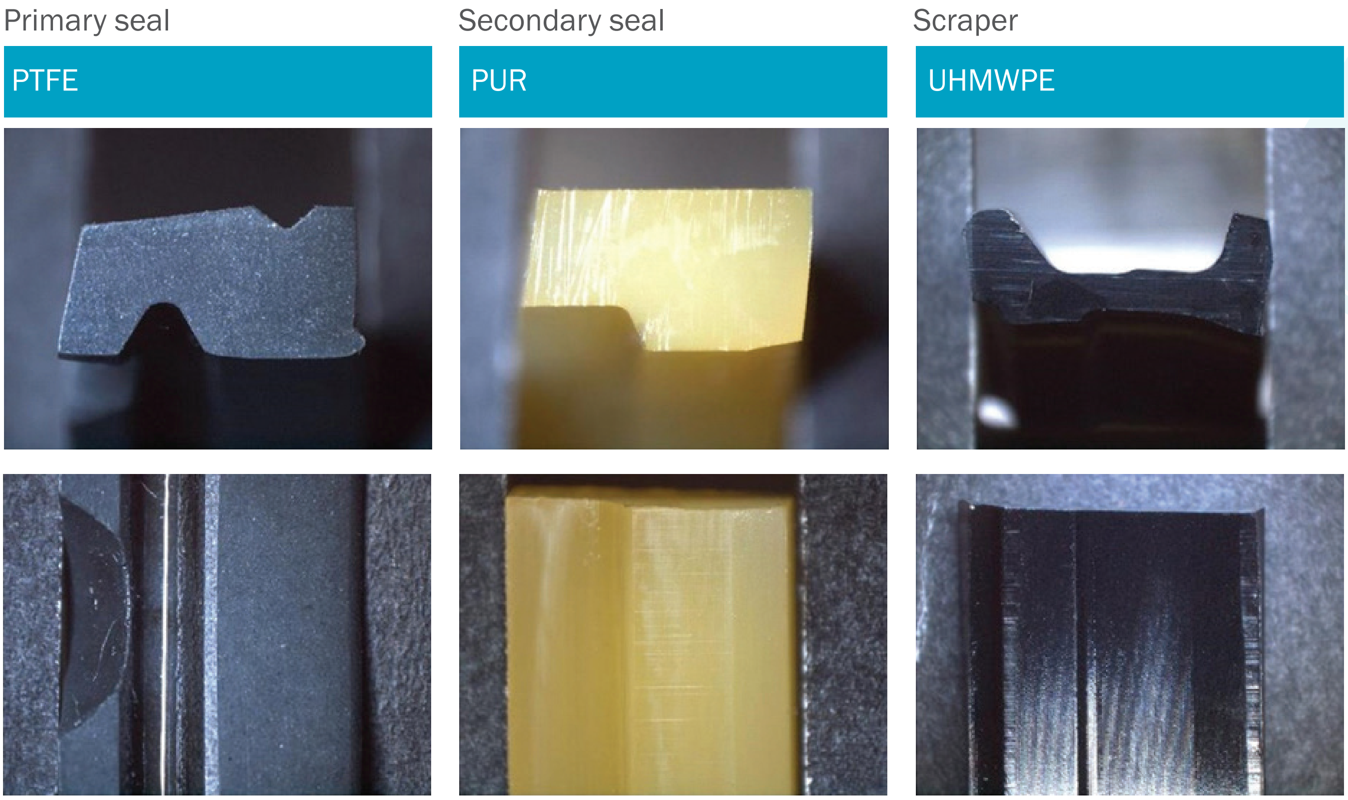


Figure 9: Lubrication Management sealing system after testing

The wear values of the Lubrication Management sealing system, which were evaluated by the change in the profile height (W dimensional loss measured before and after the test), are approximately 1% to 2% for the primary seal. This is substantially lower than the same measurements in the standard sealing system where the loss was approximately 7% to 8%.

In addition to the wear values of the primary seal, a significant improvement was also achieved for the secondary seal, where wear was reduced from 5% to 6% to less than 1%.

Summary and Conclusion

In this whitepaper, an extended approach for the description of mating surfaces for dynamic seals was presented, which takes into account the trend toward alternative coating processes with regard to the necessary substitution of chrome.

Laser cladding-coated piston rods have been used in experiments to show traditional sealing recommendations for chrome coated pistons cannot adequately describe these coatings and optimize the tribology of a hydraulic system. If an extended approach to measurements, analysis and recommendations are taken, it is proven that wear can be reduced both on the piston rod and the seals in the hydraulic system.

Furthermore, studies with Lubrication Management sealing systems have shown that the current performance limits of sealing systems can be considerably extended and a higher degree of robustness can be achieved, even with respect to tribologically critically assessing mating surfaces.

Holger Jordan

Director Global Technical Management
Trelleborg Sealing Solutions Germany
Email: holger.jordan@trelleborg.com

Holger Jordan has been working for Trelleborg Sealing Solutions since 1990. As Director Global Technical Management, he is responsible for Product Portfolio Management and Gap Analyze for Industrial Applications, coordinating development partnerships in a close cooperation between our customers, Trelleborg Sealing Solutions competence centers and production sites.

Dr. Mandy Wilke

Senior Manager Global Technical Management
Trelleborg Sealing Solutions Germany
Email: mandy.wilke@trelleborg.com

Dr. Mandy Wilke has been working for Trelleborg Sealing Solutions since 2012. Following studies in mechanical engineering, she gained extensive experience especially in the field of elastomeric rotary seals. Today, as Senior Manager Global Technical Management, she is responsible for the technical support for Trelleborg Sealing Solutions Marketing Companies globally and coordinates development partnerships in close cooperation with our customers. Additionally, she is leading the Global Surface Competence Team.

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