New Radial Shaft Seals for Turbo Applications

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The seal systems of today's turbochargers for gasoline and diesel engines have to meet high standards. ElringKlinger Kunststofftechnik has developed a new patented concept for radial shaft seals where the design and the materials have both been chosen to meet the specific challenges presented by components such as turbochargers and electric compressors that rotate at high speeds.

TURBOCHARGING SYSTEMS REQUIRE HIGH STANDARDS

Forced induction systems have become indispensable elements of modern internal combustion engines today, particularly with regard to topics such as downsizing and the resulting reduction of CO_2 emissions. In fact, the technology is trending towards the integration of several parallel forced induction systems on the engine; all this under the aspect of smaller assembly sizes and higher demands regarding leakage. This poses increasingly higher hurdles particularly for gap seals such as piston rings.

In their specifications customers require a near-oil-tight turbocharger. However, this requirement is impossible, or at least very difficult to meet using traditional gap seals. Very high rotational speeds, ease of assembly and sealing efficiency during high frequency start/stop engine duty cycles are the demands made on modern sealing systems particularly in the case of turbochargers. Frequently in the spotlight of these applications is the radial shaft seal, which is supposed to meet these exacting expectations as a ready-to-install yet low-cost sealing component. In addition to the required absolute seal tightness, wishes such as very low friction and maintenance-free operation are to be met as well. Standard radial sealing components, typically made of elastomeric materials are unable to rise to these challenges.

Reason enough for ElringKlinger Kunststofftechnik to expand its existing sealing portfolio of radial shaft seals. In partnership with their customers the specialists from ElringKlinger develop high efficiency high-performance compounds with enhanced property profiles to produced low-friction sealing concepts for alternative drive systems. To develop innovative products the entire sealing system including all ambient influences are examined and considered in the design. The sealing called Speedflon is the latest addition to the already comprehensive of radial shaft seals. This innovative and unique radial sealing system represents a completely new sealing alternative to the conventional gap seals on the turbocharger's cold side. Its main differentiating characteristic is the fact that it is a closed and, at the same time, pressure-relieved sealing system.

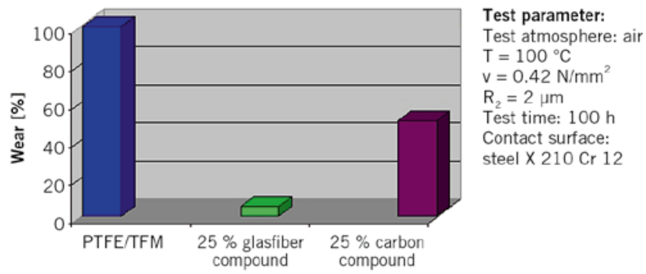


FIGURE 1 Fillers are able to significantly reduce abrasion of PTFE compounds compared with the unfilled matrix material (© ElringKlinger)

THE MATERIAL

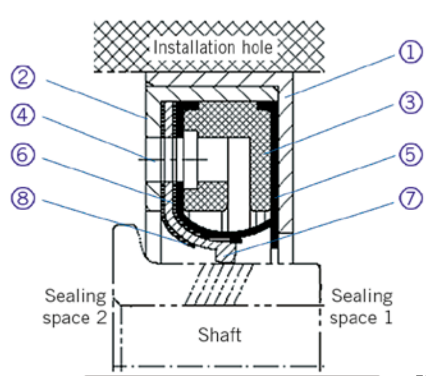
Polytetrafluoroethylene (PTFE) due to its low coefficient of friction is the ideal base material for dynamic seals. On account of the extremely stable bond between fluorine and carbon atoms and the near-complete shielding of the carbon chain PTFE has almost universal chemical resistance and can be used in extreme operating temperatures from -250 to approximately +250 °C [1].

However, performance profiles vary significantly depending on the specific sealing application. In dynamic sealing applications the tribological material properties in conjunction with the dynamic interface dictate abrasion rates which in turn control the ultimate life of the sealing system. In this light, aligning the characteristics of a particular PTFE compound to the final application is essential to ensure the best possible seal performance. By adding different combinations of fillers, **FIGURE 1**, a material can be developed with significantly lower abrasion. In addition to optimum material selection, the functionality and life of radial shaft seals is substantially determined by the contact pressure of the sealing lip against the shaft [2]. Excessive contact pressure and the resulting high friction force are unacceptable for turbocharger applications.

The new sealing is an innovative type of shaft seal which can be used to seal shafts with extremely high rotating speeds. The special characteristic is a combination of the previously described material and design aspects, plus an integrated pressure balance function. This ensures excellent sealing efficiency in combination with very low friction and wear across the entire application range.

SEALING DESIGN

The design of Speedflon and its individual components are shown in **FIGURE 2**. The radial contact pressure of the sealing lip (position 7 in **FIGURE 2**) against the shaft surface is critical for good sealing



Position	Component
1	Ext. angular ring
2	Int. angular ring
3	Inner ring
4	Pressure bore
5	Elastomer moulded part
6	Upper spring plate
7	Sealing lip
8	Lower spring plate

FIGURE 2 Speedflon seal design (© ElringKlinger)

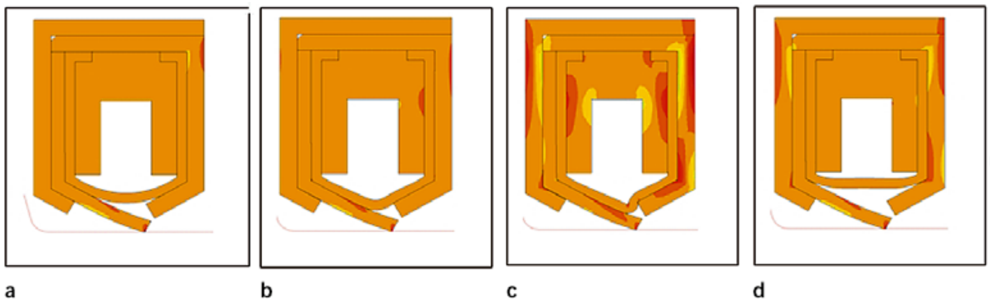


FIGURE 3 Development by means of FEM (© ElringKlinger)

performance. On the one hand, the radial contact pressure of the sealing lip has to be high enough to ensure good sealing efficiency between the medium in sealing space 1 and the medium in sealing space 2. On the other hand, the radial contact pressure must be low enough so that at high rotational speeds ≥150,000 rpm, friction levels do not cause heat which would be sufficient to generate carbon deposits in the sealing gap and subsequent higher wear of the sealing lip.

Naturally, the pressure conditions in sealing spaces 1 and 2 have a major influence on the radial contact pressure of the sealing lip. Assuming a pressure load in sealing space 2, the pressure is scensed directly on and at right angles to the seal lip. With a conventional radial shaft seal this pressurisation would immediately cause the sealing lip to lift, resulting in higher leakage. To avoid this the pressure in sealing space 2 is introduced into the interior (position 3 in **FIGURE 2**) of the seal via the pressure bores (position 4 in **FIGURE 2**). The elastomer moulded membrane (position 5 in **FIGURE 2**), which is the central element of the seal's function, is expanded due to the pressurisation. This counteracts the lifting force of the sealing lip. Should a vacuum exist in sealing space 1 the sealing lip would be pressed against the shaft to maintain good sealing efficiency. If sealing space 1 is pressurised there is no direct pressure relief. However, the bottom side, the sealing lip is supported by a metallic spring (position 8 in **FIGURE 2**) to avoid excessive radial force caused by pressure surges. A second metallic spring on the upper side (position 6 in **FIGURE 2**) of the sealing lip ensures very fast dynamic recovery of the sealing lip in highly dynamic applications. In many applications, pressure conditions on both sides of the sealing lip vary.

With respect to the very low radial contact forces of the sealing lip it is possible to integrate highly dynamic sealing aids into the sealing system which can significantly improve sealing performance. Helical return structures can be applied to the shaft or the sealing lip to ensure good separation of the media either side of the seal lip. According to the installation of standard radial shaft seals the seal can be pressed into an H8 bore for easy and convenient assembly. The seal housing typically consists of two metallic angular rings (positions 1 and 2 in **FIGURE 2**) which, depending on the application requirements, may be made of steel or aluminium. To increase the static sealing effect between the installation bore and the seal, the external angular ring can include an elastomeric coating on the outside diameter. Pressed into the installation bore, contact between the shaft surface and the sealing lip is now created by the retraction of the shaft.

PRESSURE RELIEF

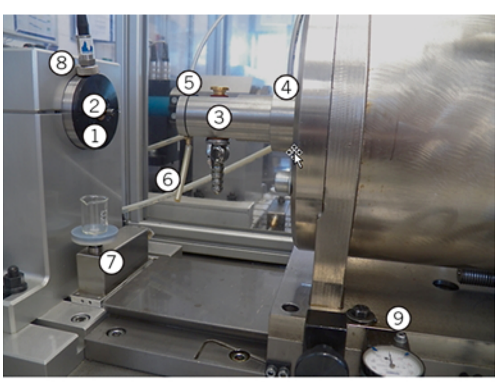
The operating principle of the seal's pressure relief was developed by means of FEM simulations. **FIGURE 3** (a) represents the condition of the seal without external pressure acting on the seal. In **FIGURE 3** (b) pressure loading of 1 bar occurred in sealing space 2 and thus also on the inside of the elastic moulded part. A further pressure increase to 3.5 bar can be detected in **FIGURE 3** (c). **FIGURE 3** (d) represents the shape of the elastic moulded part and the sealing lip under vacuum conditions (-0.3 bar).

TEST BENCH INVESTIGATIONS

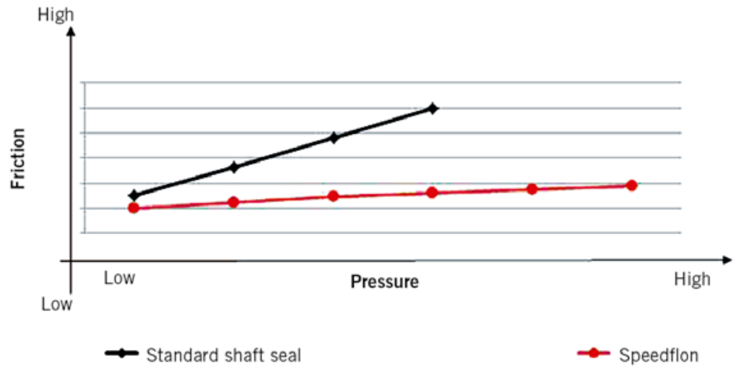
The theoretical results led to the next development step. In addition to the theoretical investigation, the seals were extensively tested on special, purpose-designed test benches. **FIGURE 4** shows a radial shaft seal test bench specifically adapted to the Speedflon seal. The shaft (position 2 in **FIGURE 4**) is driven by an electric drive unit (position 1 in **FIGURE 4**) capable of achieving rotational speeds of up to 150,000 rpm. Parameters such as pressure, fluid level, temperature, runout, eccentricity of the shaft and seal, etc. can be simulated. The effective friction on the seal is determined via the electric power dissipation on the drive unit. Thanks to the flexibility of the test space comparative measurements with other sealing systems such as piston rings can be made as well.

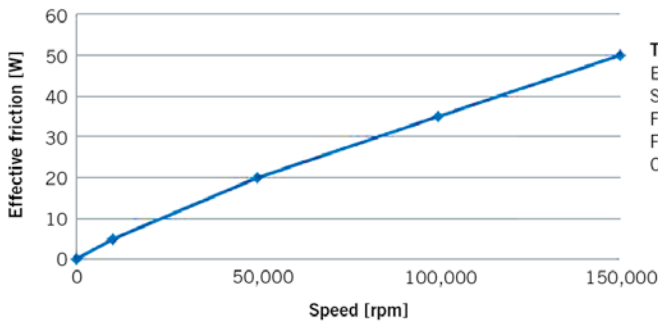
Due to these possibilities the dynamic behaviour of the new seal with ambient

FIGURE 4 Speedflon test bench (© ElringKlinger)



Pos.	Description
①	Electric drive unit
②	Shaft
③	Oil reservoir
④	Control line for sealing space 1
⑤	Control line for sealing space 2
⑥	Leakage removal
⑦	Leakage measurement scales
⑧	Vibration sensor
⑨	Coaxiality adjustment





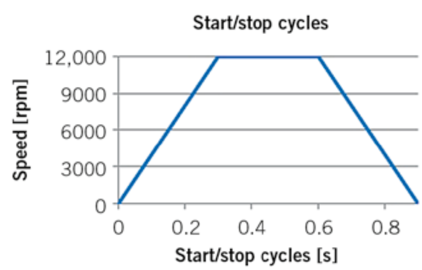
Test conditions:
Electric drive unit
Shaft diameter: 7 mm
Fluid: Castrol EDGE oil
Fluid level: shaft centre
Oil temperature: 100 °C

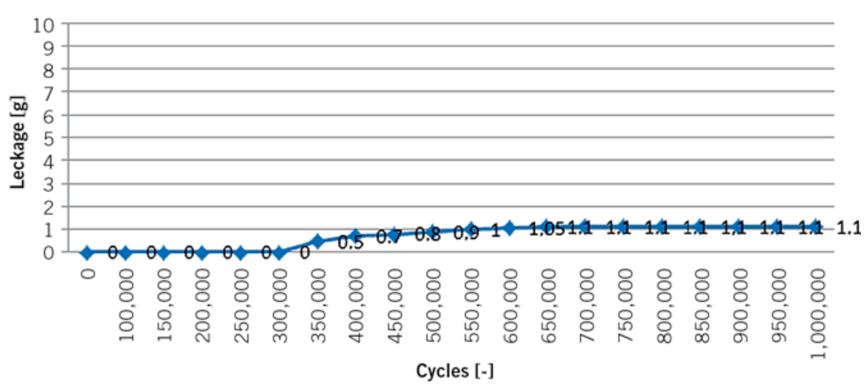
FIGURE 5 Comparison of Speedflon friction behaviour versus standard radial shaft seal (top, schematical) and effective friction measurement of Speedflon in non-pressurised operation (bottom) (© ElringKlinger)

FIGURE 6 Start/stop test run (© ElringKlinger)

Test conditions:
Start/stop simulation test bench
Shaft diameter: 7 mm
Fluid: castrol
Fluid level: shaft centre
Temperature: room temperature
Speed: 0-12,000 rpm (diagram)

Test duration: 1 million cycles





parameters such as shaft speeds of up to 150,000 rpm, temperatures of up to 160 °C, pressures of -0.5 to +4 bar were tested. The performance and functionality was consistently tested in competition with existing gap seals. Due to the closed radial sealing system, enhanced seal properties could be demonstrated. Testing of the pressure relief function revealed clear advantages in terms of friction and wear behaviour of the Speedflon seal compared with conventional radial shaft seals. The wear behaviour and the friction powers shows **FIGURE 5**.

Due to the closed sealing system excellent sealing properties were achieved even in the lower rotational speed range all the way to standstill. This results in further advantages such as new positioning options of the turbochargers in the engine compartment.

In **FIGURE 6** the sequence of a start/stop test run across 1.2 million cycles is shown. By comparison, open sealing systems such as piston rings, due to their design and function, have considerable weaknesses in start/stop conditions.

The test runs have shown that the PTFE compound specifically developed for the Speedflon sealing lip has very good wear and friction properties. Minimal breakaway force and no stick-slip effect are further advantages of the sealing lip's properties.

Another special characteristic is the possibility to use this seal with other engine charging systems such as e-boosters. The patented seal design including the sealing lip made of a special wear-resistant PTFE compound makes it possible to achieve very good sealing properties in ranges close to so-called dry-running operation, without any negative impact on effective friction. The tests at ElringKlinger do not serve as approval tests for charger manufacturers as only the seals are considered without taking the influences of turbochargers as a whole into account. However, various test set-ups at customer sites have confirmed the new, positive properties of the new sealing.

SUMMARY AND OUTLOOK

In summary, the patented Speedflon seal design including pressure relief provides uniform radial force across the entire pressure range even at high rotational speeds, resulting in pressure-independent balance of the sealing lip.

In addition to existing solutions such as piston rings or face seals, ElringKlinger Kunststofftechnik in developing Speedflon has managed to offer a unique, radially closed sealing system for use in applications with high rotational speeds such as turbochargers and electric compressors (e-boosters) as a new alternative that is attractive in terms of technology and economy.

REFERENCES
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