Chapter 2

Mechanical shaft seal types and sealing systems

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1. Mechanical shaft seal types

In this chapter, the basic working principles for single mechanical shaft seals will be put into a practical context. The chapter describes mechanical shaft seals used in Grundfos pumps as examples of the variety of shaft seal solutions for different applications.
Type A

Unbalanced O-ring seal with rigid torque transmission system

Robust O-ring seal featuring a rigid torque transmission design required for hard material pairings (WC/WC or SiC/SiC), even where lubrication is poor. The dynamic secondary seal is an O-ring. This involves a risk of wear on the shaft under the O-ring and of seal hang-up (blocking of axial movement of the rotating seal ring).

Type B

Rubber bellows seal

Bellows seal with torque transmission across the spring and around the bellows. Therefore it is not designed for hard material pairings in applications with poor lubrication. Due to the bellows, the seal does not wear the shaft, and the axial movement is not prevented by deposits or seizure on the shaft.
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**Type C**
*Unbalanced O-ring seal with spring as torque transmission element*

Low-pressure, simple O-ring seal with the spring acting as torque transmission element. Therefore the seal is dependent on the direction of shaft rotation. The shown seal is for a counter-clockwise shaft rotation.

The seal type is excellent for low-temperature, clean-water applications with a ceramic/carbon seal face pairing.

**Type D**
*Balanced O-ring seal with spring on the atmospheric side*

Due to the balancing, this O-ring seal type is suitable for high-pressure applications.

The seal is excellent for high-viscosity, dirt- and fibre-containing liquids because the spring is located on the atmospheric side. The seal features rigid torque transmission design.

**Type G**
*Rubber bellows seal with reduced seal face*

Rubber bellows seal like type B but with a narrow seal face. Due to the narrow seal face, the seal performs well in high-viscosity and anti-freeze liquids.
Type H
Balanced, cartridge O-ring seal unit with rigid torque transmission system

This seal type is assembled in a cartridge unit which makes replacement safe and easy.

Similar to the type D seal, the balancing makes this O-ring seal type suitable for high-pressure applications.

Type K
Balanced, rolled-metal bellows cartridge seal unit

The metal bellows acts both as spring and torque transmission element.

This seal type has only static rubber parts, with reduced risk of hang-up similar to type B.

Type R
Unbalanced O-ring seal, type A, with reduced seal face

O-ring seal like type A but with a narrow seal face. Due to the narrow seal face of the unbalanced design, the balancing ratio exceeds that of seal type A. This reduces the pressure and temperature operating limits of the seal.

Similar to type G, the seal performs well in high-viscosity and anti-freeze liquids.
Type O
Two seals mounted in a “back-to-back” arrangement

This seal arrangement incorporates a clean barrier fluid with a higher pressure than the pumped medium. This totally prevents leakage from the pumped medium to the environment and the clean barrier fluid secures a good lubrication of the seal faces of both seals. See descriptions on page 32.

Type P
Two seals mounted in a “tandem” arrangement

This seal arrangement incorporates a clean flushing fluid with a lower pressure than the pumped medium. This cools the seal rings of the seal in the pumped medium and prevents precipitation from leakage. See descriptions on page 36.
2. Sealing systems

Some of the shaft seals described previously can be combined with specially designed pumps and in double seal arrangements. See the principles described below.

Circulation
Sometimes it is necessary to cool the seal faces of single mechanical shaft seals or remove deposits in the seal chamber. In such cases a circulation pipe from the pump discharge side to the seal chamber can be fitted. The cooling liquid flows from the seal chamber back to the pumped medium. This ensures a good exchange of liquid in the seal chamber. A pipe dimension of Ø10/Ø8 is sufficient.

Internal circulation from the pressure side to the seal chamber can also be integrated in the pump design with the same result. See fig. 2.1.

Fig 2.1: Circulation circuit for cooling a single mechanical shaft seal

Double seals can be arranged in tandem with the seats in the same direction on the shaft, or back-to-back with the seats in the opposite direction on the shaft.

The purpose of these designs is, among other things, to control temperature, pressure or flow in the cooling/heating lubricating liquid.
Back-to-back arrangement with barrier fluid, seal type arrangement O
This term is commonly used in sealing engineering to describe an arrangement with two shaft seals mounted in opposite directions. Between the two seals is a pressurised barrier fluid. The barrier fluid has several advantages to the product-side seal as compared to a single shaft seal. See fig. 2.2.

The seal arrangement is suitable for poisonous and explosive liquids when no leakage from the pumped medium to the atmosphere can be accepted.

The barrier fluid pressure is higher than the pump pressure, as a result of which any leakage will pass from the barrier fluid to the pumped medium. The barrier fluid pressure must be minimum 2 bar or 10 % above the pump medium pressure close to the seal. As the clean barrier fluid has a higher pressure, it also serves as lubricating liquid for all seal faces.

The back-to-back shaft seal arrangement is particularly suitable for sticky media and/or liquids with many abrasive particles. The seal arrangement prevents the pumped medium from entering the seal gap and consequently prevents excessive wear.
Water or water mixed with glycerine is the most common liquid in closed pressurized back-to-back arrangements because it is non-poisonous and compatible with many types of pumped media. The barrier fluid chosen must always be compatible with the pumped medium.

To maintain the overpressure in the barrier fluid in relation to the pumped medium pressure, various pressure sources can be used as described in the following sections.

**Fixed pressure**

A pressure vessel with fixed pressure in the barrier fluid with 10% or 2 bar higher than the pressure in the pumped medium. See fig. 2.3.

The advantages are as follows:

- compensates leakage
- cools the seals by means of natural convection or forced circulation
- indicates the pressure in the barrier fluid
- possibly gives alarm when the barrier fluid level is low/high
- allows refill of barrier fluid with pressure maintained in the vessel
- constant air pressure secures the barrier fluid pressure
- indicates temperature and liquid level.

![Fig. 2.3: Pressure vessel with fixed pressure connected to a Grundfos CR pump with a back-to-back seal arrangement](image-url)
Fixed pressure obtained by means of a dosing pump
Another way of obtaining a fixed pressure in the seal chamber is by means of a dosing pump. The pump automatically keeps the level set for the overpressure. This solution is mainly used in dead-end applications where cooling from the seal chamber is sufficient. See fig.2.4.

Fig. 2.4: Dosing pump maintaining a fixed pressure for back-to-back seal in a Grundfos CR pump

1. Seal chamber with barrier fluid
2. Pump
3. Membrane vessel
4. Dosing pump
5. Pressure switch
6. Manometer for barrier fluid
7. Reservoir with barrier fluid
**Pressure intensifier**

The Grundfos pressure intensifier automatically creates a pressure that is 2 bar higher than the pump medium pressure, independent of the specific pump medium pressure. The system maintains the overpressure automatically until it is empty. The intensifier requires a discontinuous working cycle, as it has to be refilled. The barrier fluid inlet must be fitted with a non-return valve to avoid back pressure to the source. See fig. 2.5.

1. Seal chamber with barrier fluid
2. Pump with pumped medium
3. Non-return valve, inlet side
4. Safety non-return valve (>5 bar)
5. Elastomer membrane

Fig. 2.5: Pressure intensifier mounted on a Grundfos CR pump
**Tandem seal arrangement with flushing fluid, Seal type arrangement P**

The system contains a seal chamber with two shaft seals mounted in the same direction. The flushing fluid between the two seals has lower pressure as compared to the pumped medium and offers several advantages to the product-side shaft seal such as following:

- There is no evaporation in the sealing gap. This prevents the formation of deposits as well as crystallisation on the flushing fluid side.

- The flushing fluid lubricates and cools even when the pump runs dry or runs with vacuum. See fig. 2.6.

*Fig. 2.6: Grundfos CR pump with a tandem seal arrangement*
There are several ways of connecting the flushing fluid from an elevated reservoir to the seal chamber such as:

**Seal chamber with circulation from a reservoir**

Connect the seal chamber to a reservoir with circulation. The flushing fluid circulates by natural convection or a separate pump, lubricates and cools the seal faces. The flushing fluid in the reservoir must be replaced after a period of time due to contamination from the pumped medium.

**Seal chamber with dead end connection from a reservoir**

Connect the reservoir with a single pipe to the seal chamber. The flushing fluid lubricates the seal faces, but cools them less than by circulation. The flushing fluid in the reservoir must be replaced after a period of time due to contamination from the pumped medium.

**Seal chamber with external flushing fluid**

Allow the flushing fluid to circulate through the seal chamber to a drain. The flushing fluid cools and lubricates the seal faces effectively and makes it possible to monitor the seal leakage.

*Fig. 2.7: Flushing fluid examples*
Other sealing systems

Sanitary shaft seals
The demands on shaft seals in pumps designed for sterile and sanitary applications differ entirely from those made on other seals.

Often the seal needs to comply with standards and regulations. Some of these are summerized in Chapter 6.

In some instances the seal materials must comply with guidelines for cleanability and resistance to the pumped media and be capable of CIP, cleaning-in-place, and SIP, sterilisation-in-place. In addition, low roughness values and electro polished surfaces, marked yellow, are required on medium side components.

Special attention must be paid to the elastomer components of the shaft seal. Elastomer components must withstand the pumped media and temperatures in the cleaning processes. The purpose of these requirements is to ensure that all shaft seal surfaces in contact with the pumped media can be cleaned.

See figures 2.8, 2.9 and 2.10.
High-speed mechanical shaft seals
Where speeds exceed 15-20 m/sec, the seat must be the rotating part to reduce unbalance of the seal. See fig. 2.11.

Other advantages of the rotating seat are that misalignment of the shaft causes the springs to adjust only once and prevent fretting of the sleeve under the O-ring.

Fig. 2.11: (To the right) Example of a high-speed shaft seal for Grundfos BME pumping system

Air cooled top for high temperatures
For applications in working high temperatures of the clean pumped medium such as hot water or thermal oil, it can be advantageous to extend the length of the pump.

As a result, and air chamber will be formed below the seal chamber. Thanks to this arrangement, the standard shaft seal is located at a distance from the hot pumped medium, allowing the shaft seal to generate a stable lubricating film in the sealing gap. The exchange of pumped medium with pumped medium from the seal chamber is very low due to a throttle around the shaft.

An automatic air vent valve is required to vent the seal chamber. This stand-alone sealing arrangement is independent of external connections. See fig. 2.12.

Fig. 2.12: (To the right) Example of a Grundfos CR pump with air-cooled top
**Magnetic-drive system**

The magnetic-drive system constitutes an entirely different type of sealing of a rotating shaft. For applications where it is absolutely necessary to avoid leakage from the shaft seal, an alternative to a back-to-back arrangement is a can that separates the pumped medium side from the atmospheric side. The magnetic-drive system incorporates an outer and inner rotor with magnets, separated by the can. The magnetic-drive system transfers the torque from the motor to the pump shaft. The system only has static O-rings to seal the clean pumped medium, free from magnetic particles.

This stand-alone sealing arrangement is independent of external connections. See fig. 2.13.

*Fig. 2.13: Hermetically sealed system with magnetic-drive system*
External-seal arrangement
For the pumping of some types of clean and very aggressive but non-poisonous media, it can be an advantage to place the rotating part of the seal with the springs and seal driver outside the pumped medium.

This type of balanced seal requires internal overpressure to keep the seal faces together. The clearance between shaft and seat is so large that an exchange of liquid to cool the seal faces can take place. See fig. 2.14.

Submersible motors
The differential pressure between the inside and the outside of the submersible motor is small. Therefore mechanical shaft seals as well as lip seals can be used. However, the life of a mechanical shaft seals is much longer.

Special arrangements are made to prevent excessive overpressure inside the motor. See. fig. 2.15.
3. Selecting a mechanical shaft seal

The mechanical shaft seal should be selected according to the operating conditions at the shaft seal location.

These important factors must be considered when selecting a mechanical shaft seal:

- Shaft seal diameter
- Type of pumped medium
- Temperature
- Sealing pressure
- Shaft speed of rotation.

**Shaft seal diameter**
The shaft seal diameter must be selected to fit the pump shaft. If no seal with the required diameter is available, the shaft diameter can be changed with a bushing.

**Type of pumped medium**
The chemical resistance of the shaft seal materials to the pumped medium has to be considered. The viscosity of the pumped medium affects the lubrication and leakage of the seal. The viscosity of most media depends on the temperature. A single shaft seal can be used for a dynamic viscosity below 2500 cP (centipoise). For a higher viscosity, a back-to-back seal arrangement should be used.

**Temperature**
The elastomeric parts of the seal must be able to withstand the temperature of the medium around the seal. This might be different from the temperature of the pumped medium. If the temperature is above the boiling point of the pumped medium, lubrication is poor. This must be considered when selecting seal design and materials.

**Sealing pressure**
The sealing pressure is the pressure around the seal. For high pressures, a balanced seal should be used.

**Shaft speed of rotation**
If the speed of rotation is low, shaft seals with hard/hard material pairings might produce noise because the lubricating film in the seal gap is extremely thin. At speeds above 15 m/sec, a balanced seal with a rotating seat must be used to reduce seal unbalance.
In addition to these operating conditions, the content of abrasives and additives in the pumped medium might be relevant to consider when selecting seal ring materials. In some instances, the space available for the shaft seal is also an important factor. When selecting the right sealing arrangement around the mechanical shaft seal, also take into account the content of abrasives and the risk of build-up of wearing particles on the atmospheric side as well as the health hazards, explosion risk and toxicity of the pumped medium.

Summary
Mechanical shaft seals can be composed in many different ways with different performances. The type of seal selected depends on the pumped medium, temperature, pressure and speed. For harsh applications, single mechanical shaft seals can be combined using tubes, membranes, springs, valves and separate cooling liquid systems.