DYNAMIC POSITIONING CONFERENCE
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Thrusters

Thrusters and Pod-Seals

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Blohm & Voss

PROPELLER SHAFT SEALS
THRUSTER AND POD – SEALS

1. Introduction

2. Technical Basis

2.1 Lip seal

2.1.1 Sealing mechanism and influencing criteria
Essential operating conditions and characteristics
Geometry
Sealing ring materials
Rotating part (liner)
Sealing system

2.1.2 Physical and chemical influences

2.1.3 Important for selection and operation

2.1.4 Advantages/disadvantages

2.2 Rotating mechanical seal

2.2.1 Sealing mechanism and influencing criteria
Essential operating conditions and characteristics
Geometry
Rotating/Counter ring materials

2.2.2 Physical and chemical influences

2.2.3 Important for selection and operation

2.2.4 Advantages and disadvantages

Return to Session Directory

3. Selecting a seal

Questionnaire

4. Examples of thruster/pod seals

4.1 Thruster seals

4.2. Pod seals

Literature: H.K. Müller
Abdichtung bewegter Maschinenteile
(Sealing Moving Mechanical Parts)
Medienverlag

F.W. Reuter
Dichtungen in der Verfahrenstechnik
(Seals in Processing Technology)
Resch Verlag

Simrit Standard Catalogue
Freudenberg

E. Mayer
Axiale Gleitringdichtungen (Axial
Rotating mechanical Seals)
VDI – Verlag

Introduction

Wish and Reality

Nature has created or developed unimaginably complex systems in many areas. However, no organisms exist that are formed similar to a wheel. The problem of the rotating seal has simply not been solved by nature; even though, when considered superficially, seals are very simply constructed.

The requirement that a seal has to be leak proof is understandable as a result. Unfortunately it is also physically impossible.

Every seal has a gap with a differential pressure. Technically speaking this acts as a throttle, thus allowing a fluid transfer even under ideal conditions.

The fact is that, more or less, every seal is prone to leakage, we speak here of "technical tightness".

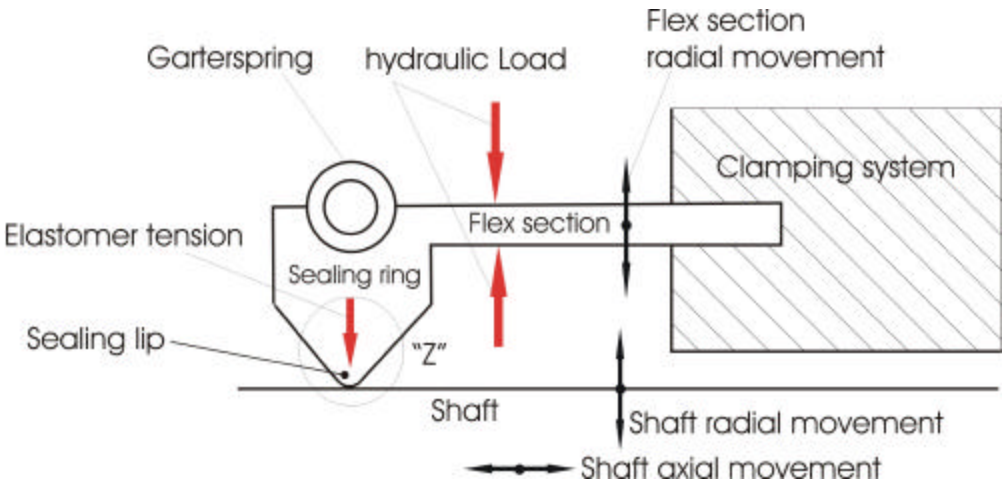
The requirement is thus: "Minimum leakage with maximum service life"

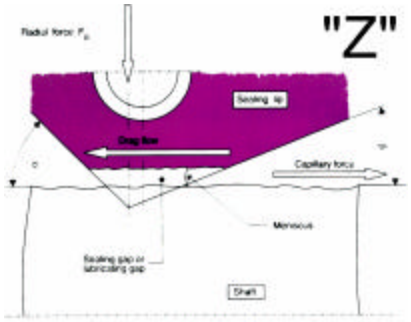
2. Technical Basis

2.1. Lip seal

2.1.1. Sealing mechanism and influencing criteria

a. Essential operating conditions and characteristics





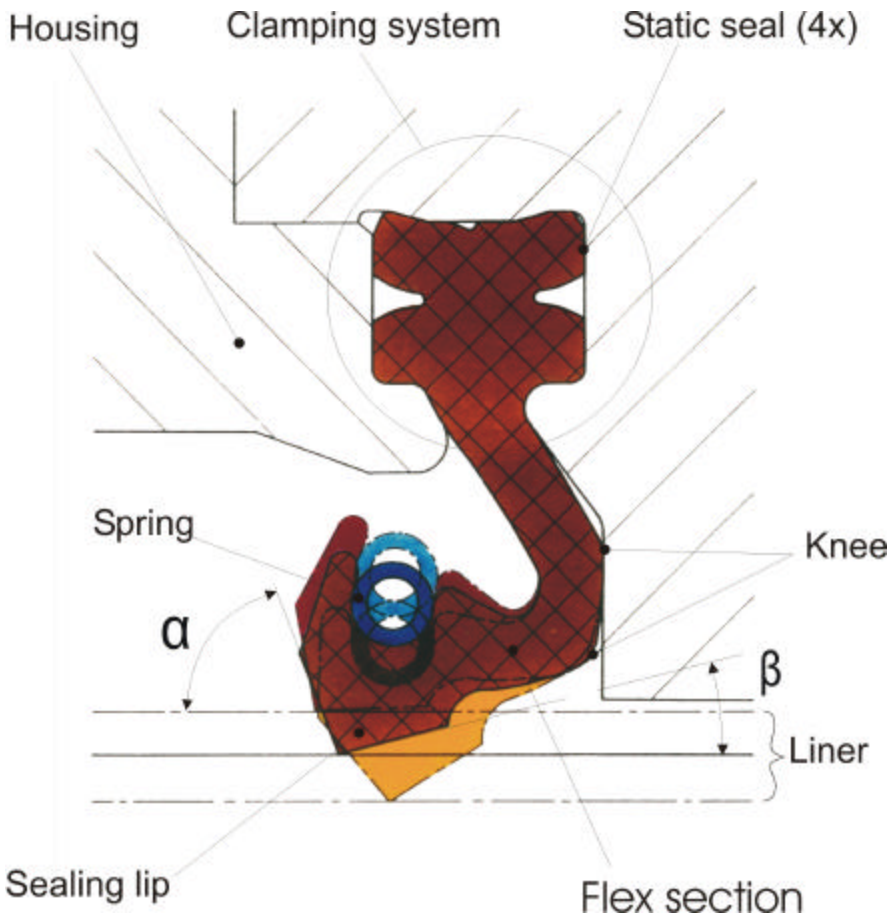
The basic function of a sealing ring can be divided into two main areas:

1. Static sealing of the sealing ring in the housing

2. Static and dynamic sealing between the sealing ring lip and the shaft (liner)

   The sealing ring is subject here to a complex interaction between the sealing ring material, the rotating counter face (liner), the fluids (oil/water) to be sealed and the surroundings influenced by the ship operation.

b. Geometry



Mounting	- Guiding the sealing ring in the housing - Reliable static sealing - Sealing material must not be pressed towards knee due to uneven pressure - The sealing ring must not be allowed to slip out of the housing or to twist during mounting.
Knee:	Functions like a swivel; important for the radial mobility and sealing ring loading
Diaphragm: (knee section)	The diaphragm surfaces and the position of the knee determine the hydraulic loading on the sealing ring.
Ring lip:	The angles ? and ? are important for the functioning of the sealing ring (lubrication)

c. Sealing ring material

The most important sealing ring materials are:

FPM Fluoro - rubber

NBR Acrylic - Nitrile - Butadiene - bituminous rubber (Acrylonitril - Butadien rubber)

Max temp.	In oil	In air	Short-term	Storage stability	Dynamic functionality key- up to:
FPM	**110**	**130**	**160**	**6 years**	**- 1°C**
NBR	**60**	**80**	**120**	**4 years**	**- 11°C**

The temperatures given are from our experience with ship's seals.
(Higher values are given for agricultural and industrial applications)

Most important in regard to the sealing ring material is the base polymer (50-70%), the additive (30-50%) and the production process.
The selection of the additives (type, quantity, quality),together with the production process allows an unlimited number of possibilities for developing the material in one direction or another.

For ships' seals, the materials used must be resistant against oil and sea water, whatever the proportion of oil to water may be.
In particular: water/oil emulsions can be extremely aggressive.

In regard to developing materials, it is necessary to carry out long-term tests (2000h) with actual ships' seals. This means in reality, that testing continues over a period of some 3 months. If "only" 60 different mixtures are to be tested, it will take a development period of 15 years. Three tests taking place in parallel would reduce the period to 5 years.

Material development is, as a result, extremely expensive.

d. Rotating part (liner)

The most important parameters for the liner are:
Tribological property, surface quality, hardness and surface geometry.

Cr Ni steel with a high alloy content is used.

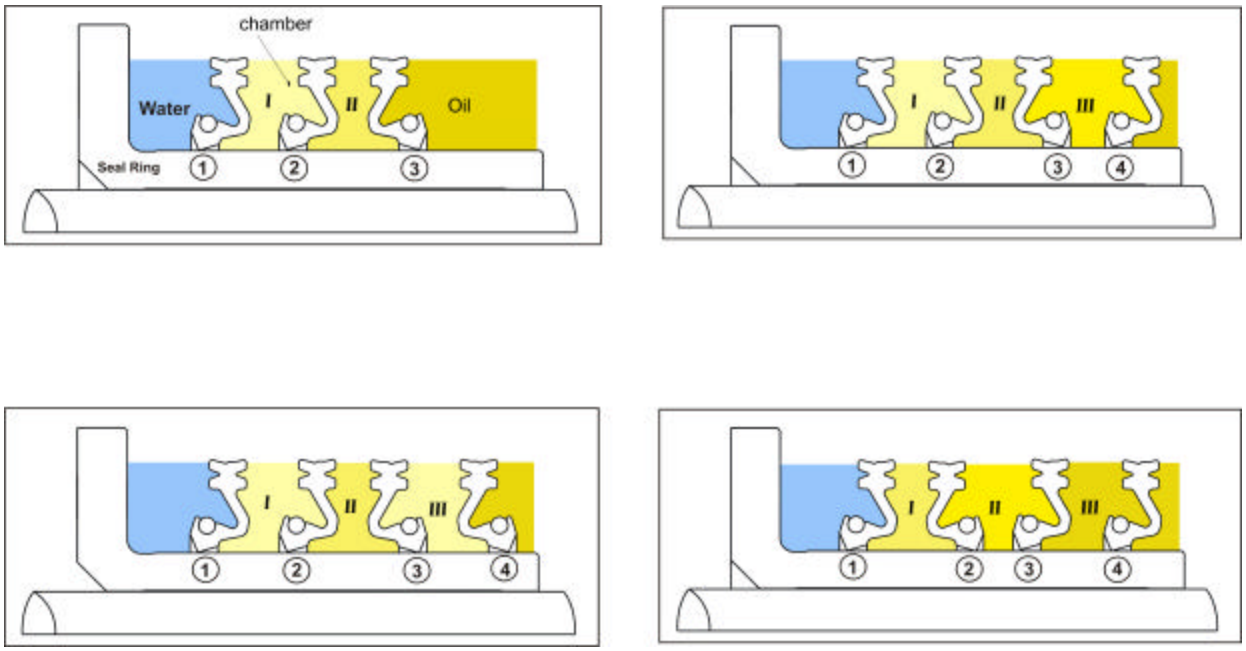
Cr - content	~	27%
Ni - content	~	4 - 7%
Mo- content	~	1 - 5%

Hardness: 250 - 270 HB
Structure Austenitic - Ferritic
Problem: A compromise between hardness (important for the sealing ring) and resistance to sea water must be found.

Materials that are highly resistant to sea water have a hardness that lies below 200 HB, which means that wear is too high under normal ship operating conditions.

e. Sealing systems

Example: 3/4 sealing rings (double the number is also feasible)



The sealing system (sealing ring arrangement/number) and the supply to the chambers is extremely important for the success or failure of a seal.

If the details of the application (see also the questionnaire in paragraph 3.0) are sufficiently exact, a seal specialist will be able to suggest a solution. But, because the operating conditions of a ship or ship propulsions vary considerably, a wide variety of different seals must be used. Unfortunately, there is no perfect solution available for all applications.

2.1.2 Physical and chemical influences

a. **Pressure (water/oil)**

The water/oil pressures and the sealing system itself determine the load on the sealing ring.

High sealing ring load ✍ Wear, heat, Material ageing Service life ?

b. **Nominal speed/ Circumferential speed**

The shaft rotating motion forms a lubri-lubricating film between the sealing ring and the liner which should be kept as stable as possible.
As a rule, the circumferential speed lies between 3-6 m/s (Navy ships 5 - 8 m/s). Extremely high circumferential speeds cause high temperatures in the sealing ring/liner gap.

c. **Radial/Axial Motion**

High radial and axial oscillations cause short and strong pressure peaks resulting in a strong pumping effect.

Water ✍ Oil
Oil ✍ Water

No problem when together with a peak pressure absorber! This must be known in advance, however.

d. **Temperatures**

High temperatures cause a thin lubricating film in the seal gap which raises the temperature even further. Water and oil emulsions are also influenced by high temperatures; they sometimes become chemically extremely aggressive against the elastomer with rising temperatures.

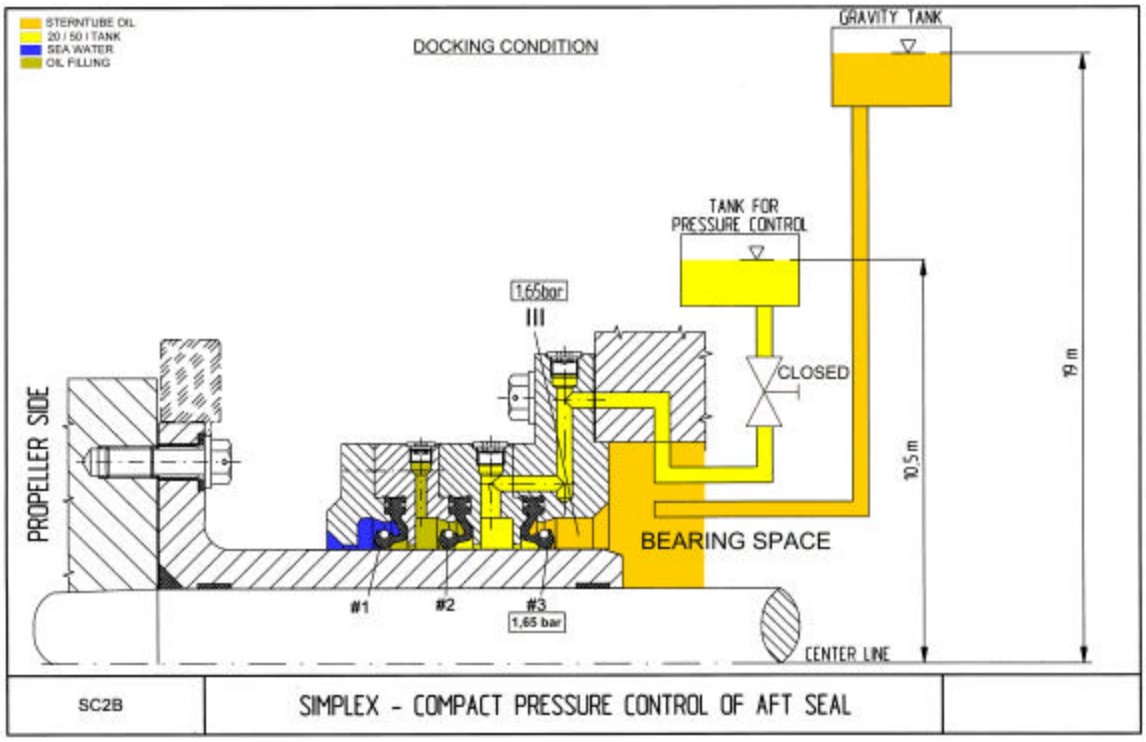
e.	Dirt	Because seals work with a very small seal ring/liner clearance (approx. 1µm), very fine dirt that enters the gap is particularly dangerous. Lubricating film break down, wear and high temperatures result. No effective method for avoiding this is available. However, several seals can be positioned axially behind each other.
f.	Fluids (oil/water)	Important for lubrication and cooling. Some water and oil emulsions are very aggressive against sealing ring materials. Trial tests should always be carried out. If possible: select a sealing system with a good supply of oil to the sealing ring and a sealing ring load that is as low as possible.

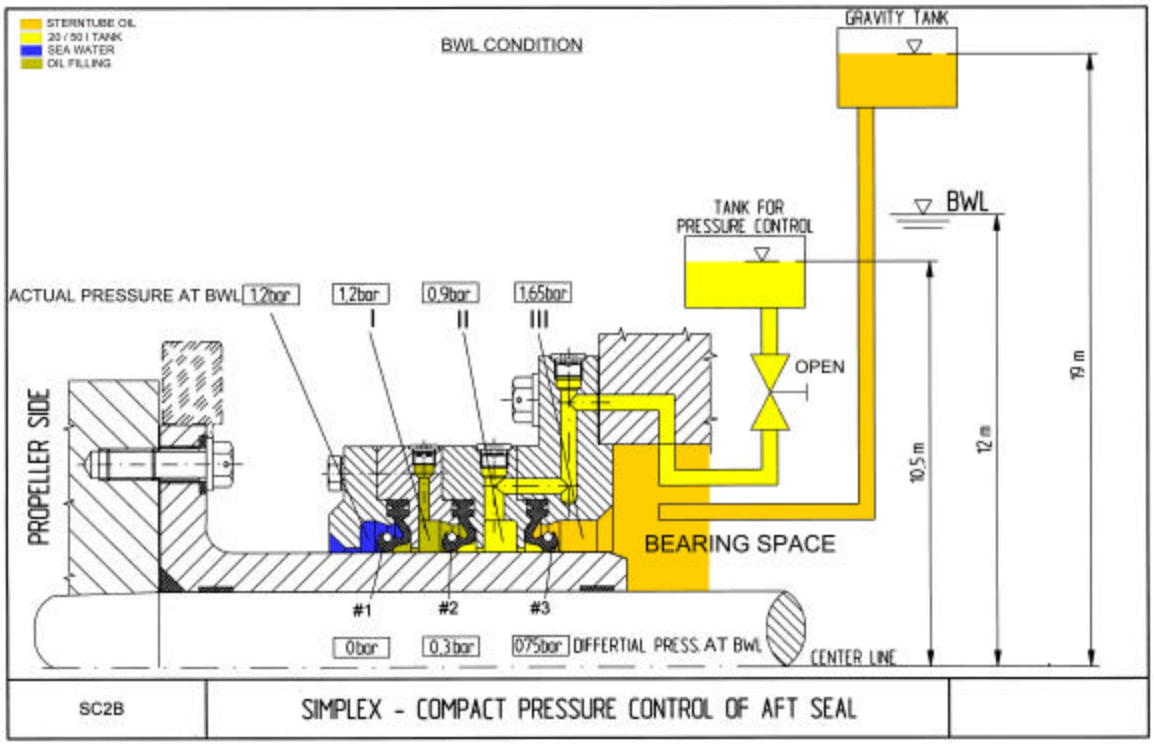
2.1.3 Important for selection and operation

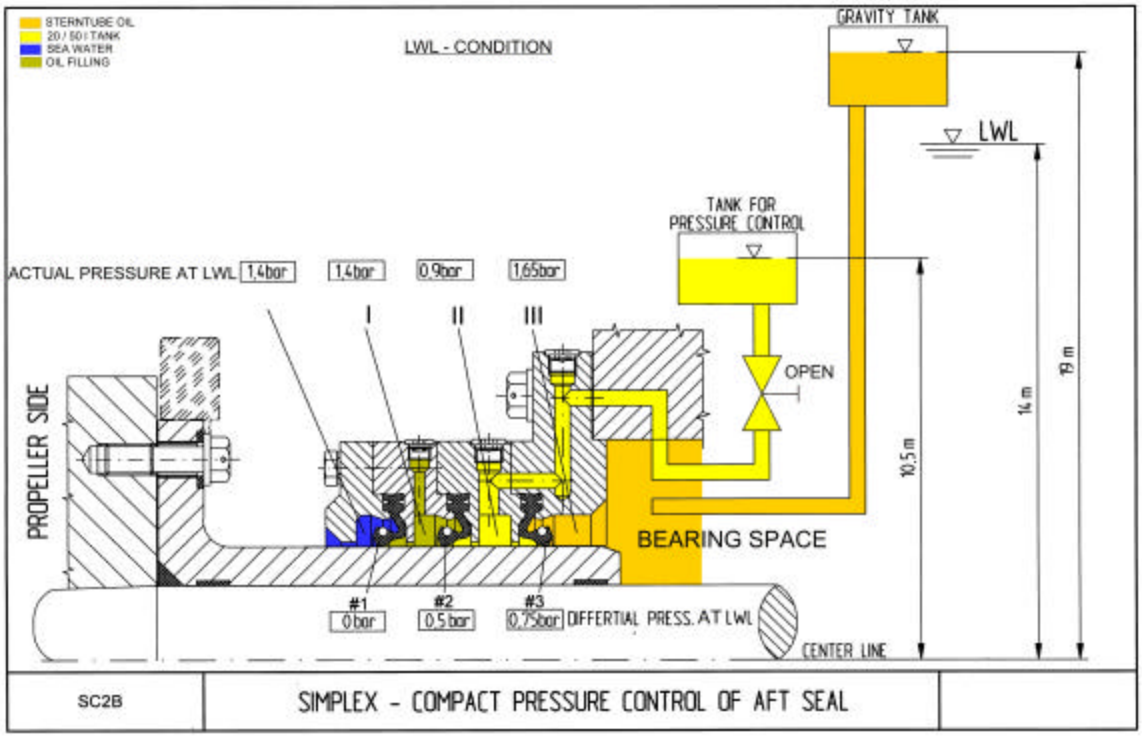
Where possible, state all technical operating conditions to ensure a correct selection of the seal.(see 3.0)

* Sealing ring loading

Important for maintaining the sealing ring loading:
Tank heights to be checked, switch-over point to be
Changed to 2nd tank.



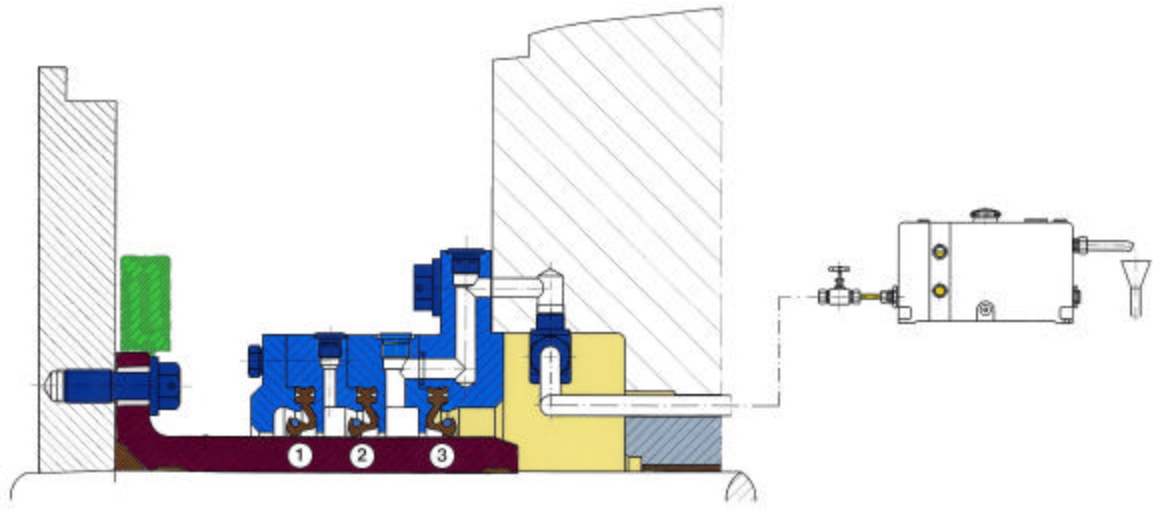


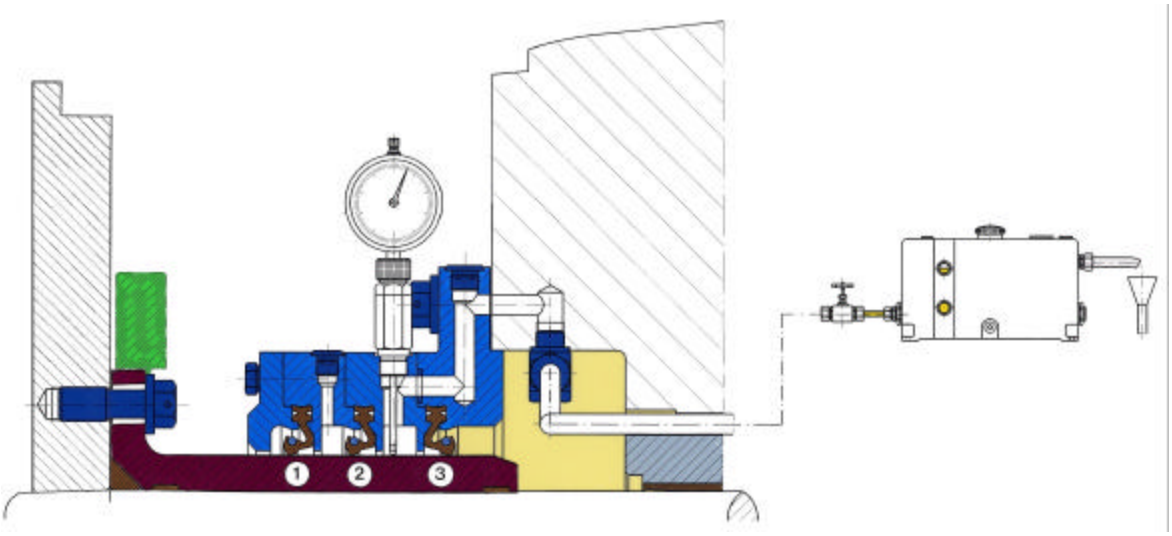


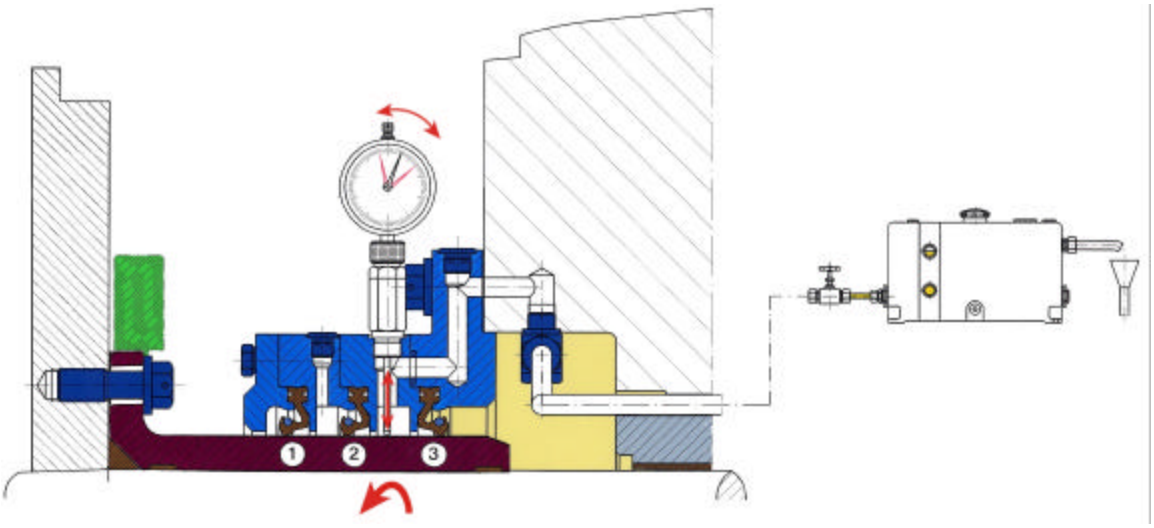
Return to Session Directory

Installing seals is one of the most frequent sources of error.
Check concentric rotation of the liner

Oil not reaching chambers (bore covered by packing
or pipe connected incorrectly.)
Fill pipe line and sealing chamber with oil.
(lubricating and cooling the sealing surface is important)






1
2
3

Material compatibility (sealing ring) with water/oil

The sealing ring must be checked for compatibility with water/oil. A list giving the approved oils is available.

New oils are tested before being approved.

Synthetic and environmentally friendly oils cannot presently be used in conjunction with water.

2.1.4 The advantages and disadvantages of lip seals

Advantages: Any number of seal rings can be included in a seal arrangement (redundancy).
No problem in terms of axial and radial oscillation normal to ships
As a rule, sealing system consists of a simple construction
Compact design
Sealing ring load can be changed during operation
(Tank height)
Seal immune against shock load
Problems with lips seals do not normally occur suddenly (long period of advance warning)

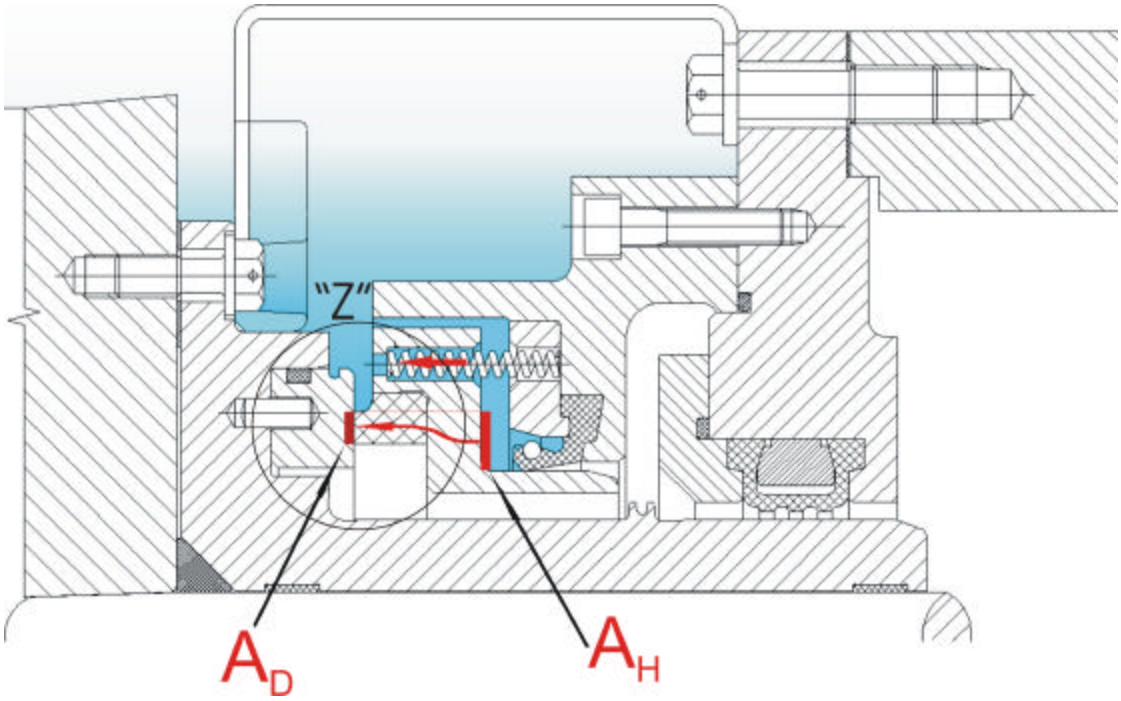
Disadvantages: The sealing ring load is limited. Submarines, for instance, always have a mechanical face seal.
Processes in the seal gap are nearly impossible to calculate (empirical values are very important)
Temperature levels are limited depending on the sealing ring material

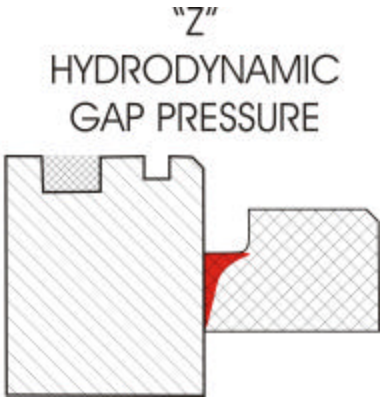
2. Technical Basis

2.2 Mechanical face seal

2.2.1 Sealing mechanism and influencing quantities

a. Essential operating conditions and characteristics





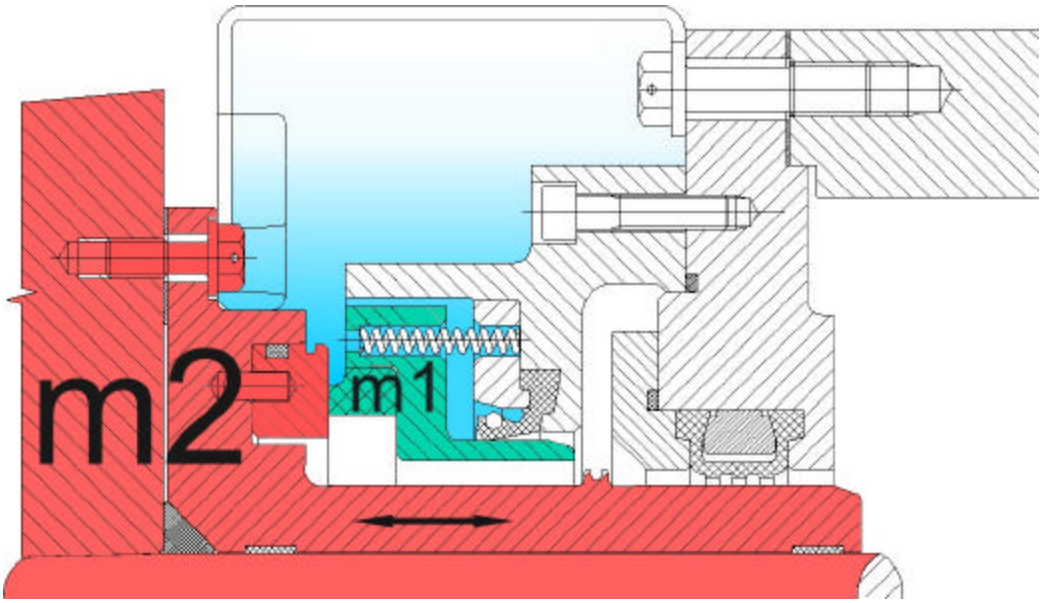
The sealing effect of a mechanical face seal is caused by spring elements and supported by the pressure of the medium to be sealed. As in the case of a valve, the sealing effect increases parallel to the pressure. This axial force forces a rotating mechanical ring against a stationary counter ring, or vice-versa.

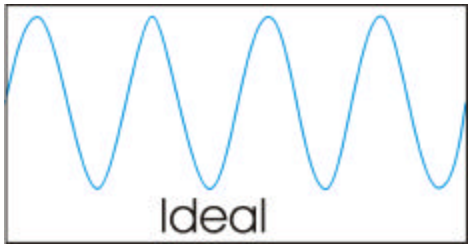
In order that the previously-described valve-like sealing effect builds up, the fluid to be sealed must be sealed at the secondary seal on the shaft and housing side (simmer ring, o ring etc)as well as at the seal gap.

The desired effect combined with sufficient operational time can only be achieved when several basic requirements are fulfilled.

- The right design matching the application
  (pump seals cannot be used as ship's seals)

- Axial oscillations are a basic problem



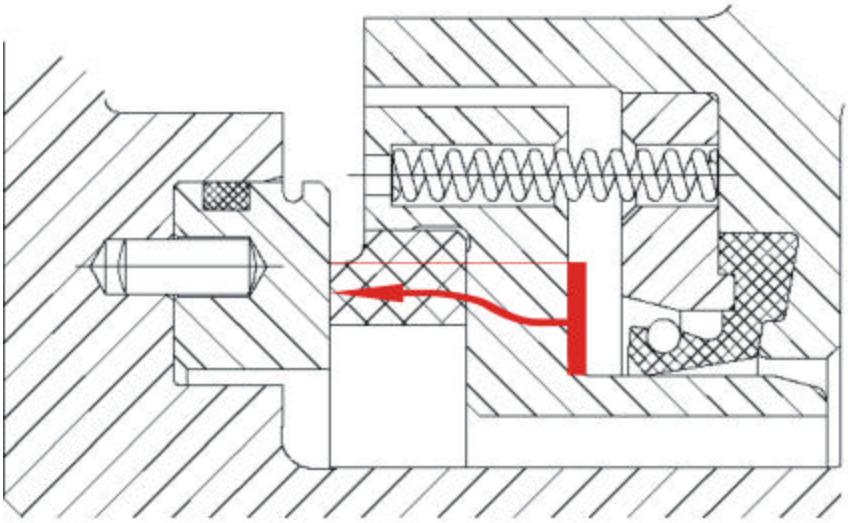


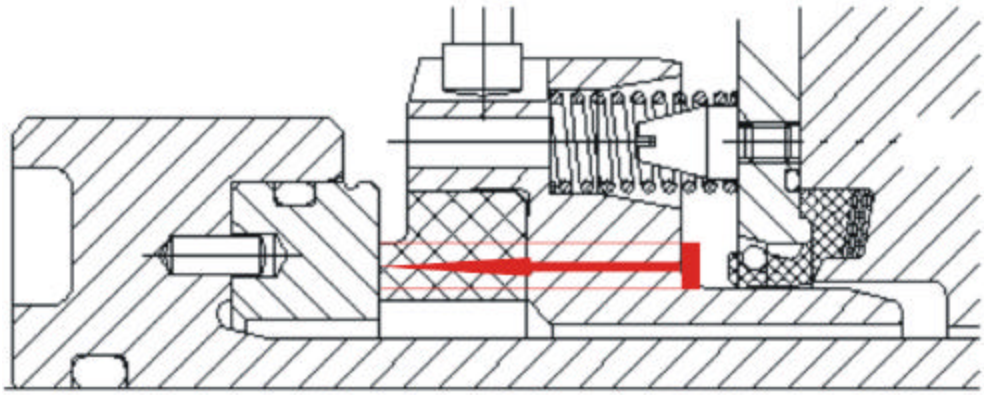
With axial oscillations, the mechanical face seal can only function or seal optimally if m_1 and m_2 oscillate with the same frequency. This is physically impossible. Because this concerns a damped system, a phase shift always occurs between the exciting mass m_2 and the damped single-mass oscillator m_1 .

In practical terms, this process means the seal gap more or less opening up to a large degree depending on the type and extent of the axial oscillations.

- Important also, is the selection of the material (with new material pairs, tests should be carried out)
(also see 2.2.3)

b. Geometry





Rotating mechanical seals can be categorised according to load. The so-called K factor shows the surface relationship between the hydraulically loaded area and the seal gap area K = AH/AD

The load factor K characterises the amount of pressure of the rotating ring on the counter ring, thus representing the hydraulic force closing the seal gap.

If the sealing pressure differential ? p is greater than 10 bar, pressure-relieved mechanical seals are usually used.

Pressure seals are nearly always used exclusively for ships' seals. One exception is submarines, which are always equipped with pressure-relieved rotating mechanical seals.

c. Rotating/counter ring materials

There is a confusing choice of materials available for mechanical seal rotating and counter rings.

The technical significance of materials to date varies considerably.

? Increasing significance
? Constant significance
? Decreasing significance

The main groups consist of:

Artificial carbon ?
Plastics ?
Metals ?
Carbides ?
Metal oxides (ceramic) ?
Non-oxidised ceramic (SiC)?
(SiC-Si)

The selection of materials requires physically substantiated criteria. These result from the processes that take place in the seal gap (pressure, circumferential velocity) and the physical conditions in the vicinity of the seal (e.g. dirt).

Main requirements: One of the two contact faces should be capable of a minimum wear (edge compression is reduced);
the other should be as wear-resistant as possible. Important is the tribological suitability of the materials (lubricating film build up, low friction). A mechanical seal ring should have good thermal conductive qualities.
Corrosion-resistant, high mechanical bearing strength (distortion).
Emergency running properties

Individual solutions are normally required for use on ships.

2.2.2 Physical and chemical influences

a. Pressure (water) Water pressure in connection with the K - value and the spring elasticity determine sealing load (seal gap). Excessive

changes in pressure are a problem for mechanical seals. The seal gap geometry changes continually (leakage).

High seal gap load ? wear, heat

b. Nominal speed/ circumferential speed

As soon as the shaft rotates, a lubricating film is produced between the rotating and the counter ring This process is comparable with the build up of a lubricating film in a thrust bearing. High nominal speeds cause high temperatures in the seal gap. If oil is sealed against, carbonizing can occur in the seal gap. Steam can also occur in the case of water.
? Wear, leakage, high temperatures

c. Radial/axial movements (oscillations)

Axial oscillations result in a pumping effect in the seal gap. Through the phase shifts between rotating ring and the counter ring, the seal gap will be partially opened.

High load on secondary seal
An O-ring cannot be used as a secondary seal for ship's seals.

d. Temperature

The thermal output produced by a mechanical seal is determined by the following parameters:
friction value μ (0.009 to 0.25)
Contact speed
Contact pressure
Contact face area

The large bandwidth for the friction value μ indicates the complexity in the relationship between seal construction, rotating and counter ring materials and the medium to be sealed. If possible, the medium to be sealed should be clearly defined (water or oil).

e. Dirt

The seal gap of a mechanical face seal lies in the µ metre range. Very small and hard particles of dirt are a particular problem. Even if a so-called hard-hard pair (SiC) is used, the lubricating film in the seal gap is affected ? Wear, high temperature.

2.2.3 Important for selection and operation

What is very important for the function and service life of a mechanical seal is the automatic setting of the seal gap. Fluid must enter the gap and produce a stable lubricating film in all conditions. A mechanical face seal is certainly comparable with a hydrodynamic friction bearing.

1. The correct selection of materials
   Rotating ring/counter ring/spring

2. A rotating ring holder with a secondary seal must be designed for ships' use.

3. The rotating ring must be easy to move axially at all times

4. If possible, no axial shaft oscillations

5. Tensile stress and sudden compression of carbon and ceramic ring edges via internal pressure, centrifugal force and friction torque are to be avoided through appropriate design.

6. Rotating ring and mating ring should be secured against rotation (friction torque support!).

7. Flatness of the sealing surfaces

8. At least one of the sealing rings forming the gap should demonstrate good thermal conductivity.

9. The temperature of the fluid at the gap entrance must be sufficiently below the evaporation temperature. Reliable lubricating film production in the seal gap.

10. The higher pressure should affect the outer circumference.

11. The spring strength must be high enough for the counter ring to follow the rotating ring under pressure-less conditions.

Installation errors:
Contact faces damaged prior to installation
Secondary seal damaged
Foreign matter in the gap during installation (dirt)
Installation dimensions incorrect (installation length!)
Secondary seals damaged during installation (e.g. gasket on the flange)

2.2.4. The advantages and disadvantages of mechanical face seals

Advantages:

A large variety of different materials can be used.

The seal gap load, or the complete seal, can be calculated very effectively.

High pressures (e.g. submarines) can be sealed-off safely.

Disadvantages:

Only one seal gap (no redundancy)

Problems with axial oscillations (pump effect)

Sealing system technically complex

Shock loads result in leakage or seal breakage.

Seal failure occurs without any advance warning (suddenly)

3. Seal Choice

Questionnaire

Thruster / Pod Manufacturer:	
Yard:	
Shipowner:	

Thruster		Pod	

Open sea		Shallow water		Low ice class		Ice breaker	

Operating area	Cold water	-3 to +15°C	
	Warm water	+16 to +32°C	

Dirt load	Low	
	Medium	
	High	

Draught	BWL / Shaft centre line	[m]	Operating time period	[%]
	LWL / Shaft centre line	[m]	Operating time period	[%]
	Additional:	[m]	Operating time period	[%]

Absolute enviroment friendly	

Oil pressure in gear / bearing housing	Constant:			bar
	Varying	bar	bar	bar
Lube oil supply ? gear / bearing housing	Full	Oil type		
	Half (shaft centre line)			
	Spray lubrication			
Shaft diameter: [mm]	Shaft rpm max. [1/min]			

Operating time per year [h]	2,000	
	4,000	
	6,000	
	8,000	

Return to Session Directory

4. Examples of Thruster / Pod Seals

4.1. Thruster seals

SC 2 A	(no pressure control)
SC 2 B	(with pressure control)
	Oil supply diagram
SC 2 M	(with pressure control and spare seal ring)
	Oil supply diagram
SC 2 B/SC 2 B	Contra-rotating propeller
	Oil supply diagram

4.2. Pod Seals

SC 2 B	(4 seals rings/separating chamber/pneumostop)
	Oil supply diagram
SC 2 B	(5 seal rings/separating chamber/pneumostop)
	Oil supply diagram
SC 2 SI	(4 seal rings/pneumostop/Airspace)
	Oil supply diagram
Carboplan SC	(Mechanical face seal plus lip seal)

4.1. Thruster seals

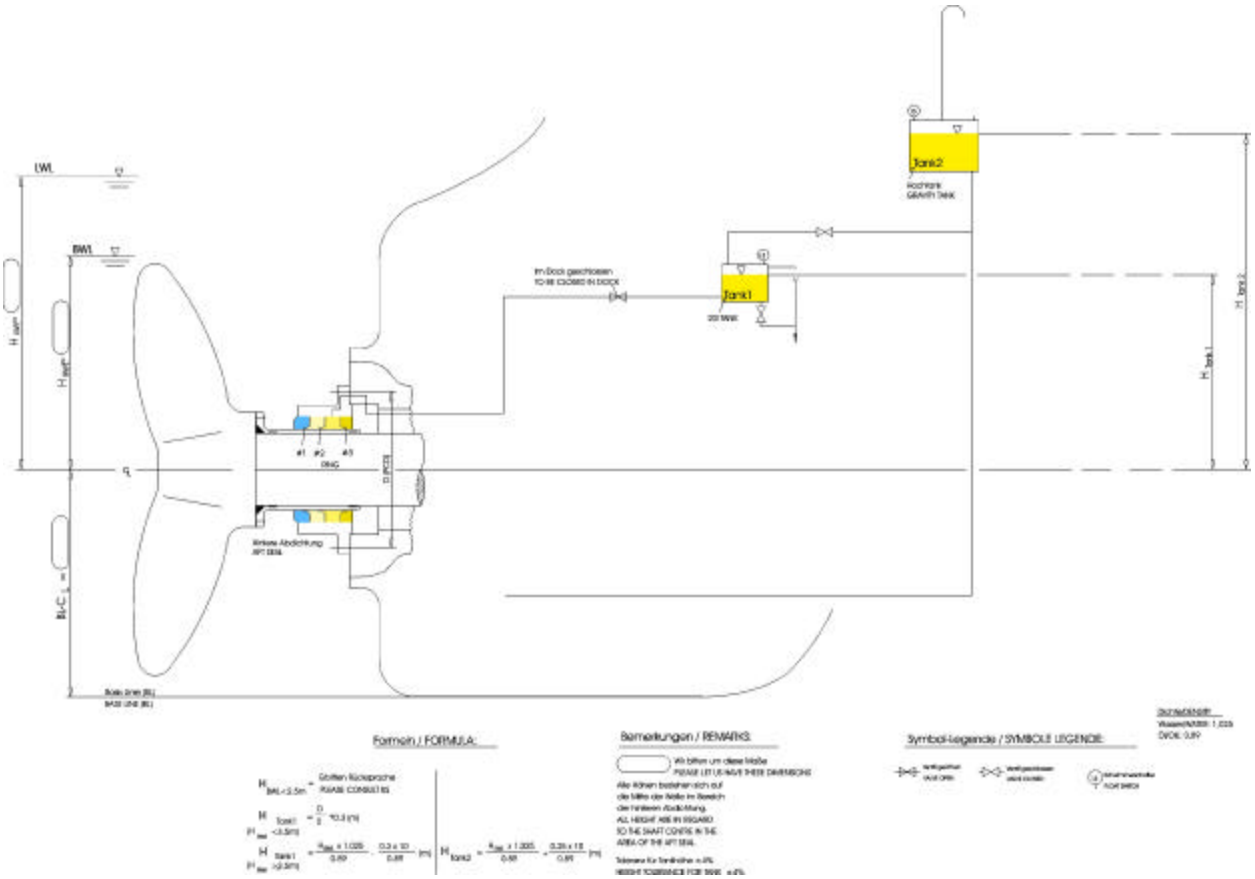
SC 2 A (no pressure control)

4.1 Thruster seals

SC 2 B (with pressure control)

4.1 Thruster seals

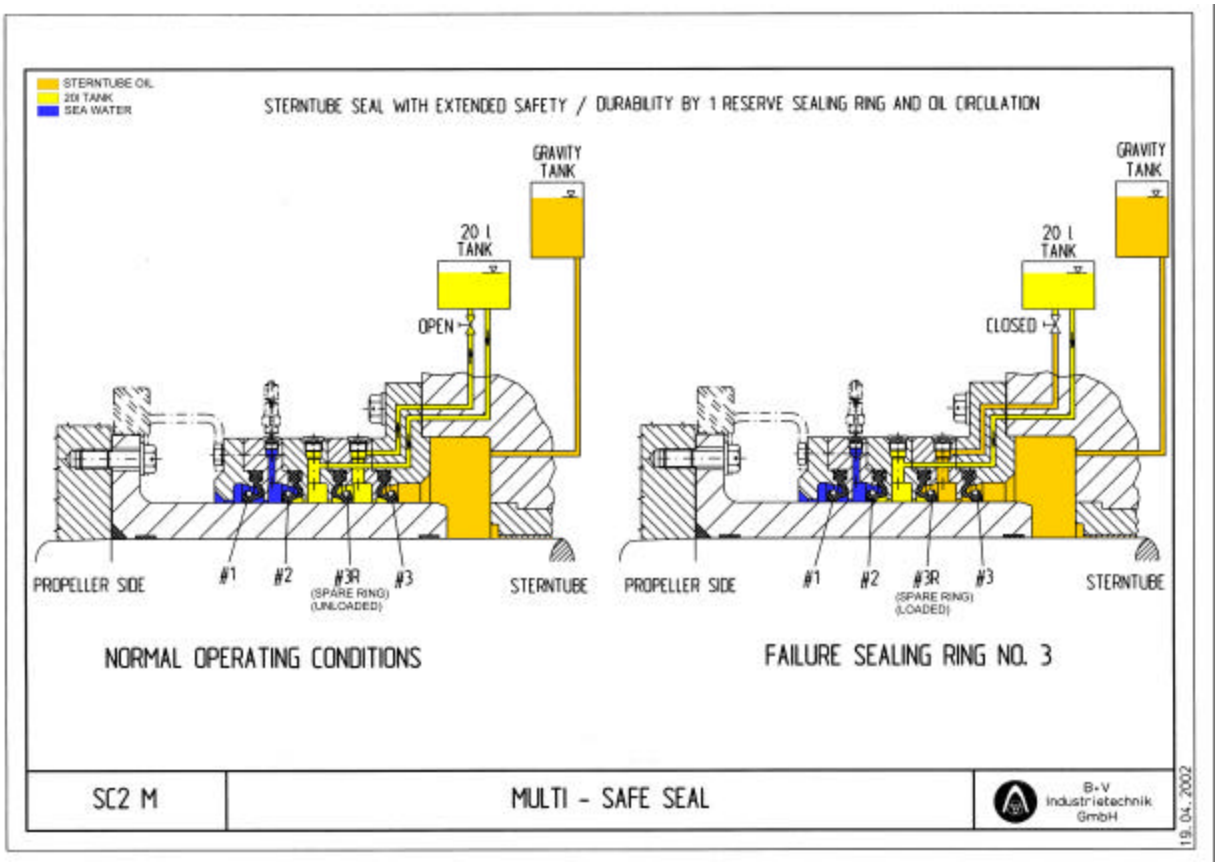
Oil supply diagram



Return to Session Directory

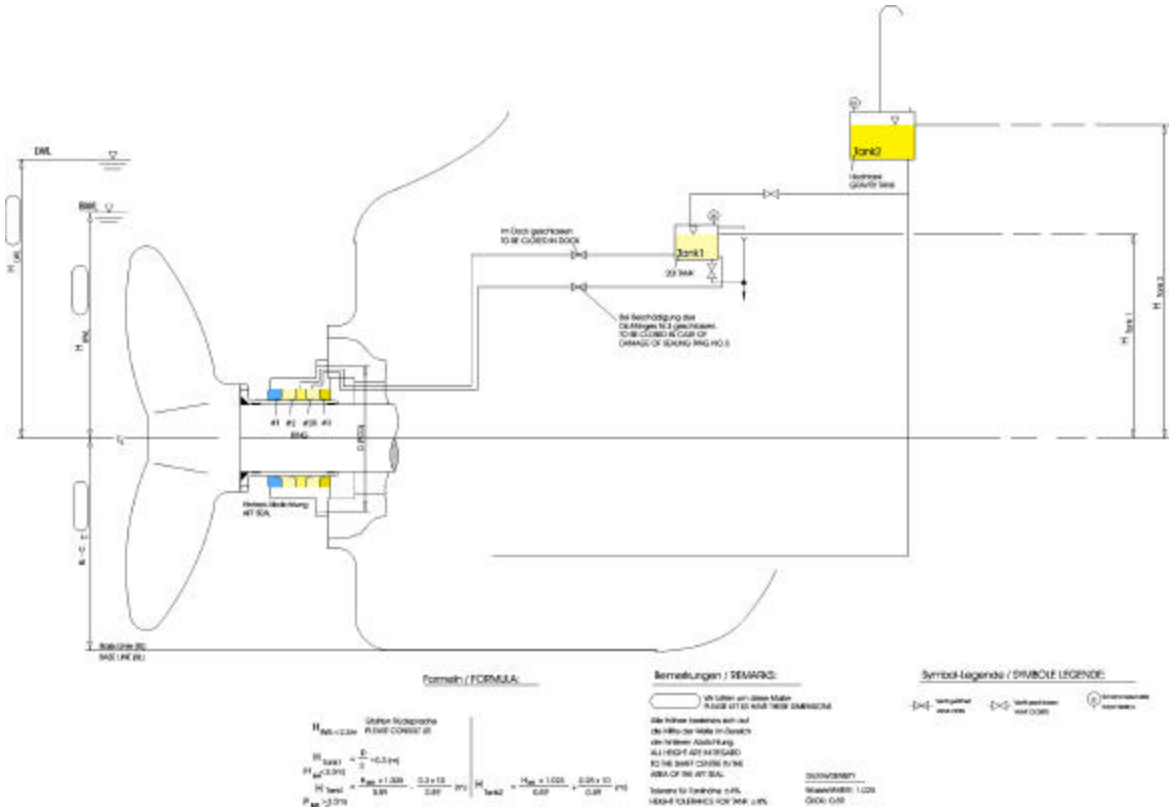
4.1. Thruster seal

SC 2 M (with pressure control and spare seal ring)



4.1. Thruster seal

Oil supply diagram



4.1 Thruster seals

SC 2 B / SC 2 B Contra-rotating propeller

4.1 Thruster seals

Oil supply diagram

4. Examples of Thruster / Pod Seals

4.2. Pod Seals

SC 2 B (4 sealing rings/separating chamber/pneumostop)

Oil supply diagram

SC 2 B (5 sealing rings/separating chamber/pneumostop)

Oil supply diagram

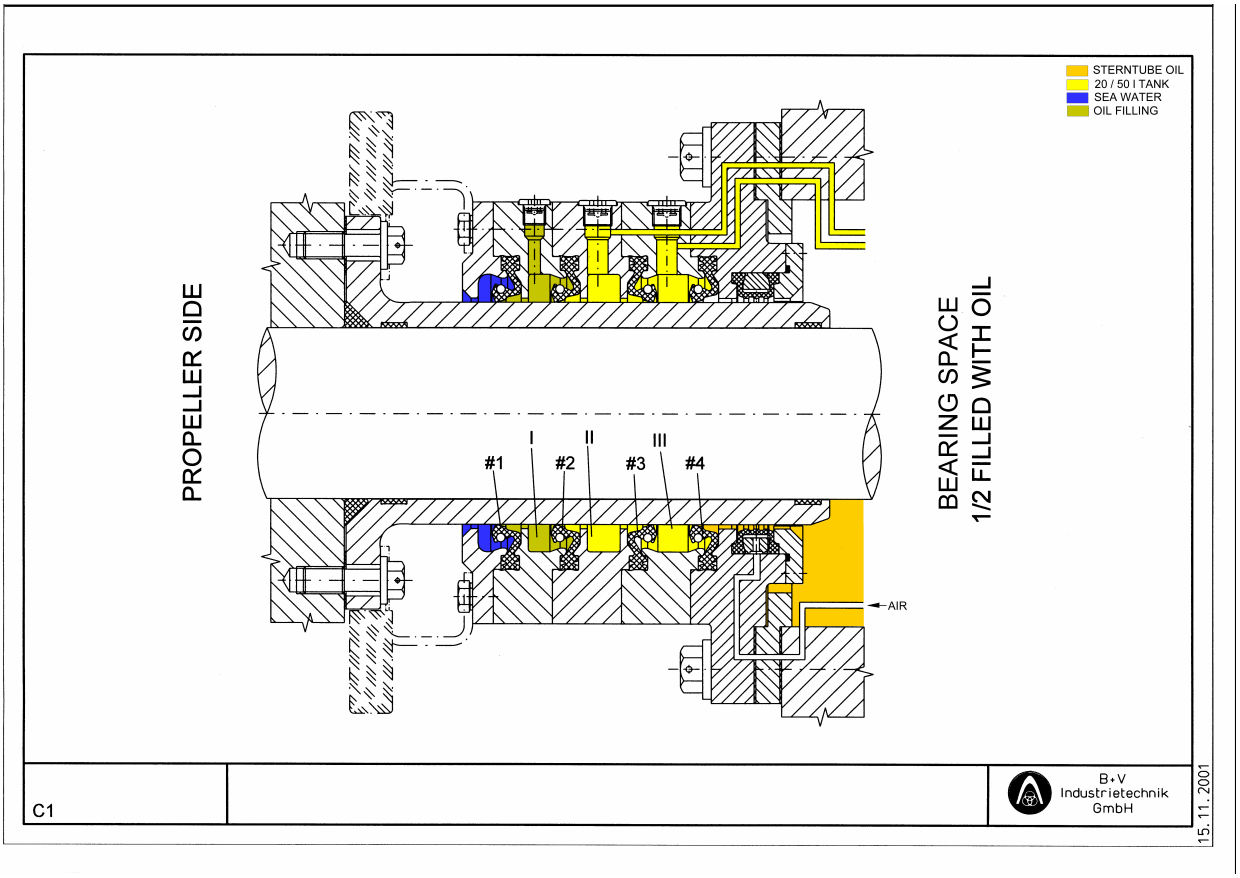
SC 2 SI (4 sealing rings/pneumostop/airspace)

Oil supply diagram

Carboplan SC

4.2 Pod Seals

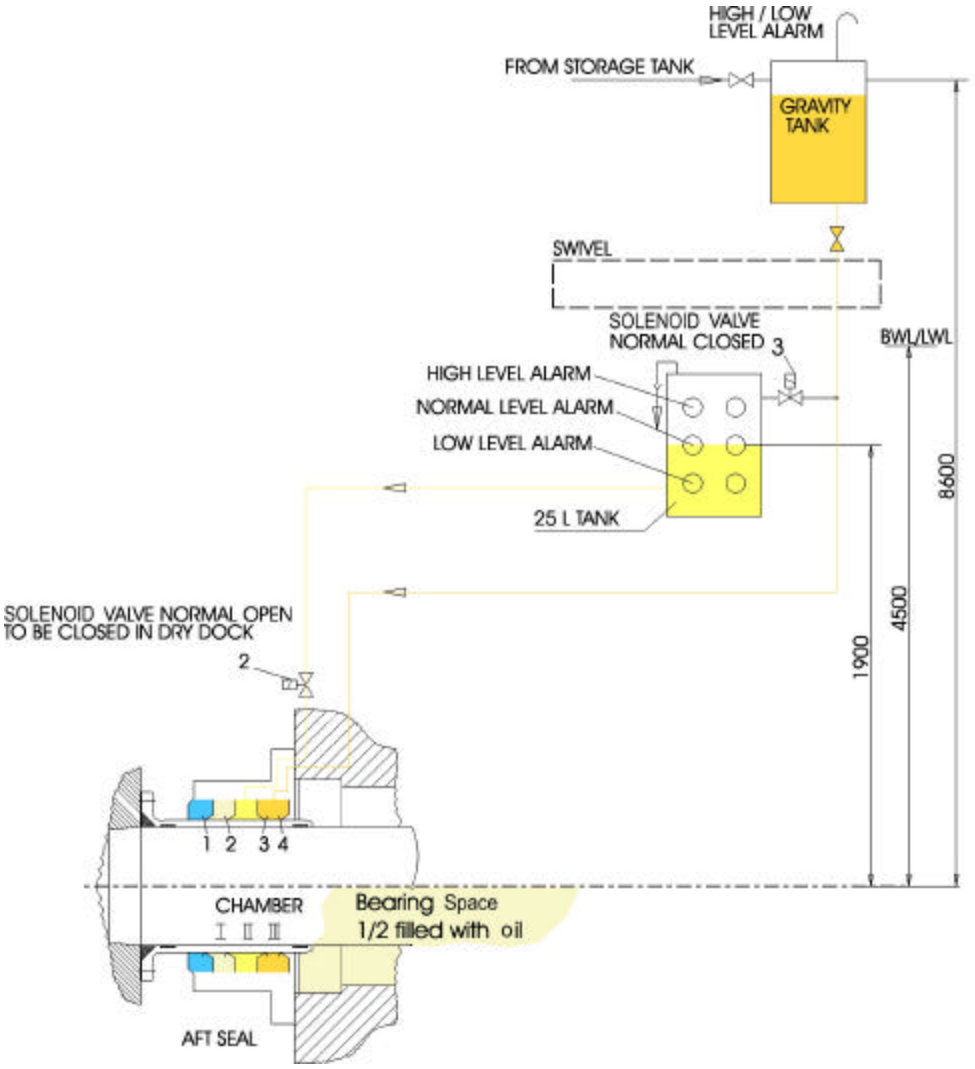
SC 2 B (4 sealing rings/separating chamber/pneumostop)



Return to Session Directory

4.2 Pod Seals

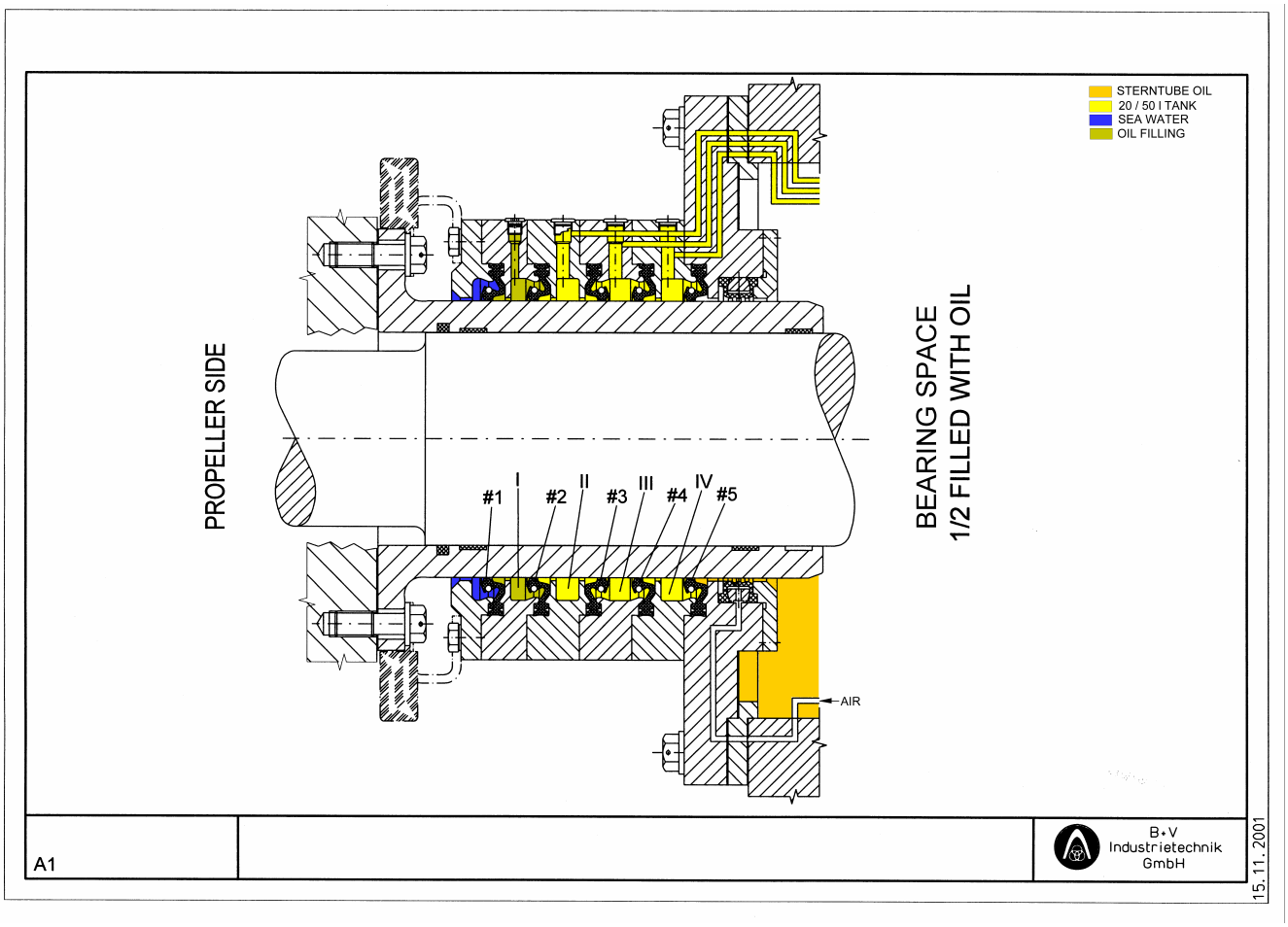
Oil supply diagram



Return to Session Directory

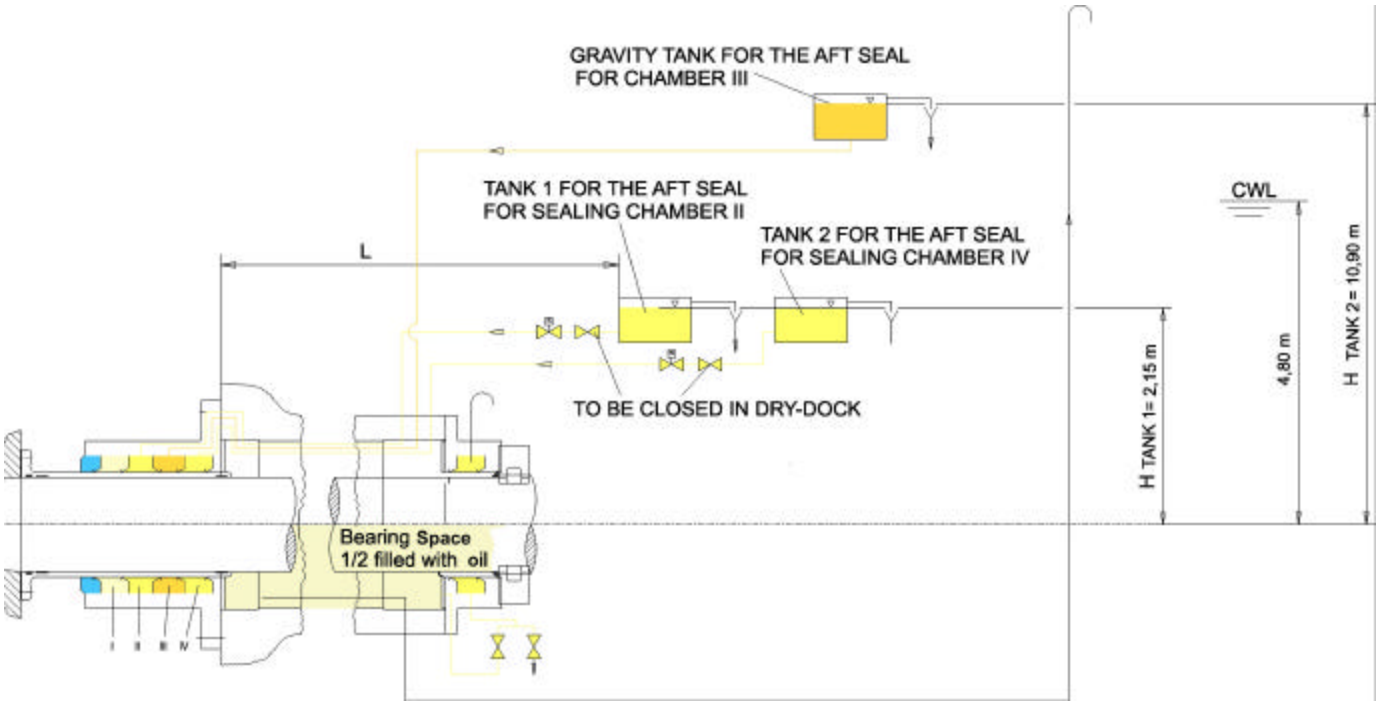
4.2. Pod Seals

SC 2 B (5 sealing rings/separating chamber/pneumostop)



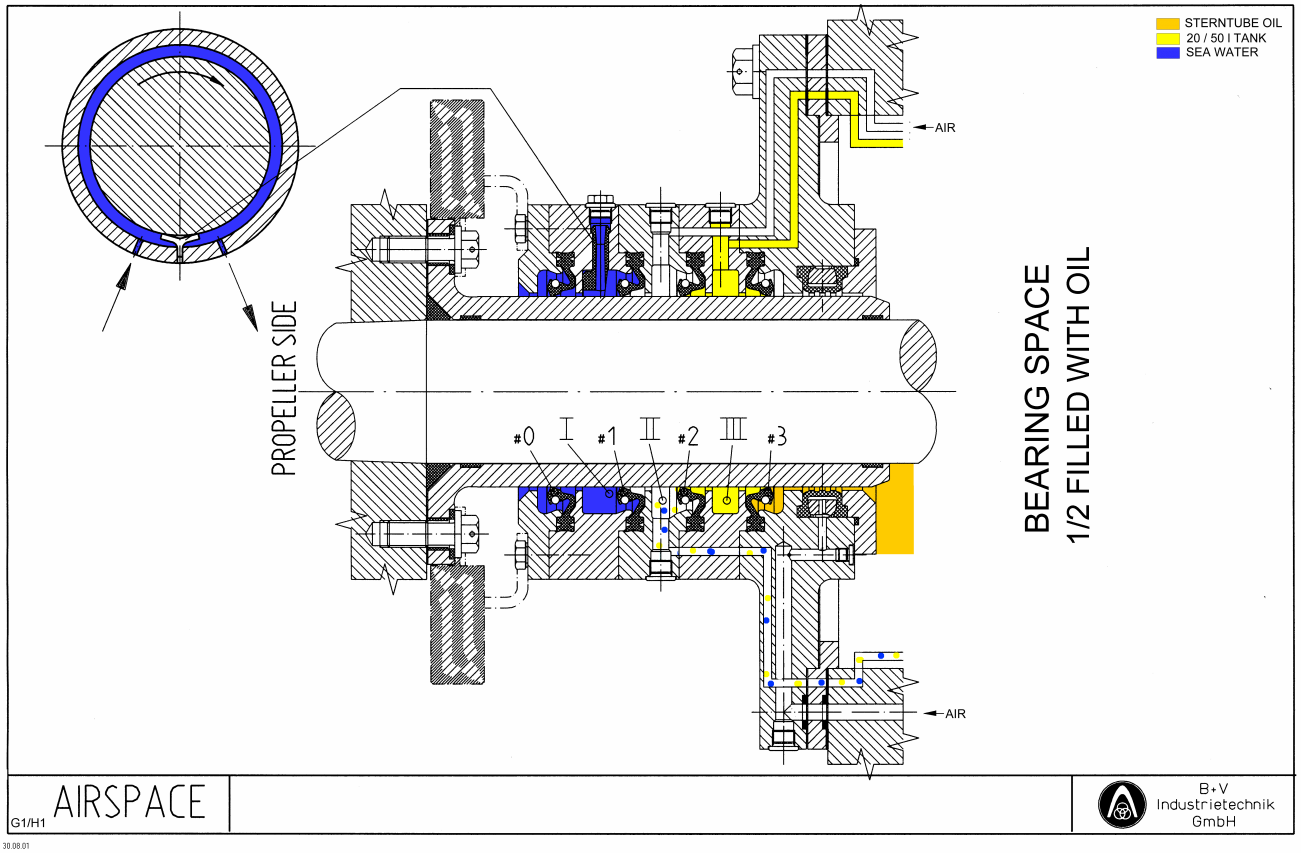
4.2. Pod Seals

Oil supply diagram



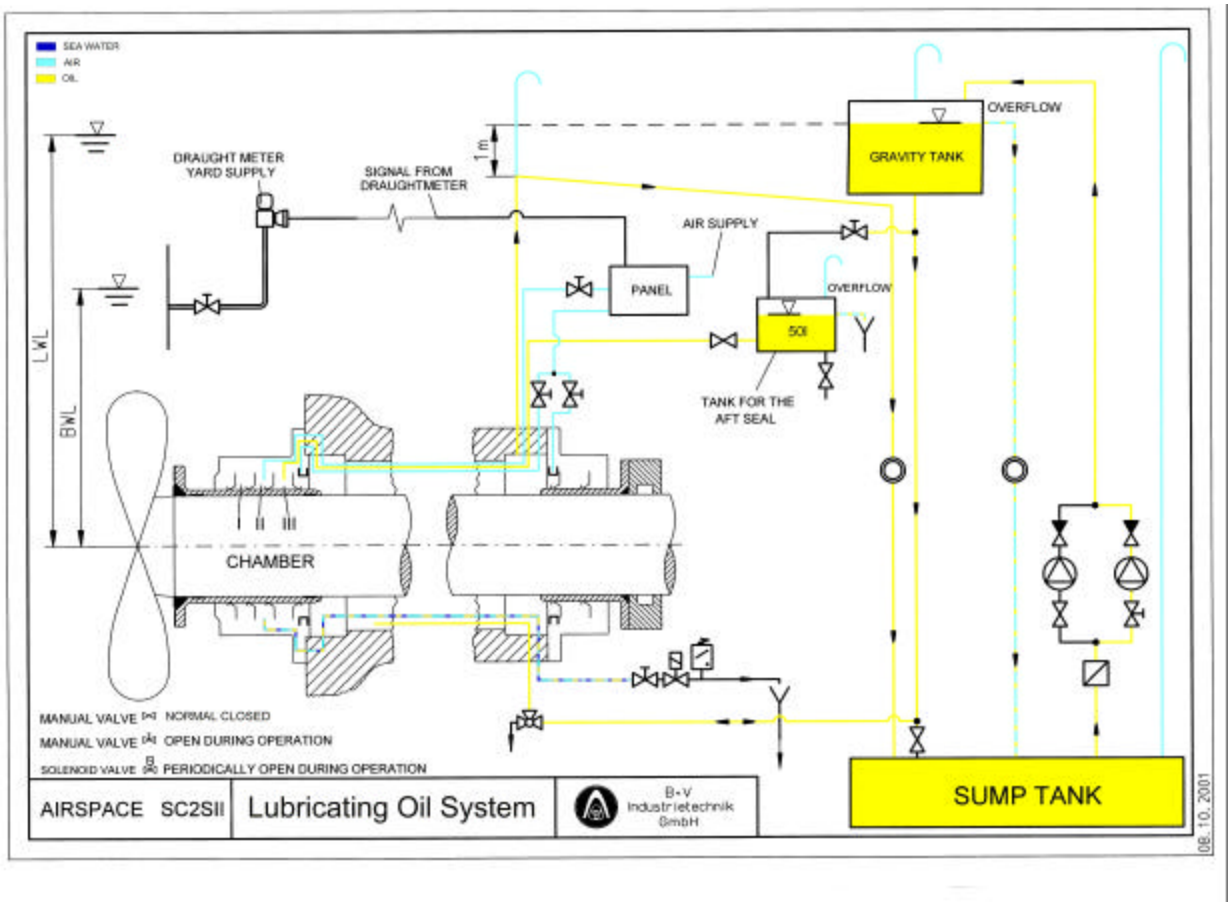
4.2 Pod Seals

SC 2 SI (4 sealing rings/pneumostop/airspace)



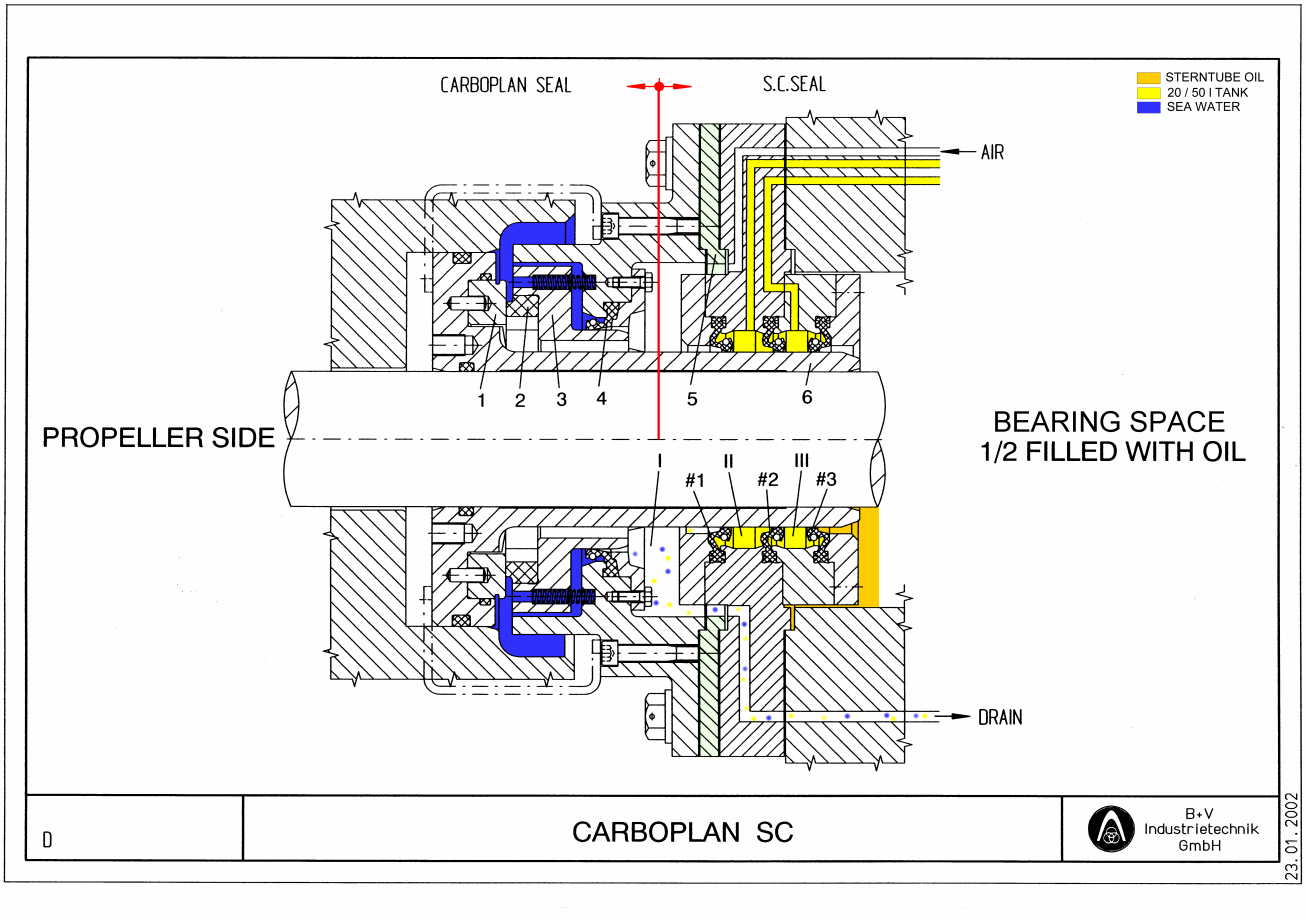
4.2 Pod Seals

Oil supply diagram



4.2. Pod Seals

Carboplan SC



Return to Session Directory

IMPORTANT: Seal Choice Questionnaire

Thruster / Pod Manufacturer:
Yard:
Shipowner:

Thruster		Pod	

Open sea		Shallow water		Low ice class		Ice breaker	

Operating area	Cold water	-3 to +15°C	
	Warm water	+16 to +32°C	

Dirt load	Low	
	Medium	
	High	

Draught	BWL / Shaft centre line	[m]	Operating time period	[%]
	LWL / Shaft centre line	[m]	Operating time period	[%]
	Additional:	[m]	Operating time period	[%]

Absolute enviroment friendly	

Oil pressure in gear / bearing housing	Constant:			bar
	Varying	bar	bar	bar
Lube oil supply ⇒ gear / bearing housing	Full	Oil type		
	Half (shaft centre line)			
	Spray lubrication			
Shaft diameter: [mm]	Shaft rpm max.			[1/min]

Operating time per year [h]	2,000	
	4,000	
	6,000	
	8,000	