Mechanical Seals for Food Processing

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Outline

- Definition of the problem
  - What are we trying to achieve
  - What are the constraints imposed
- How design variations on parts are used to solved specific problems
  - Seal faces
  - Springs
  - Secondary seals
  - Materials of construction
  - Drive mechanisms

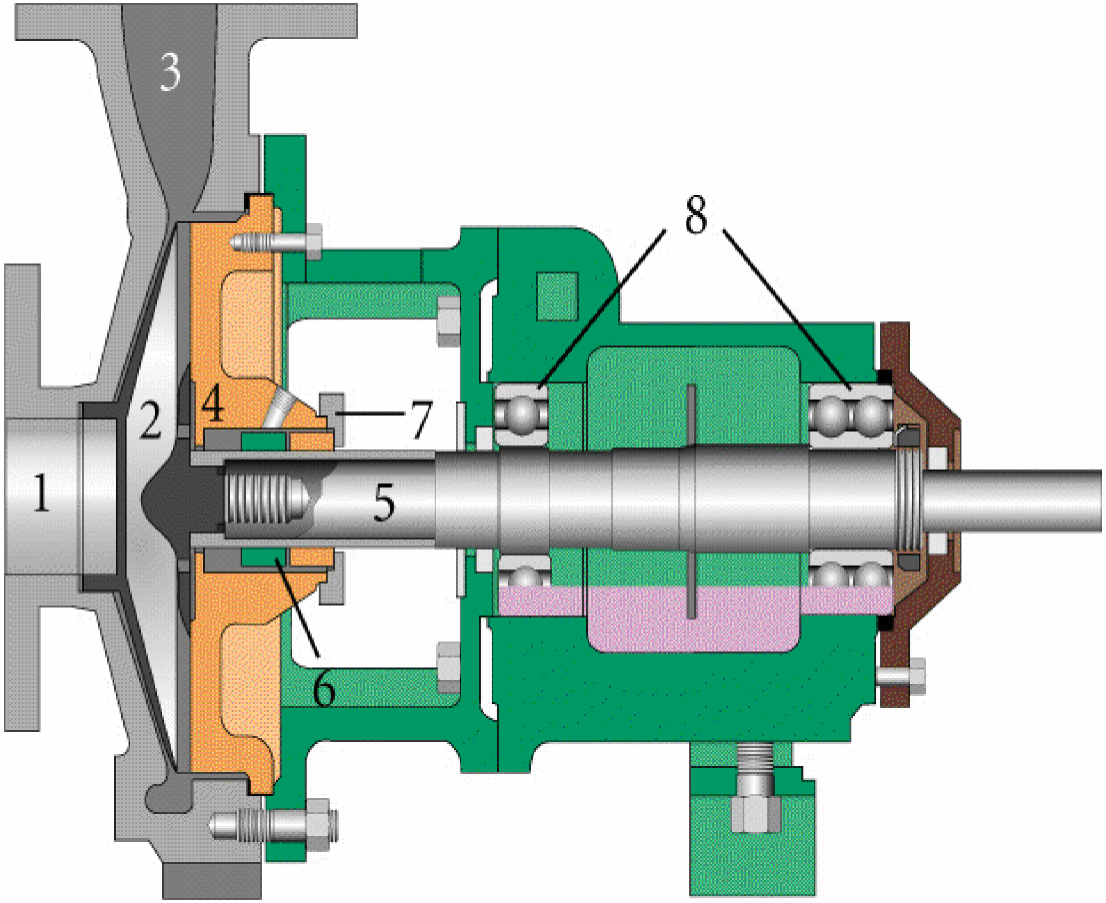
Outline

- How design variations have an impact on sanitary designs
  - Constricted areas
  - Self draining areas
  - “Cleanability”
    - In Place
    - Out of Place
  - Sterilization

Definition of the problem

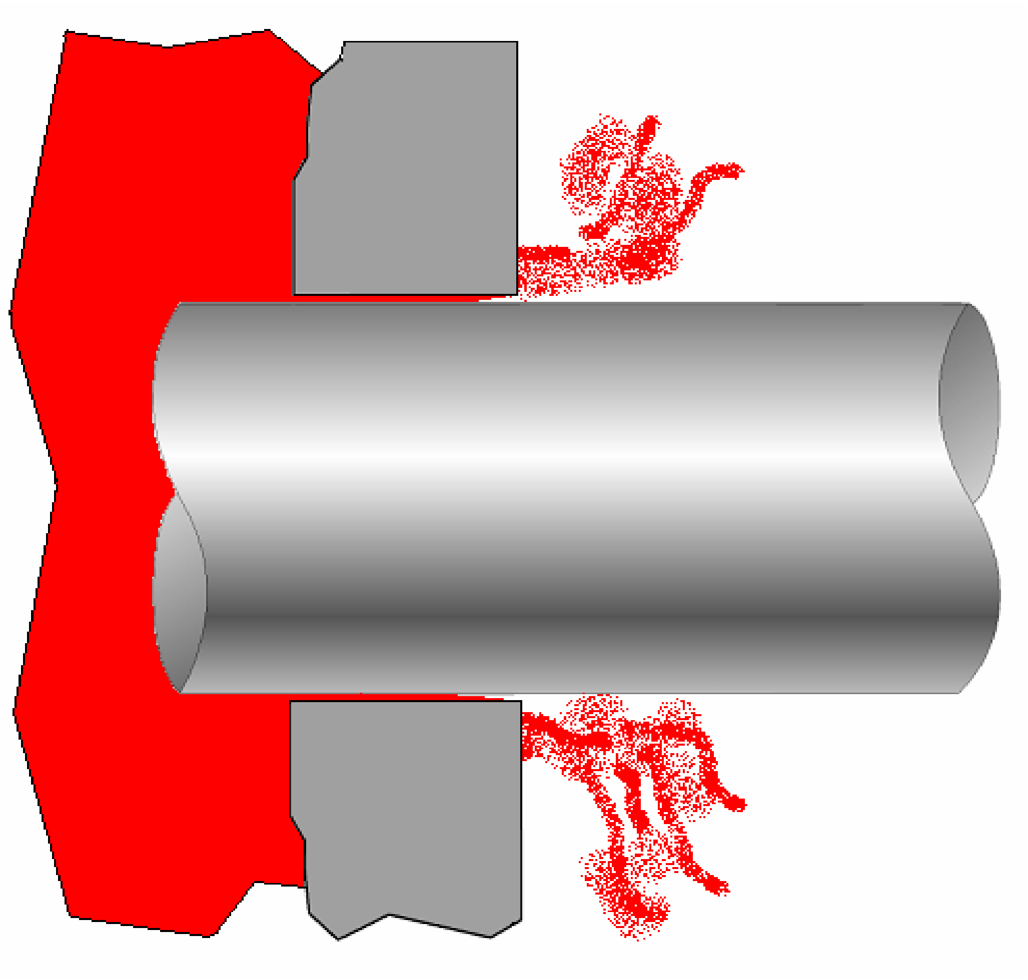
- How to minimize the gap between parts that are in relative motion
- There can be axial (reciprocating) or rotary motion for centrifugal devices

Typical Centrifugal Pump

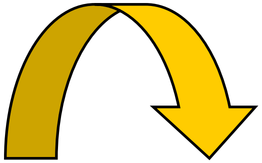


1 - Suction
2 - Impeller
3 - Discharge
4 - Back plate (stationary)
5 - Rotating Shaft
6 - Mechanical Seal in seal chamber (stuffing box)
7 - Seal gland
8 - Radial and thrust bearings

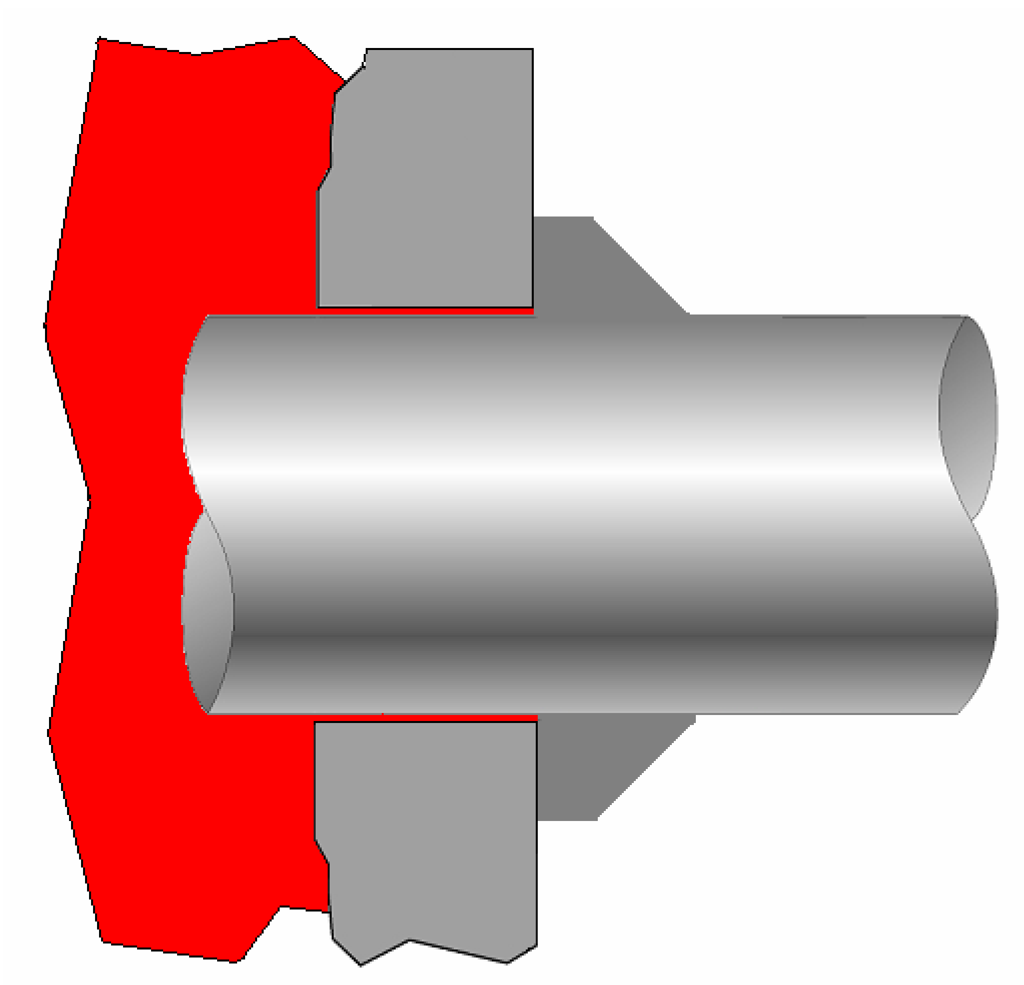
Definition of the problem



Liquid escapes between the rotating shaft and the Stationary housing wall

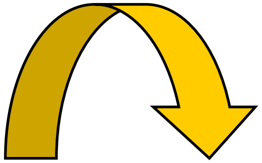


Definition of the problem

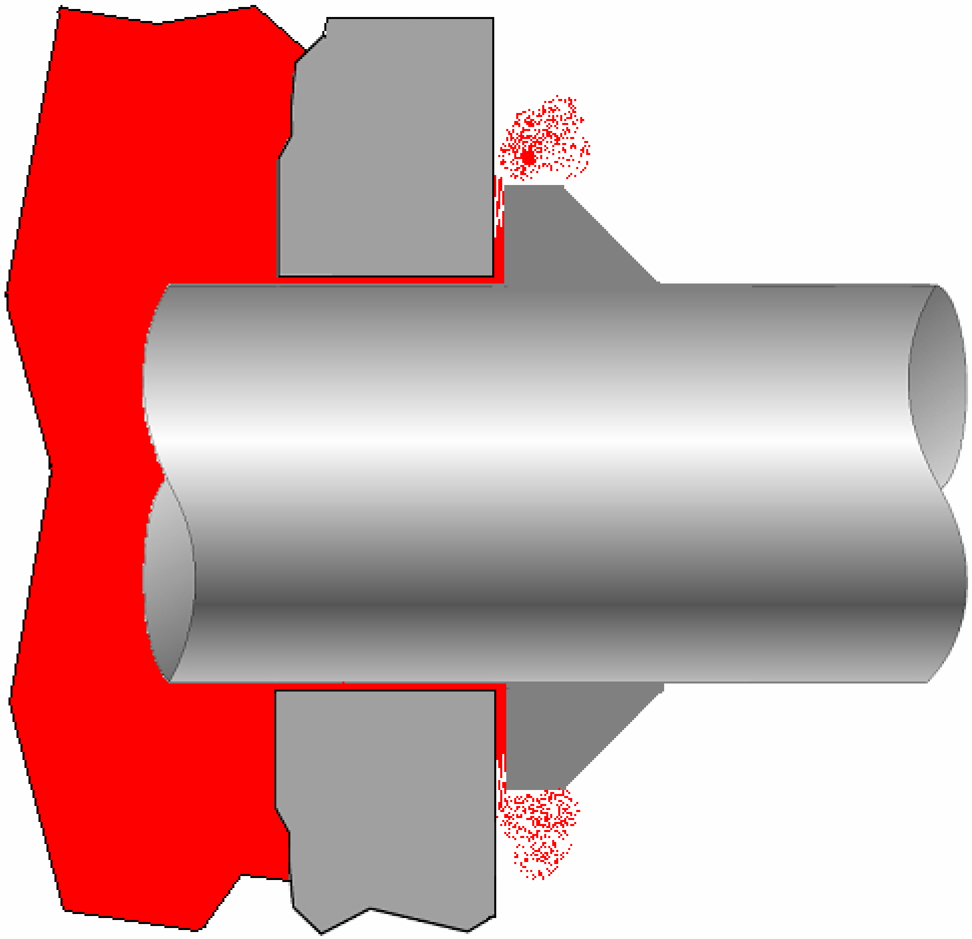


The first concept of an end face mechanical Seal

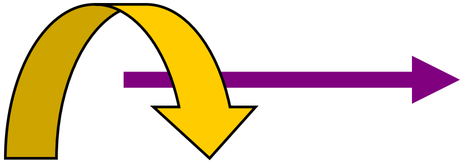
Add a step on the shaft



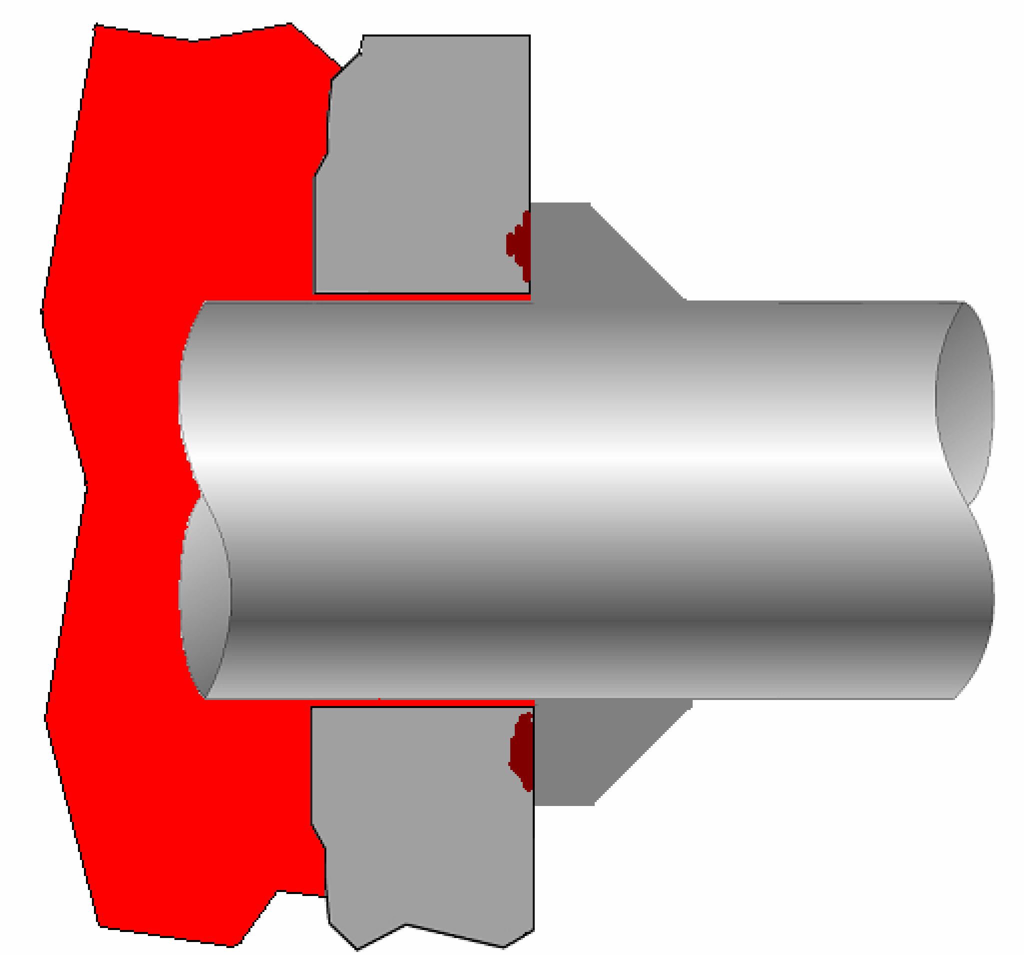
Definition of the problem



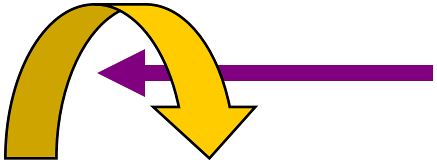
A small axial motion of the step away from the wall results in leakage



Definition of the problem



A small axial motion toward the wall results in heat build-up, wear and degradation resulting an eventual leakage



Definition of the problem

- Seal configuration will be determined by its ability to compensate for physical constraints
- Seal face configuration will be determined by its ability to maintain an intended profile
- Design variations on parts are used to solve specific problems
  - Springs
  - Secondary seals
  - Materials of construction
  - Drive mechanisms

Definition of the problem

- How do we accommodate axial motion perpendicularity and wear
- To achieve a long life
- With easy maintenance
- And low cost

Definition of the problem

- We need replaceable wearing parts to avoid having to change shafts and housings
- We need wear resistant material for long life
- We need to accommodate rotary as well as other small axial motion

Definition of the problem

- And we need an extremely small gap between parts in relative motion
- Leakage is proportional to
  - The film thickness to the third power
  - The pressure differential
  - The mean face radius
  - And inversely proportional to the face width
- The gap typically needs to be less that 0.00002 inches or less that 1/2 micron
- All this while being subject to high relative speeds, high pressures, high temperatures, corrosive and dirty environments

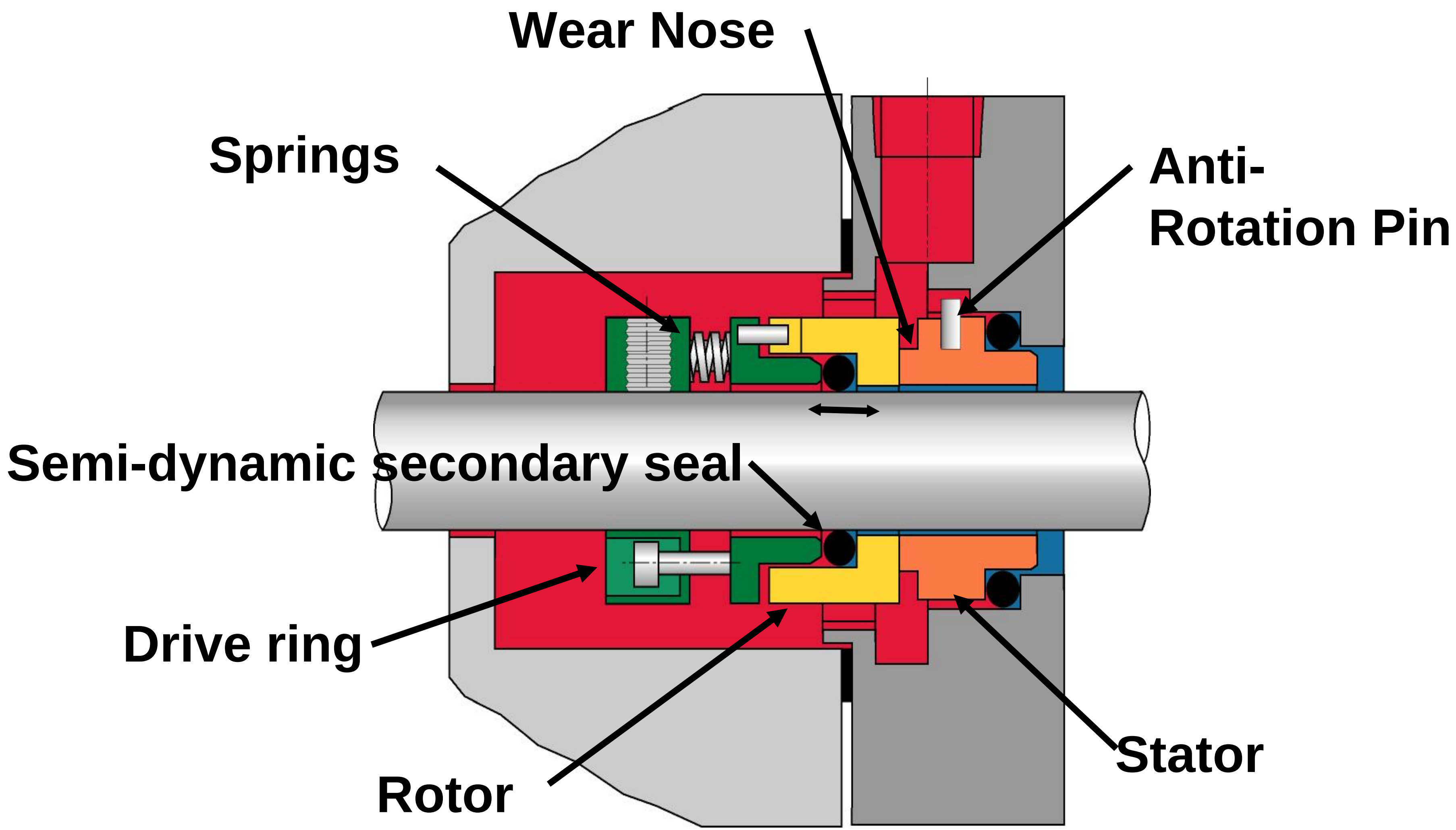
Definition of the problem

- There are several types of seals with similar configurations but that operate under different conditions
  - Liquid lubricated seals
  - Contacting dry running seals
  - non-contacting gas lubricated seals
  - non-contacting liquid lubricated seals
- This could be a topic for several classes

Understanding Mechanical Seals

- The Science of mechanical seal design is extremely simple
- There are only two requirements
  - **Keep the faces together**
    - **Configuration design**
  - **Keep the faces flat**
    - **Face design**

Understanding Mechanical Seals

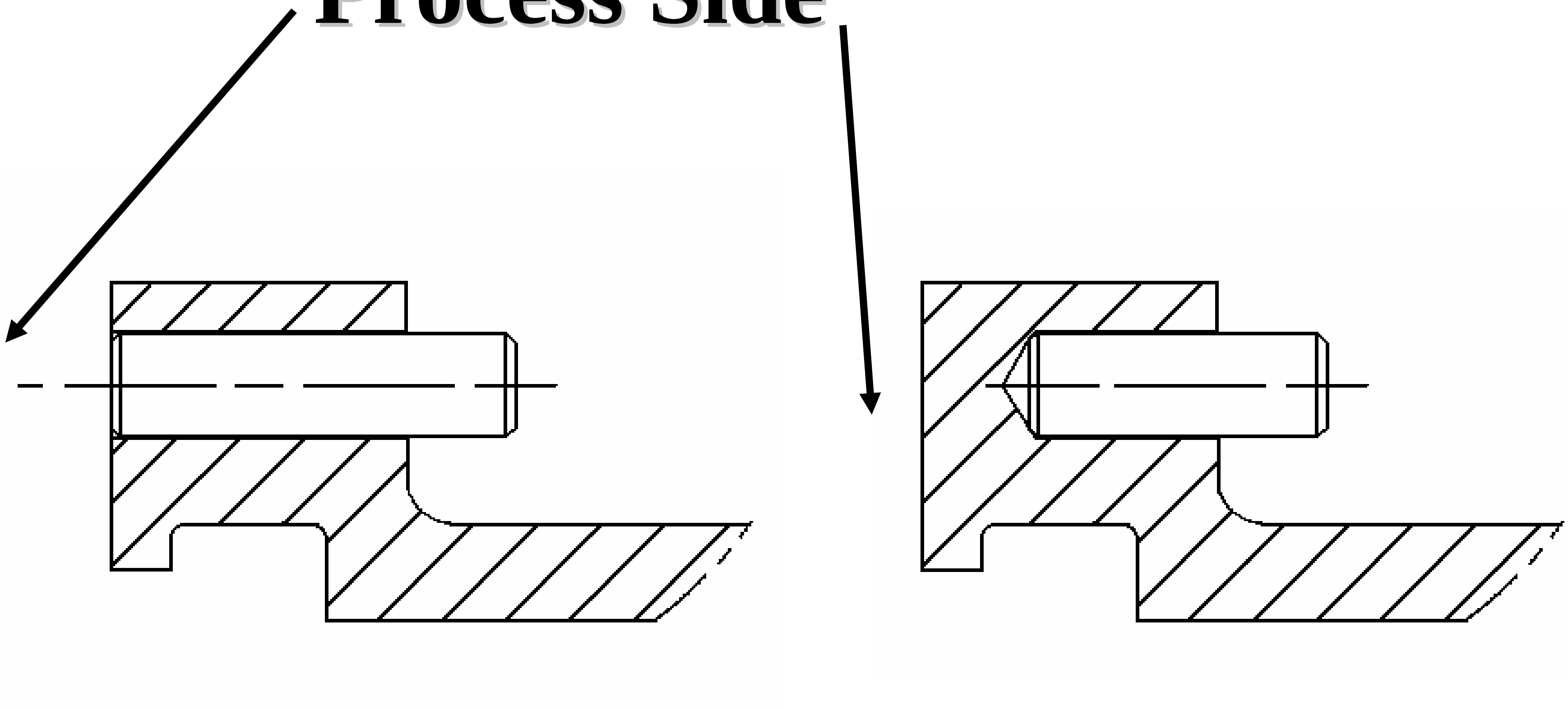


Drive mechanisms

- Pins in holes
  - Line contact. Most common method
- Lugs in slots
  - Surface contact assuming perfect manufacturing
- Flats, dimples
  - On the outside of a seal ring this can be a most effective method. It place the face material under compression
- Cushioned
  - Elastomer or other gasket material between a metal part and a seal face can evenly distribute drive loads
- Critical in viscous products, products that set up, high pressure applications.
- Drive mechanisms can create non axi-symmetric face deflections that are evidenced by uneven face wear
- Wear on drive mechanism can result in seal hang-up

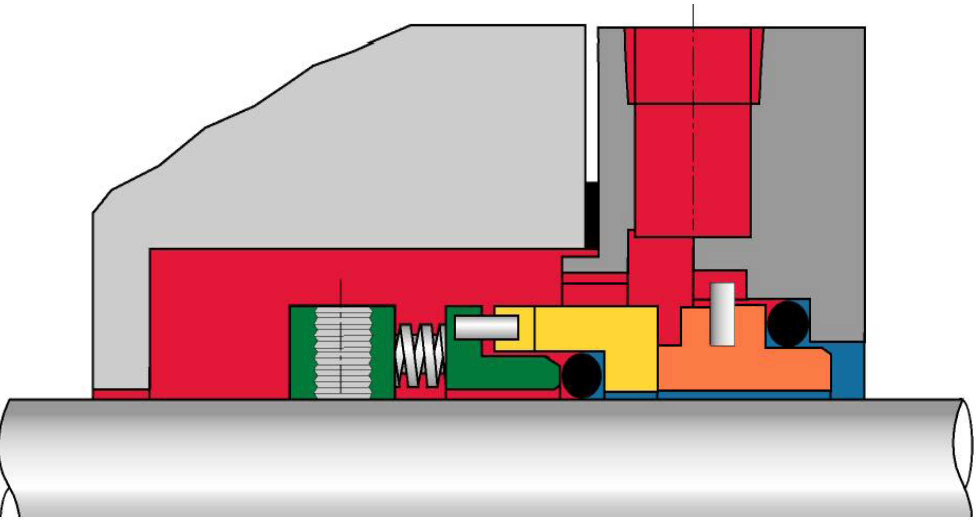
Drive mechanisms
Pins

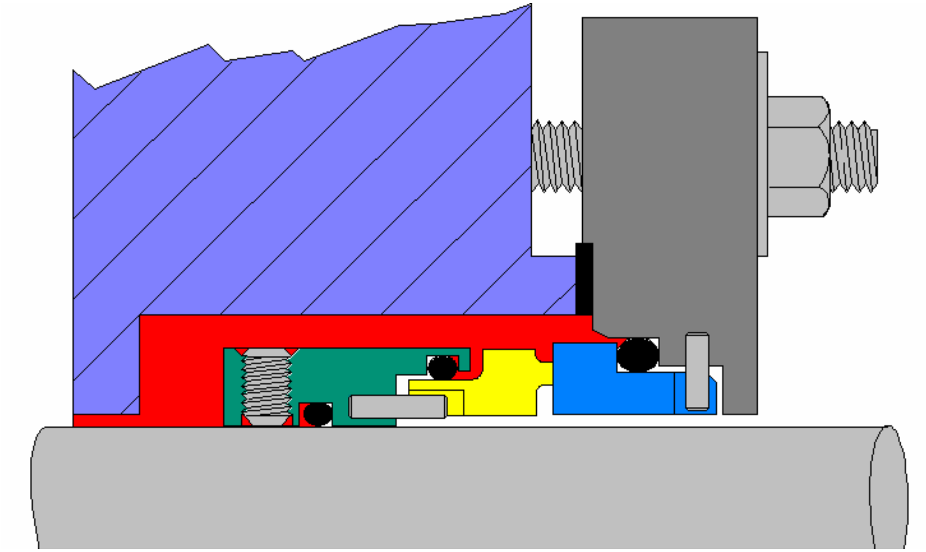
Process Side



Keep features away from the product side

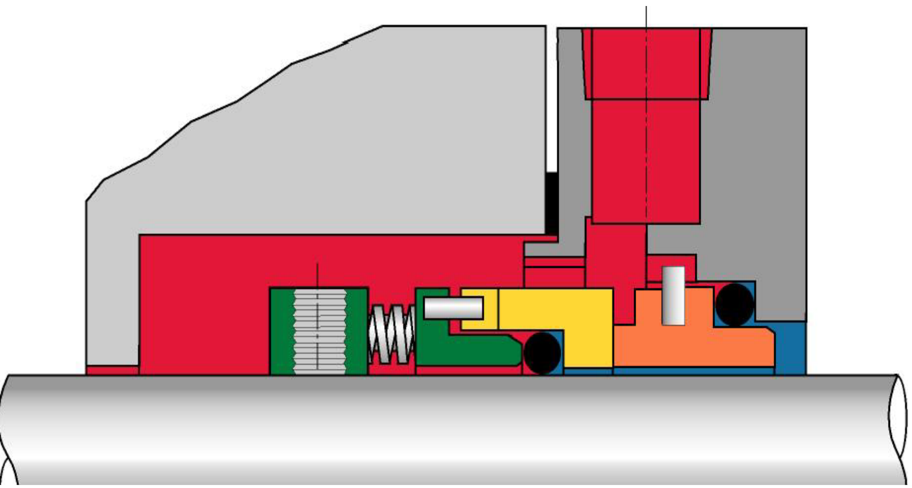
Drive mechanisms
Pins

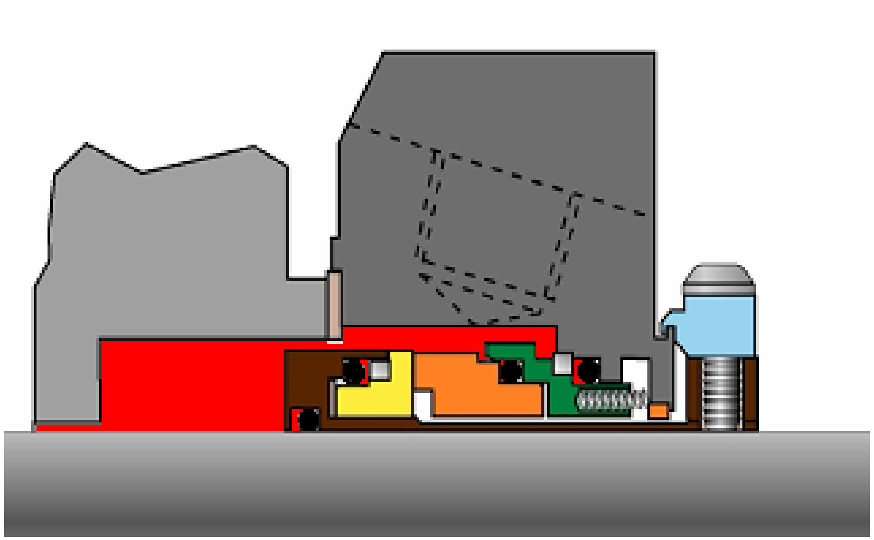




Keep drive pins and slots away from the product side

Drive mechanisms
Screws



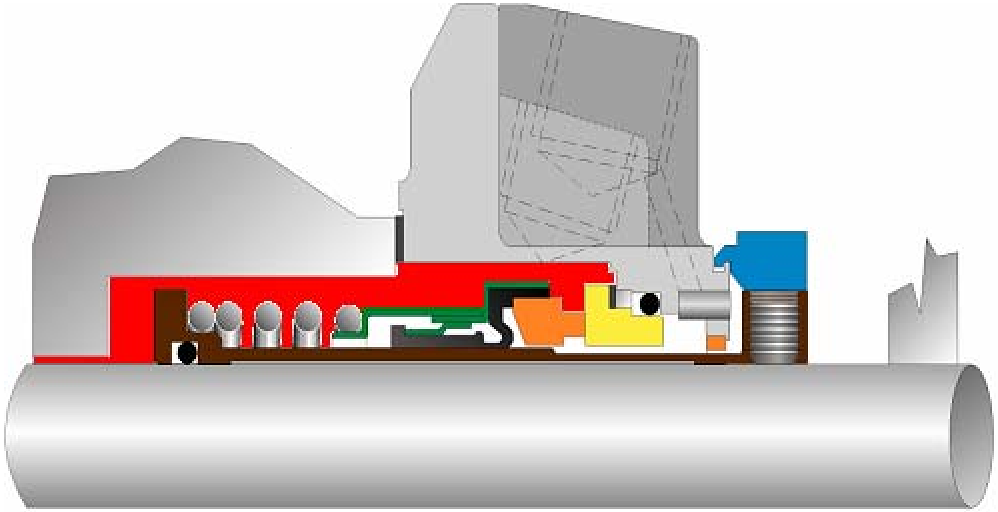


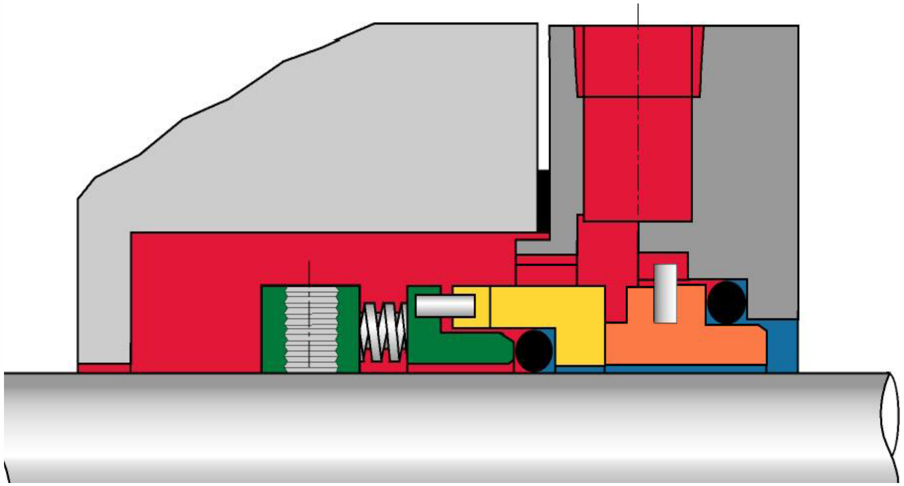
Keep screws away from the product side
Use cartridge seals

Spring Mechanisms

- Coil springs
- Multiple coil springs
- Springs inside or outside of the fluid
- Bellows
- Leaf springs
- Crest to crest wave springs
- Linear vs. non linear spring rate

Spring Mechanisms

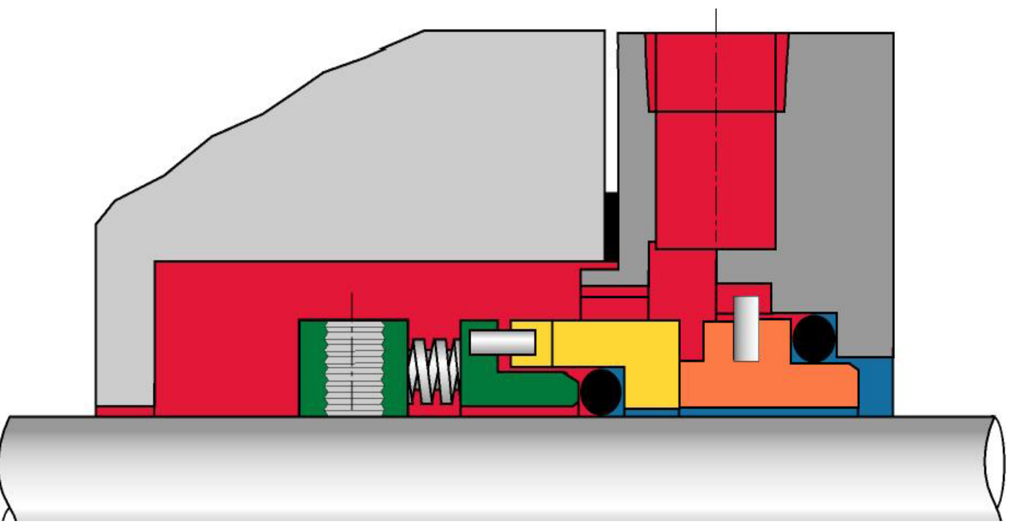


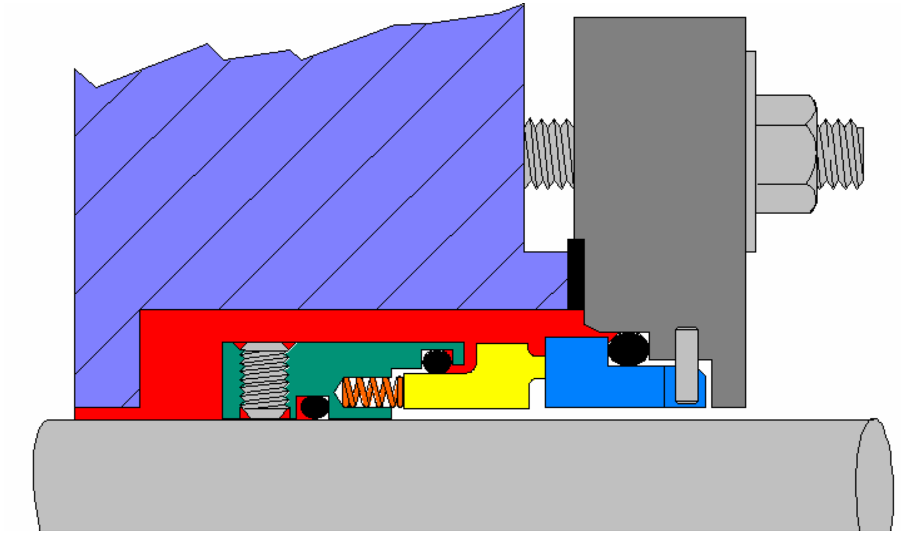


Single coil spring
Uneven face loading
Long travel
Can be used for driving the face
Direction of wind can matter
One per size
Not likely to clog in dirty services

Multiple coil springs
Even face load
Shorter range of travel
Same spring for a range of sizes
Prone to clogging
Lots of small cavities

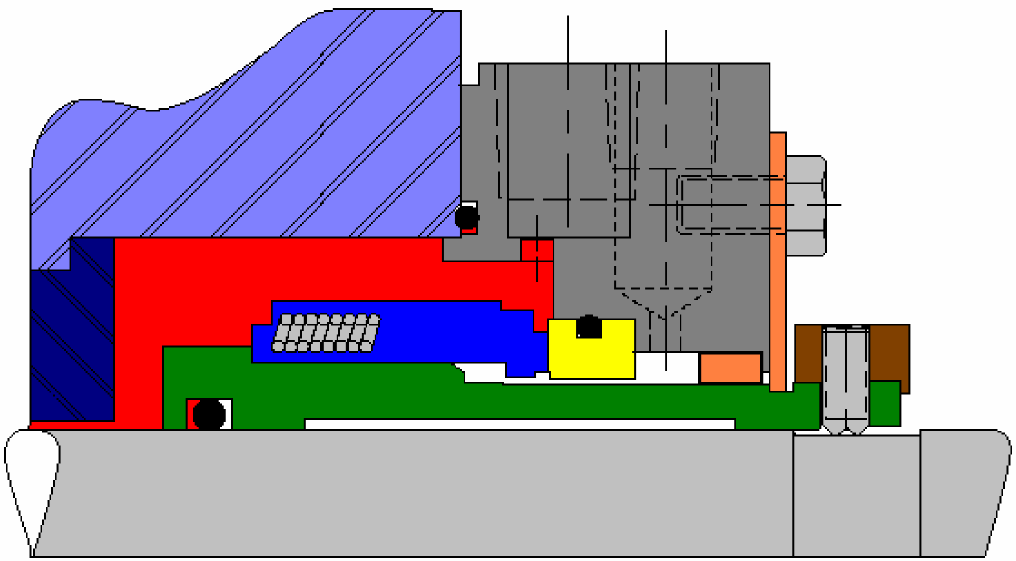
Spring mechanisms

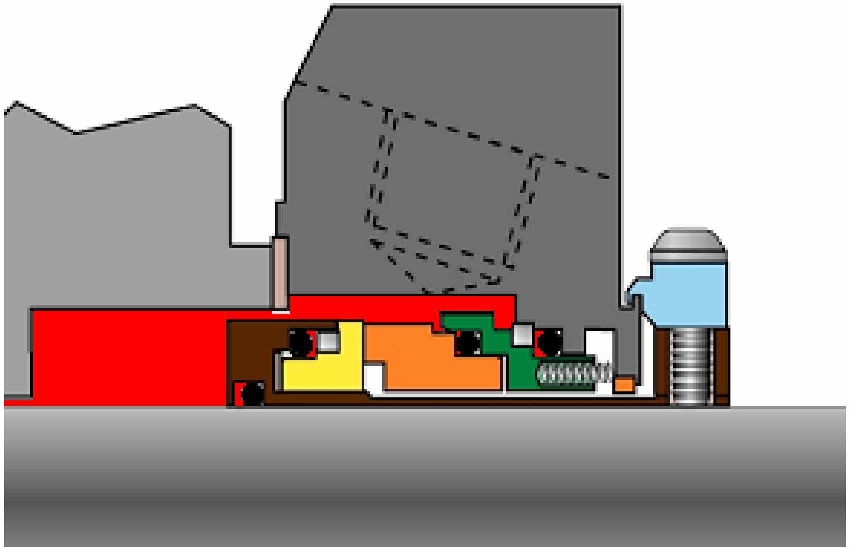




Keep springs away from the product side

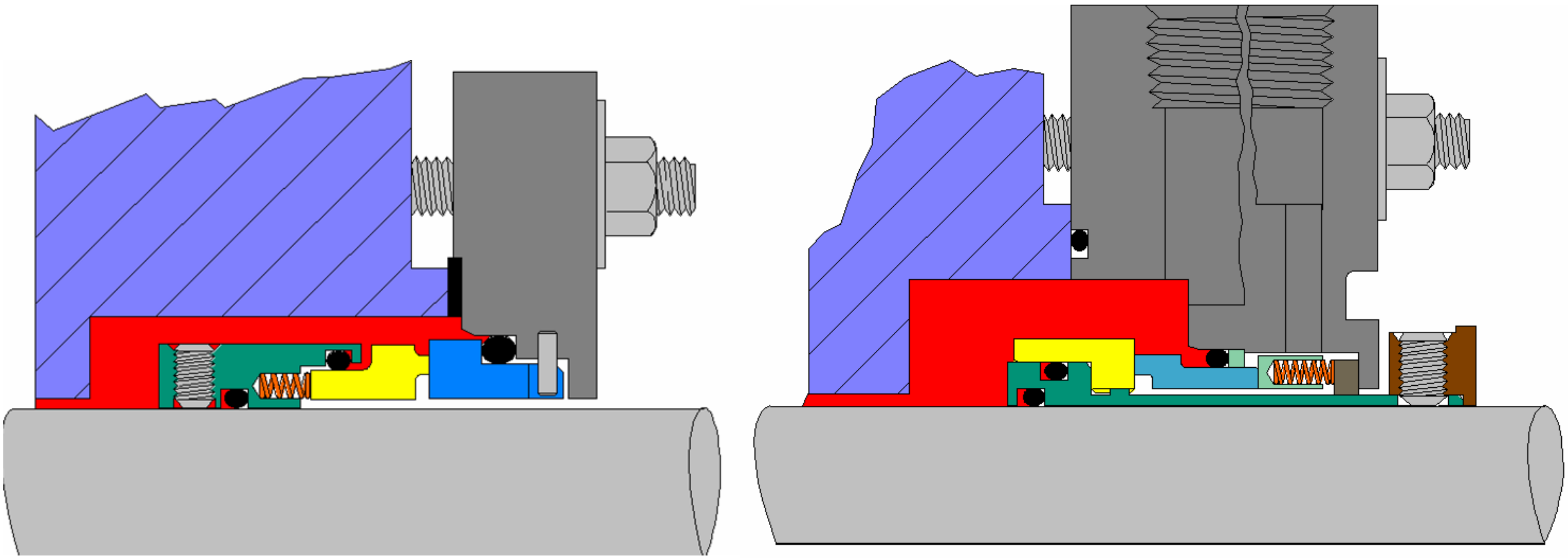
Spring mechanisms





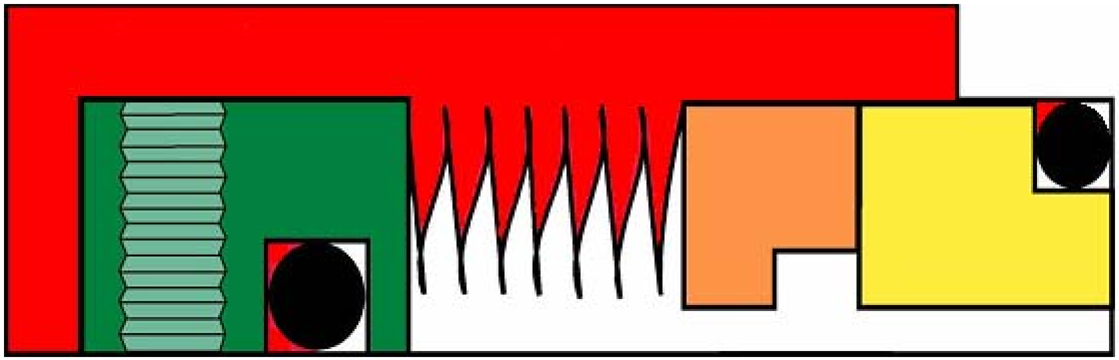
Keep springs away from the product side

Spring and drive mechanisms



Keep features away from the product side

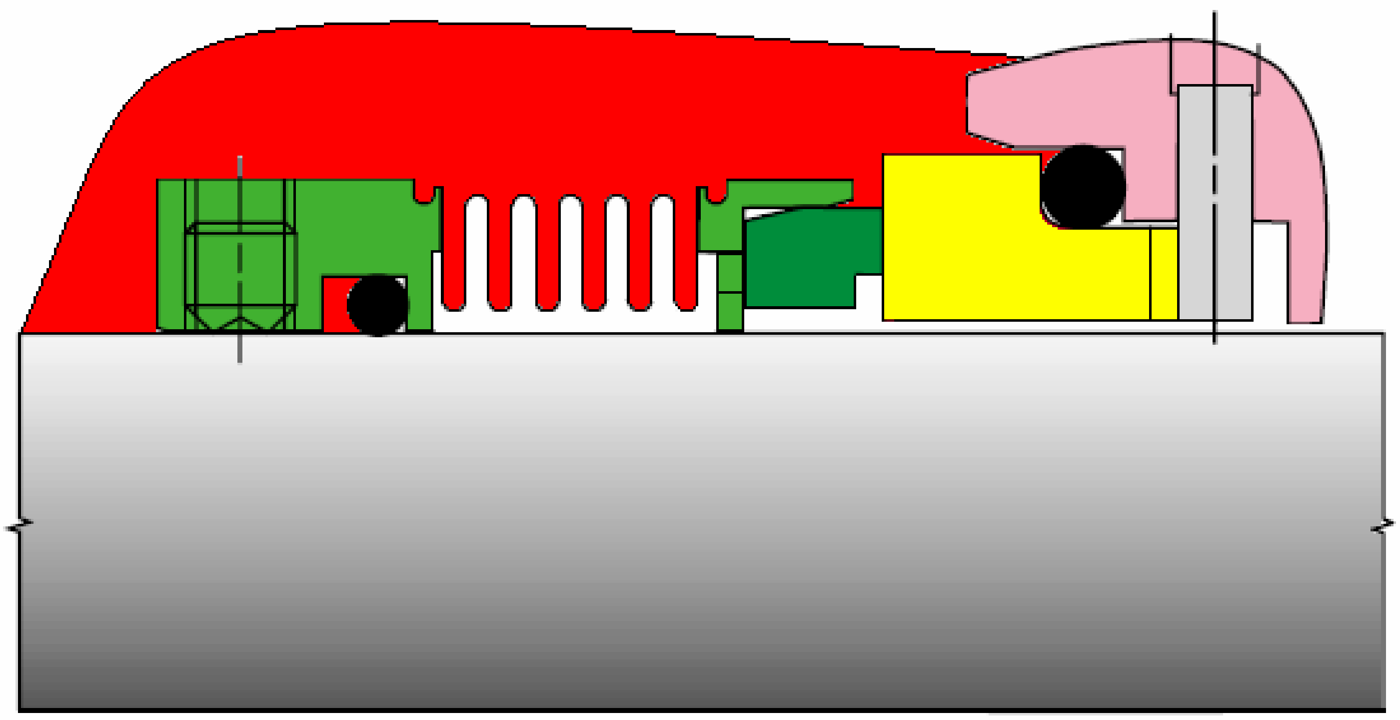
Bellows



Welded Metal Bellows
Plates are welded at ID and OD
Good pressure capabilities
No secondary seal friction
Lots of small places

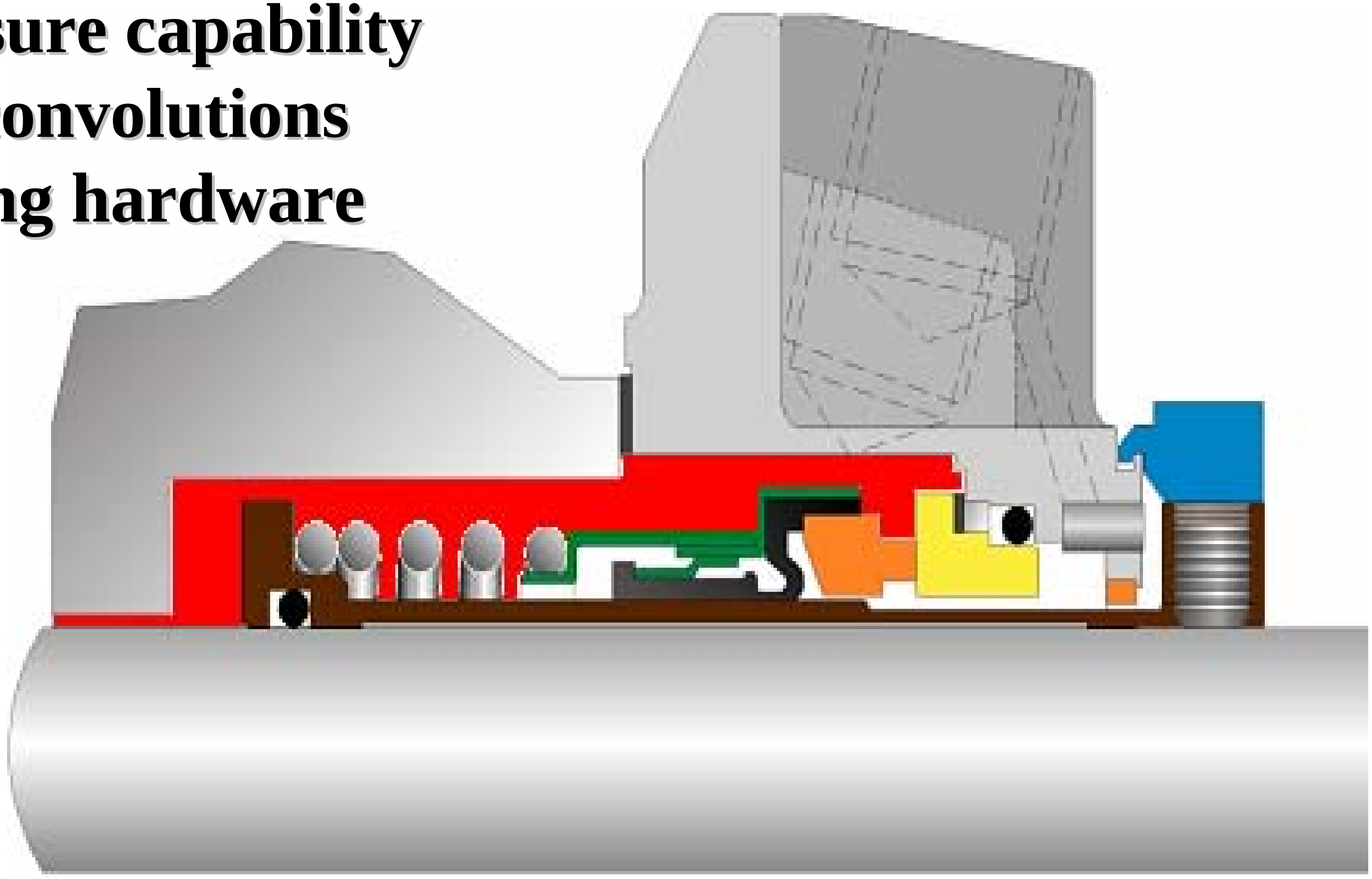
Bellows

Convoluted metal bellows
Medium pressure capability
Long axial space required
Large radii



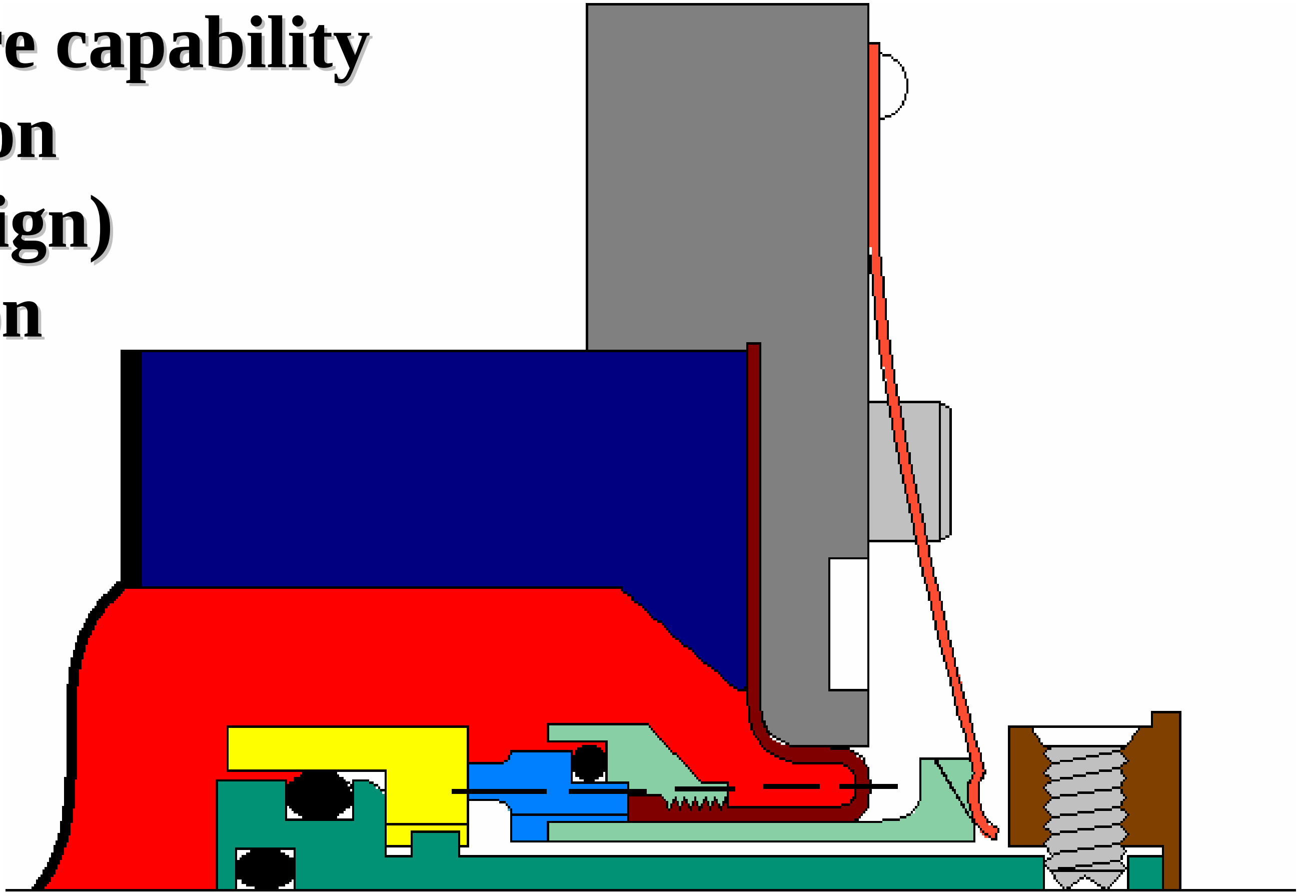
Bellows

Rubber bellows
Low pressure capability
Large convolutions
Attaching hardware



Bellows

- Convoluted rubber bellows
- Medium pressure capability
- Large convolution
- (Leaf spring design)
- Not very common



Secondary seals

- O-rings
  - Most common, low cost and reliable. The amount of compression used on the O-ring will have a significant impact on the ability of the flexibly mounted seal face to track the mating face
- Bellows
  - Eliminates secondary seal friction
- U-Cups, Chevron,
  - Chemical inertness but friction can be significant
- Spring Energized Teflon Seals
  - Chemical inertness, must be made to the groove exact size; the spring faces the pressure side
- Graphite
  - Excellent chemical resistance, high temperature capability, requires high pressure loading to seal

Corrosion

Corrosive effects of the product on the material used in the seal can have a significant effect on seal performance. The integrity of the seal faces must be maintained, and parts must be free to move. In extreme cases, corrosion can create leak paths through stationary metal parts.

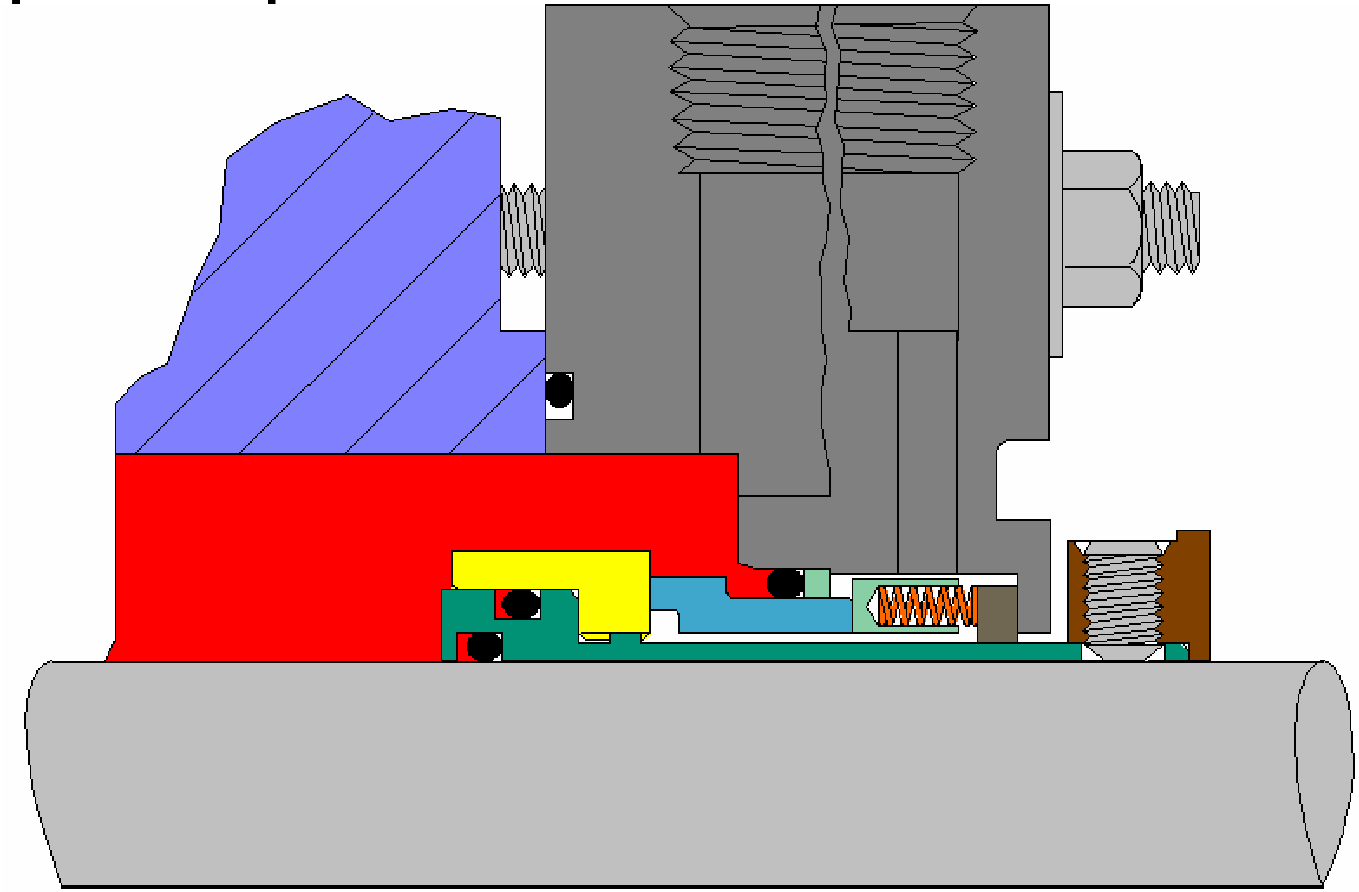
- Metal degradation
  - Alloy selection must be appropriate. Corrosion tables are available
- Spring corrosion
  - Highly stressed parts can be more prone to corrosion. Chloride stress corrosion is a particular problem for springs
- Elastomer hardening, swelling
  - Elastomer compound compatibility charts are available from elastomer and seal manufacturers
- Face material
  - Carbon graphite, sintered or reaction bounded silicon carbide, tungsten carbide, and aluminum oxide are the most common face material with different corrosion resistance
- Wetted/non wetted parts can be of different material. Non-metallic or glass lined parts can be used in some designs instead of metal parts.

Seal environment

- Keep space around the seal
- Allow circulation around the seal
- Avoid constricted spaces
- Provide connections for cleaning
- Provide passages for cleaning
- Consider dual seals

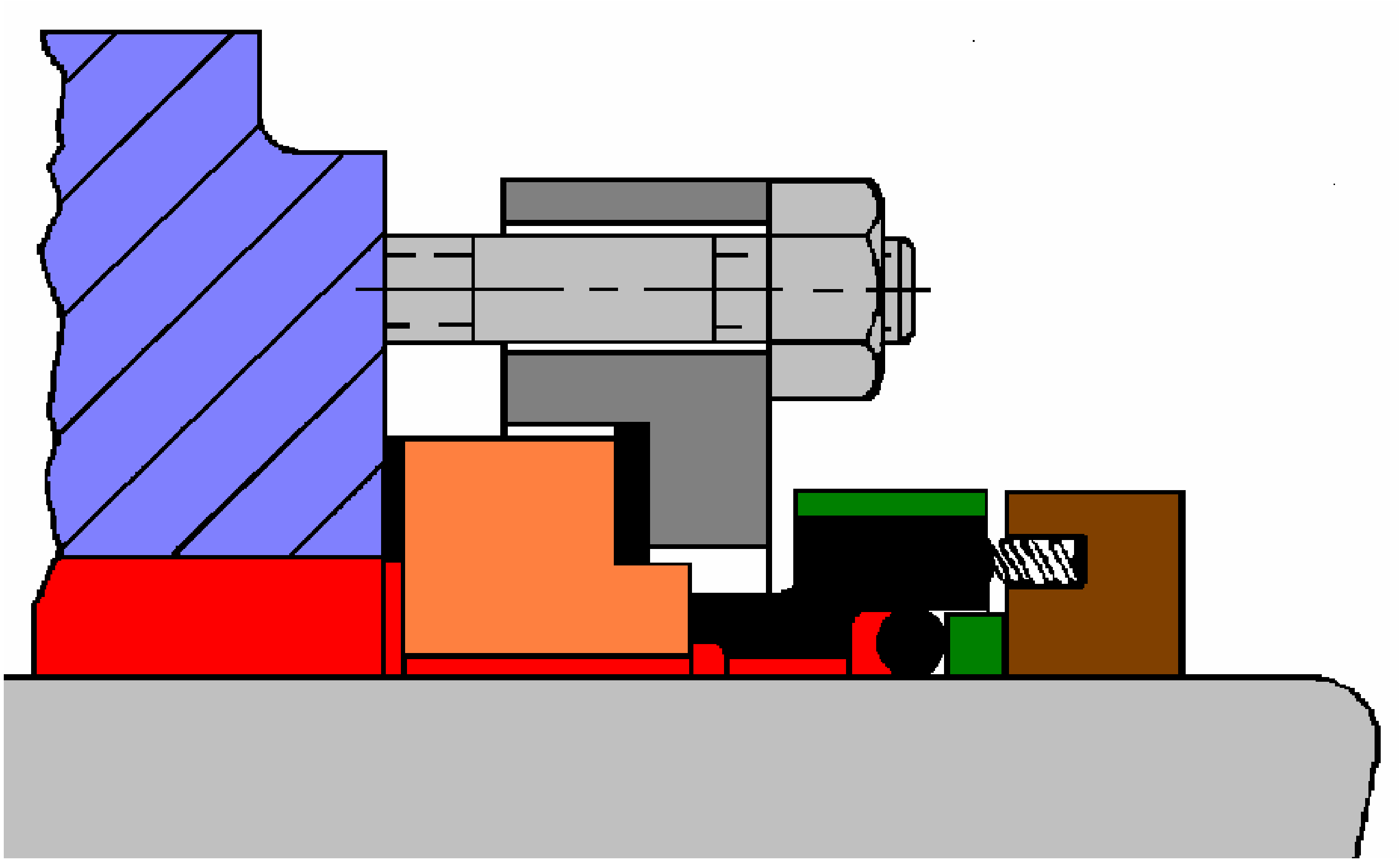
Seal environment

❖ Keep space open around the seal

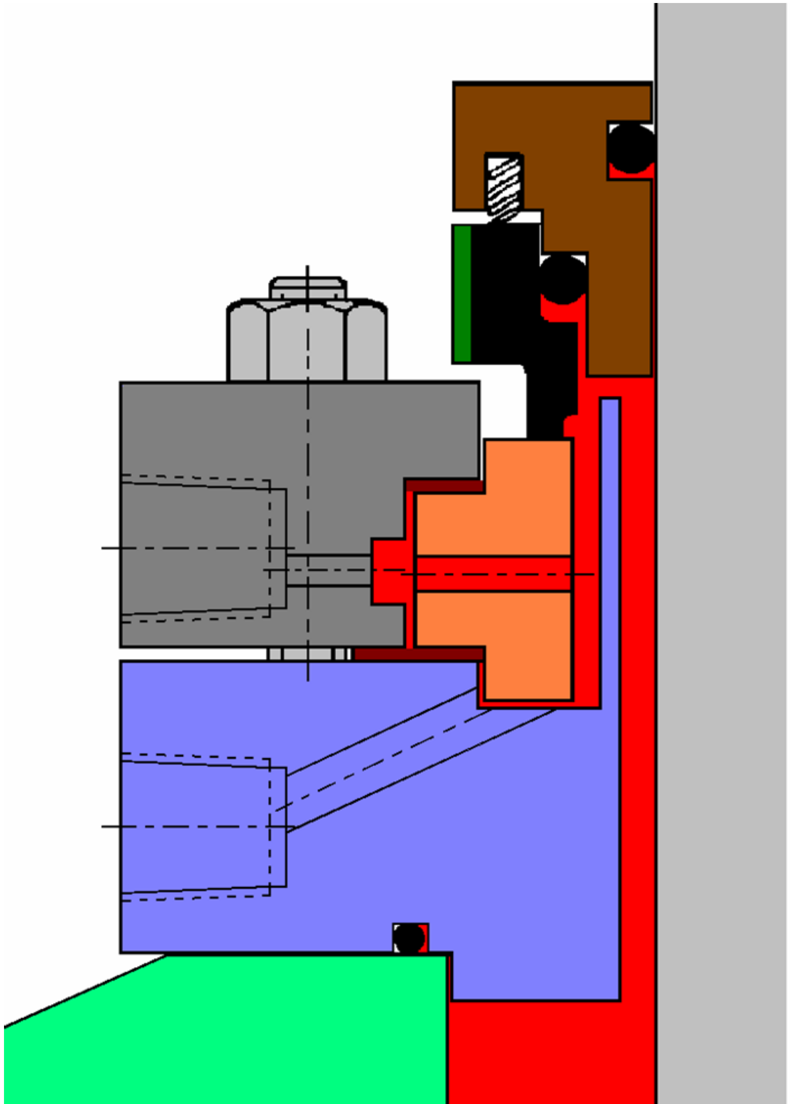


Seal environment

- Avoid constricted spaces



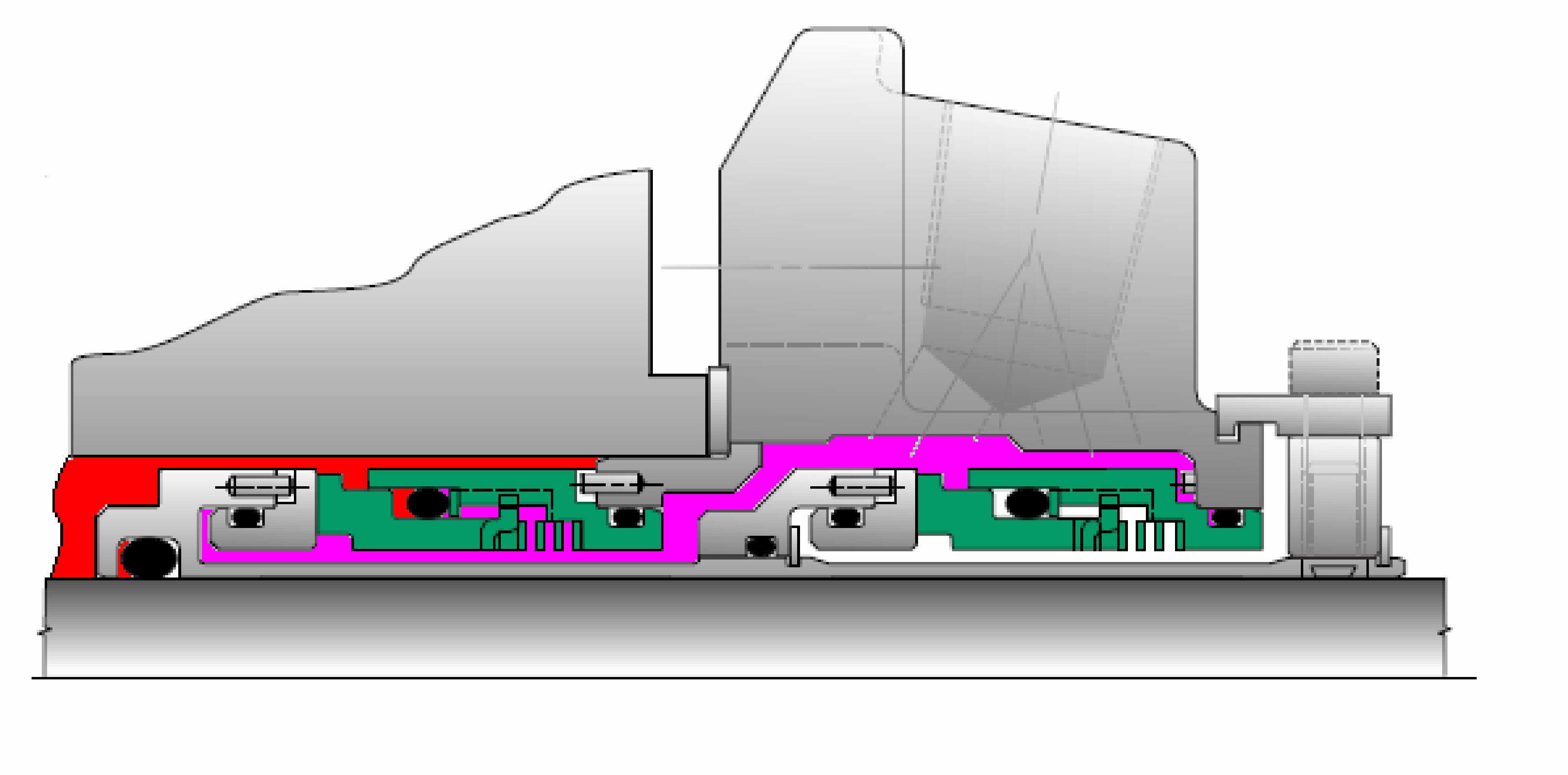
Seal environment



- Provide connections for cleaning
- Commonly used in mixer applications
- Requires external piping

Seal environment

- Dual seals do not seal the product
- They can seal a clean fluid



Face Design

- Faces can be deformed by
  - Pressure loads
  - Uneven temperature distribution in the face
  - Uneven loads from support surfaces
  - Uneven loads from drive mechanisms

Face Design
Frictional loads

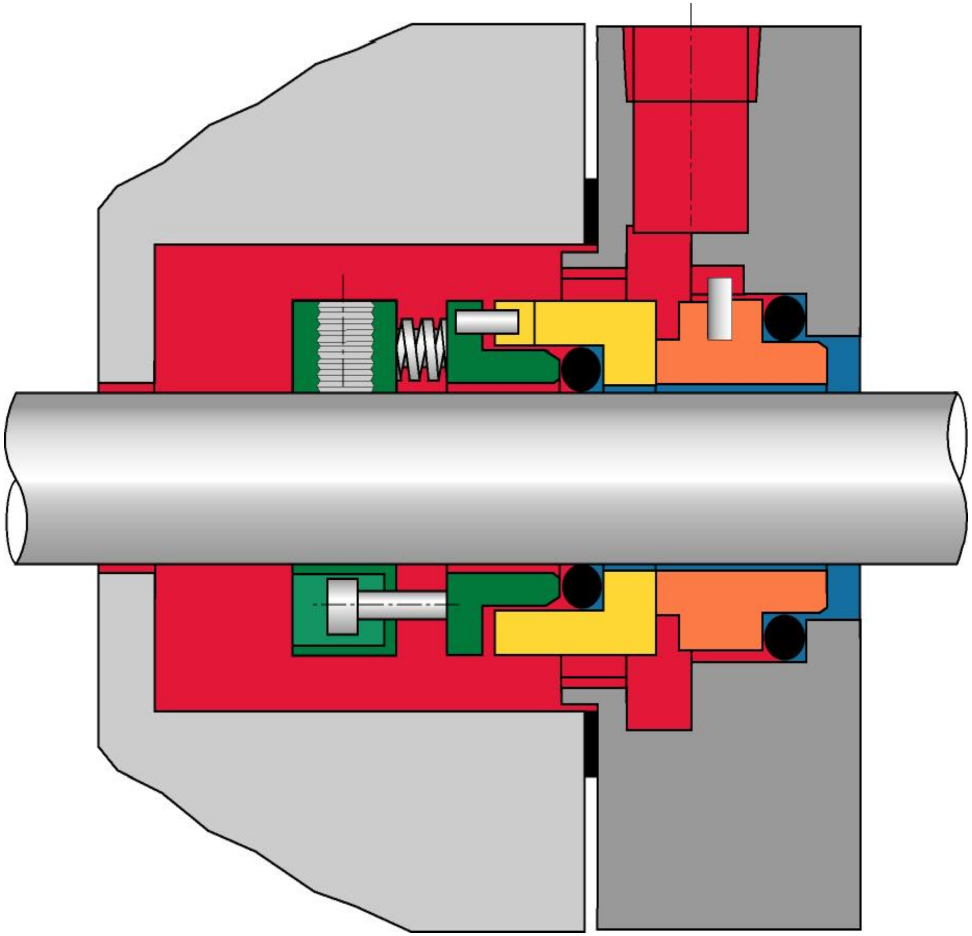
- Heat is generated from the friction between the two seal faces
- $Q = [P(B-K) + Ps] \times V \times \mu \times A$
  - P = Sealed pressure
  - B = Balance ratio
  - K = Pressure drop across the seal face
  - Ps = Spring pressure
  - V = surface velocity at mean face diameter
  - μ = Coefficient of friction between faces
  - A = face area
- The sealed pressure is given, but seal design can have an impact on all other factors

Face Design
Frictional loads

- The balance ratio is controlled by face geometry
- The pressure drop across the face is influenced by the face deflection
- The spring pressure is designed primarily to overcome secondary seal friction
- The surface velocity can be minimized by keeping the face as close to the shaft as possible
- The coefficient of friction is influenced by the product sealed but also by the choice of face material combination
- The face area is a function of how close the face is to the shaft and how wide it is
- The face width is a compromise between leakage and reduced heat.

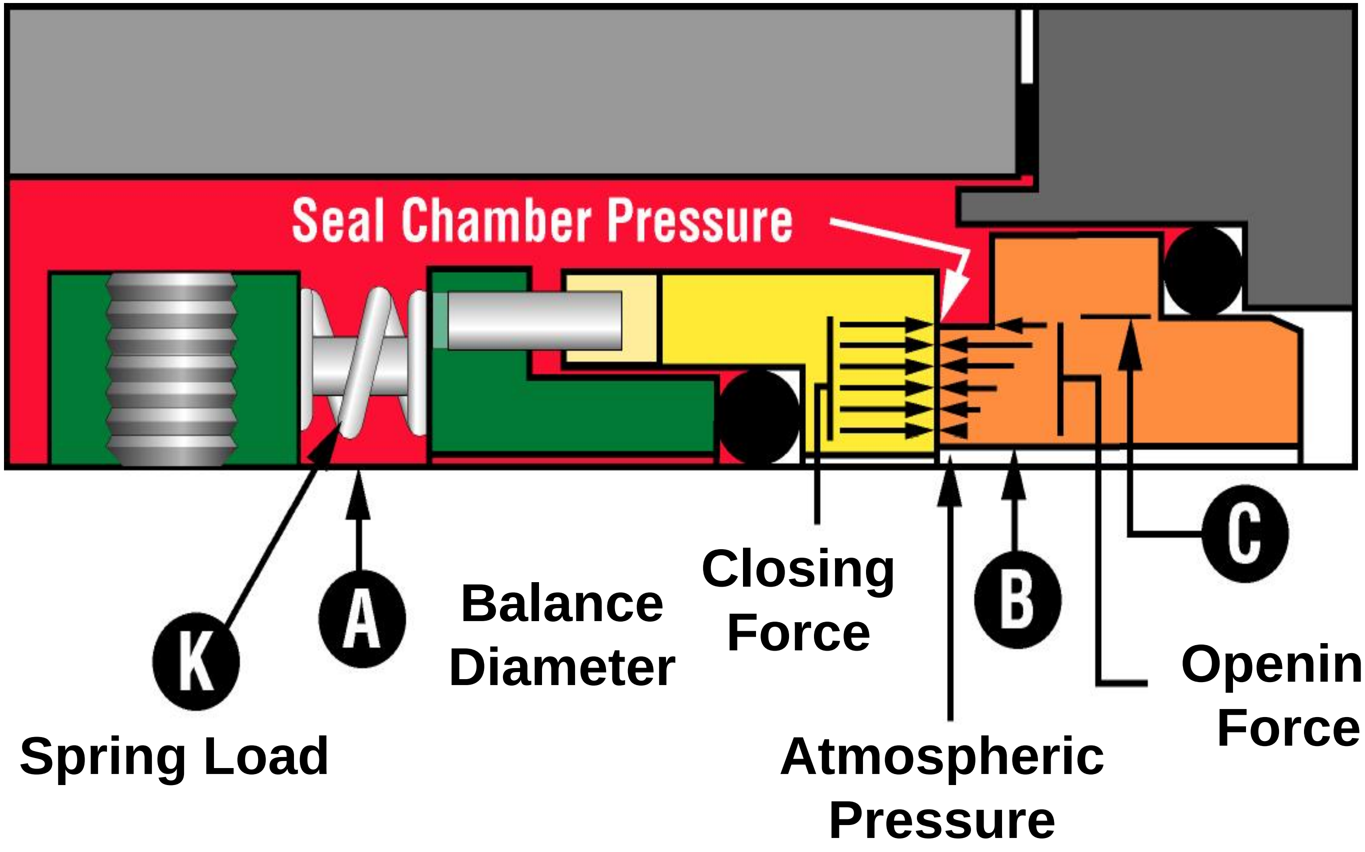
Unbalanced Seals

- Simplest seal design
- Process pressure in seal chamber creates high closing forces on seal faces
- Has reduced pressure capabilities



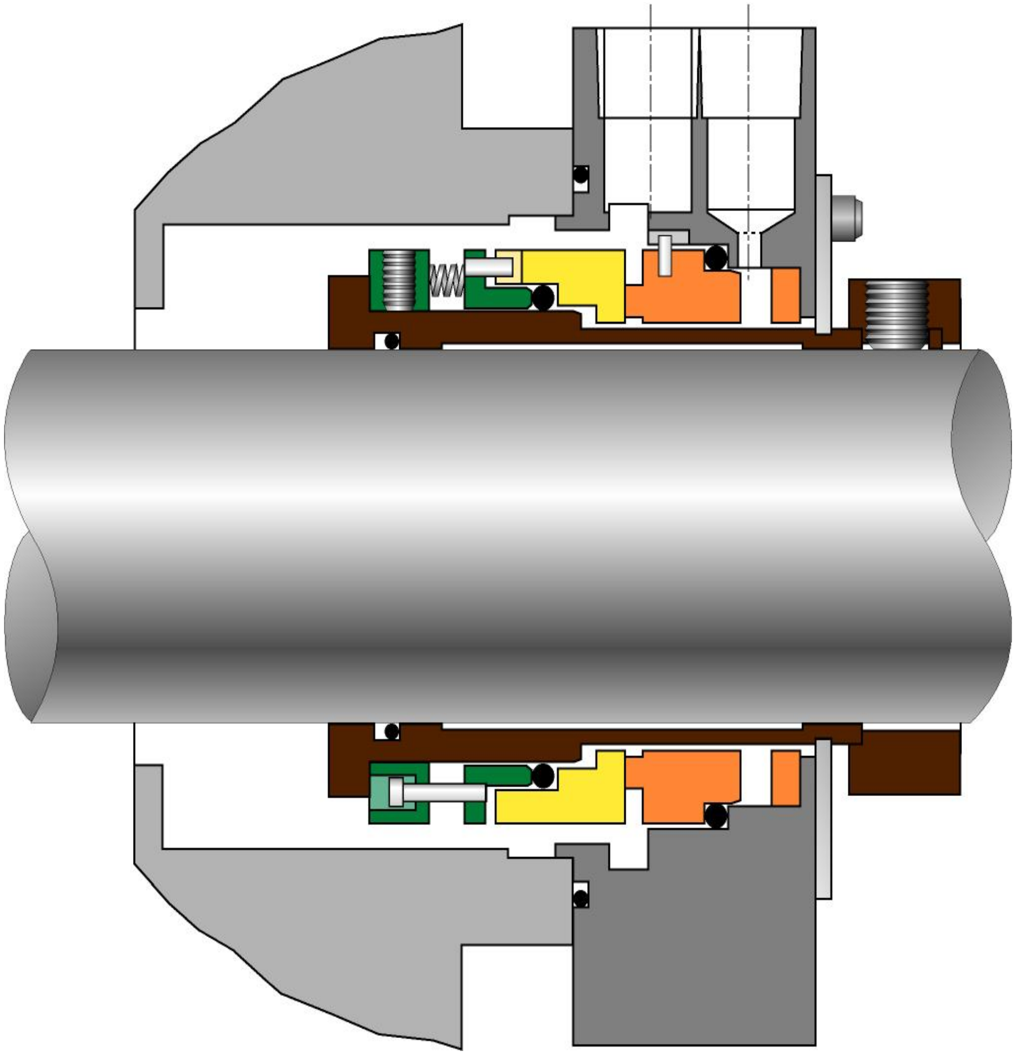
Unbalanced Seals
- Forces Acting on Seal Faces

$$F_{spring} + F_{closing} - F_{opening} = F_{net}$$



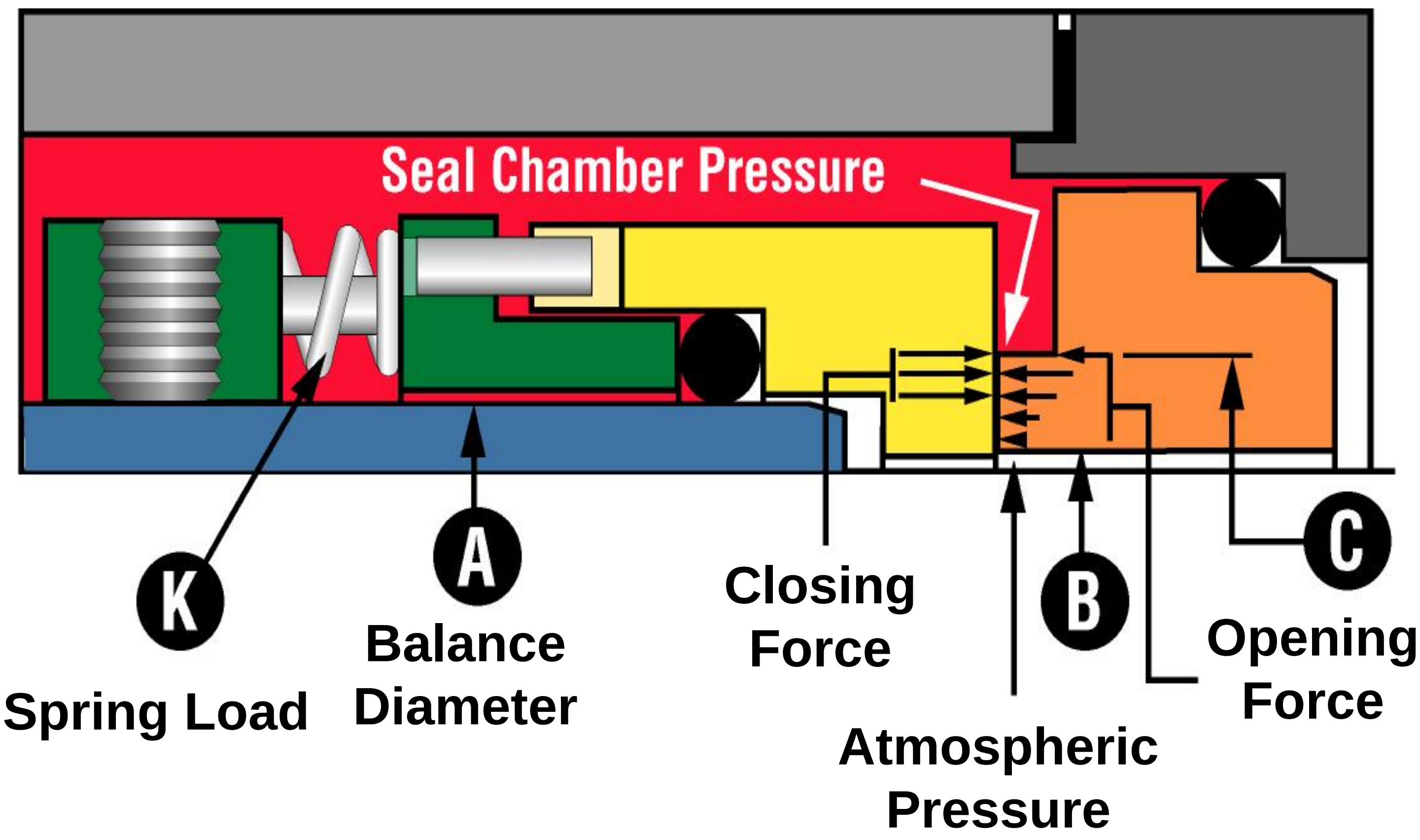
Balanced Seals

- Balances out portion of hydraulic loads for process fluid pressure to reduce closing forces on seal faces
- Has increased pressure capabilities



Balanced Seals
- Forces Acting on Seal Faces

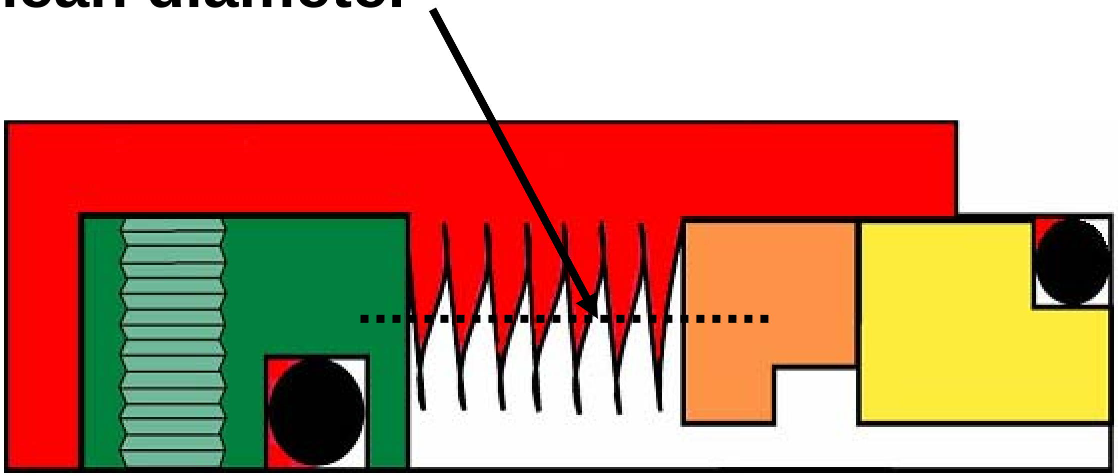
$$F_{spring} + F_{closing} - F_{opening} = F_{net}$$



Balanced Seals
Metal Bellows Seals

- Bellows eliminates the need for a semi-dynamic secondary seal

Balance diameter is bellows mean diameter



Balanced Seals
Balance Ratio Calculations

$$\frac{\text{Closing Area}}{\text{Opening area}} = \text{Balance Ratio}$$

The formula reduces to:

$$\frac{OD^2 - BD^2}{OD^2 - ID^2} = \text{Balance Ratio}$$

Most commonly the ratio is between 70% and 80%

It is strictly a geometric relationship

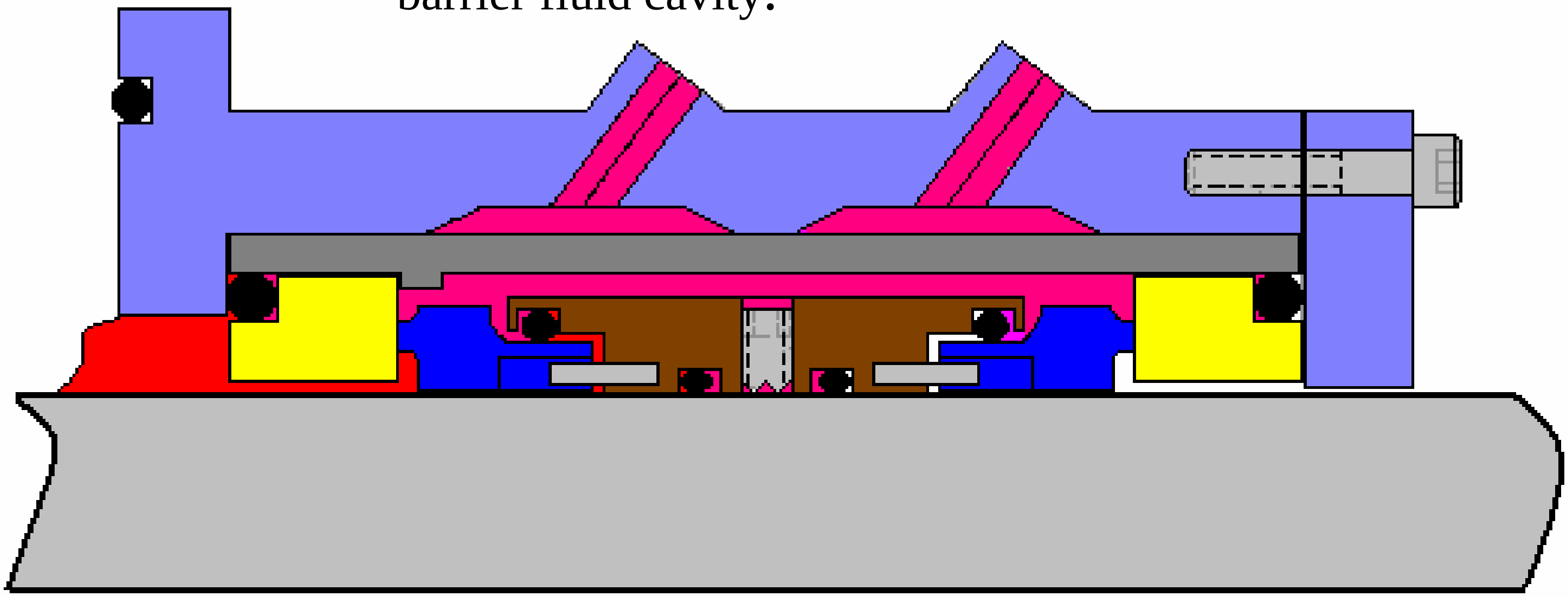
In reality the ratio of closing to opening forces depends on the face profile and fluid viscosity

It is important for pressure capability but also for temperature sensitive fluids

Balanced Seals

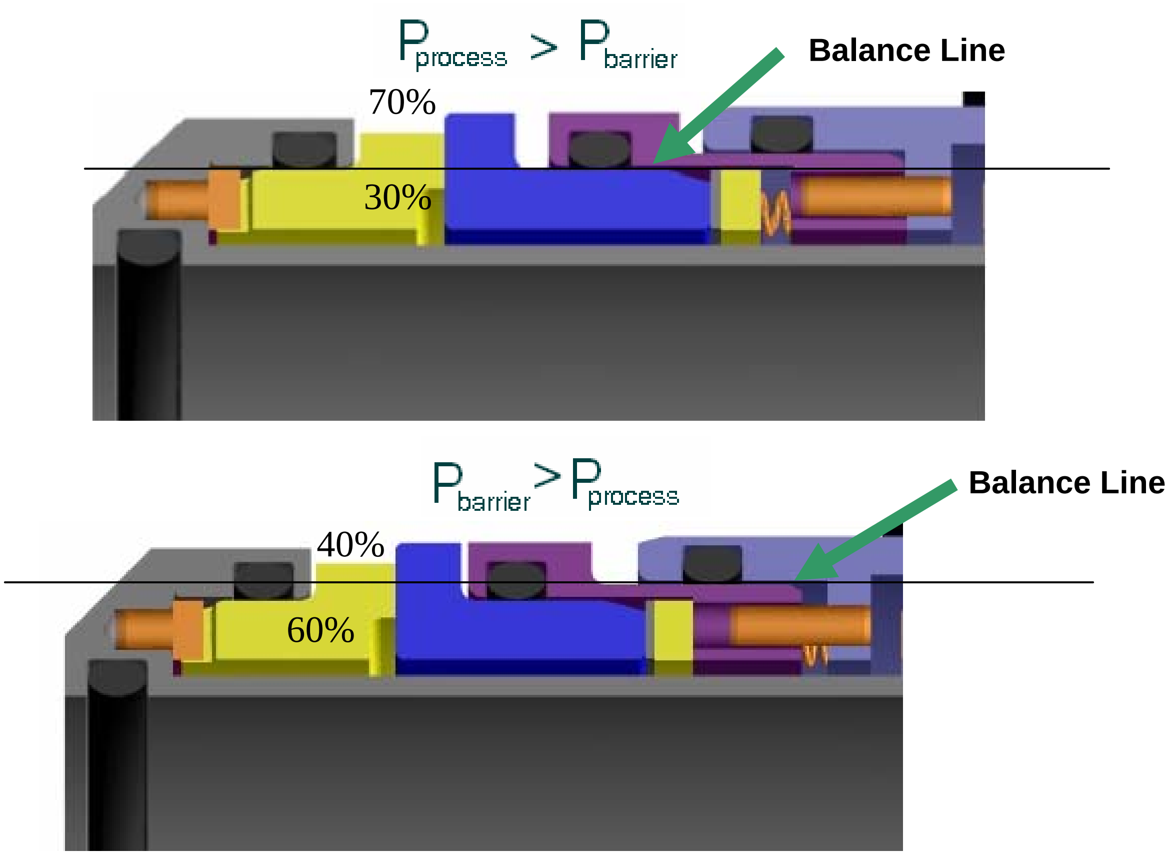
Balance in Double seals

These seals are only balanced for higher barrier fluid pressure. If the barrier fluid pressure is lost, the inboard seal will open and product will get in the barrier fluid cavity.



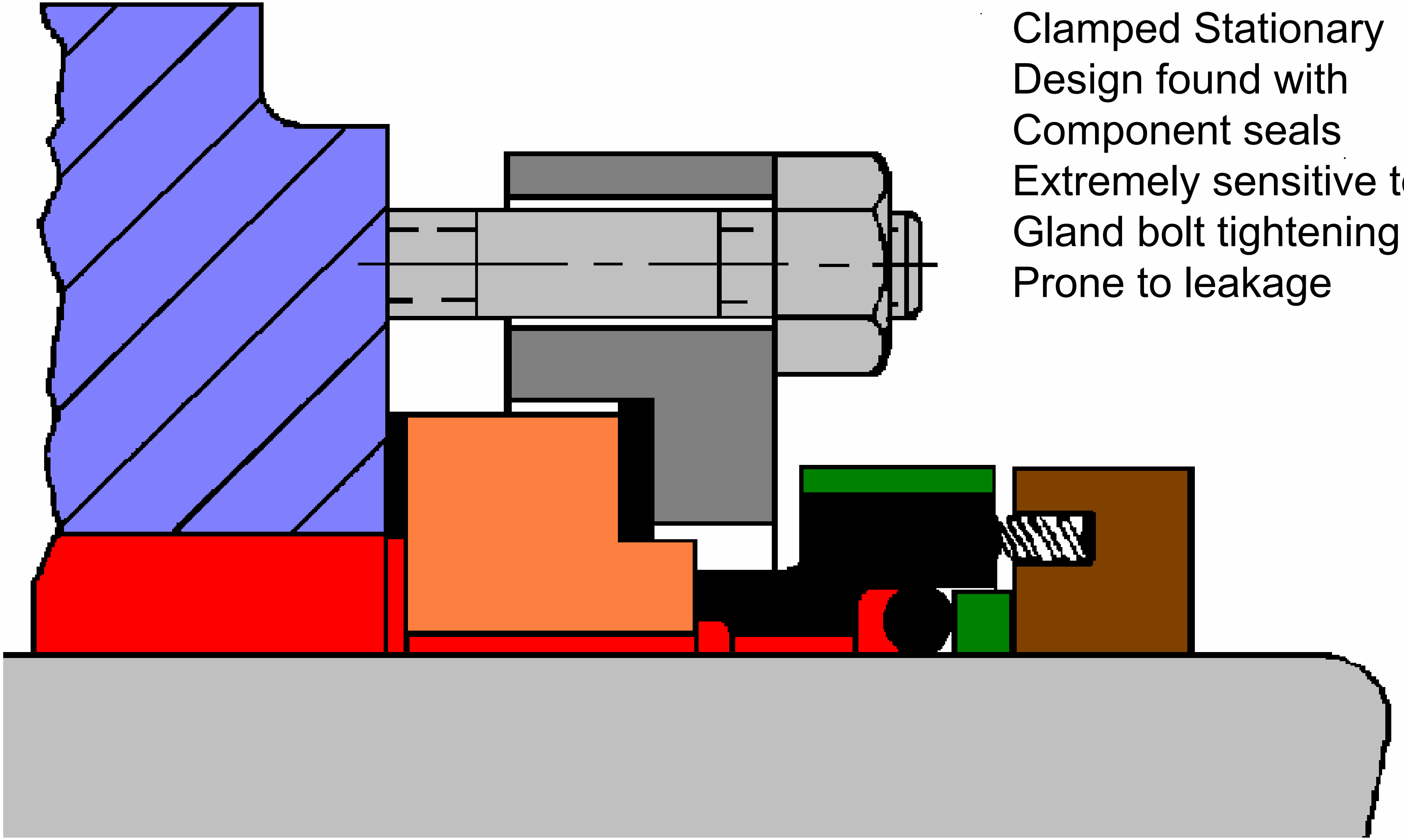
Balanced Seals

Balance in Double seals



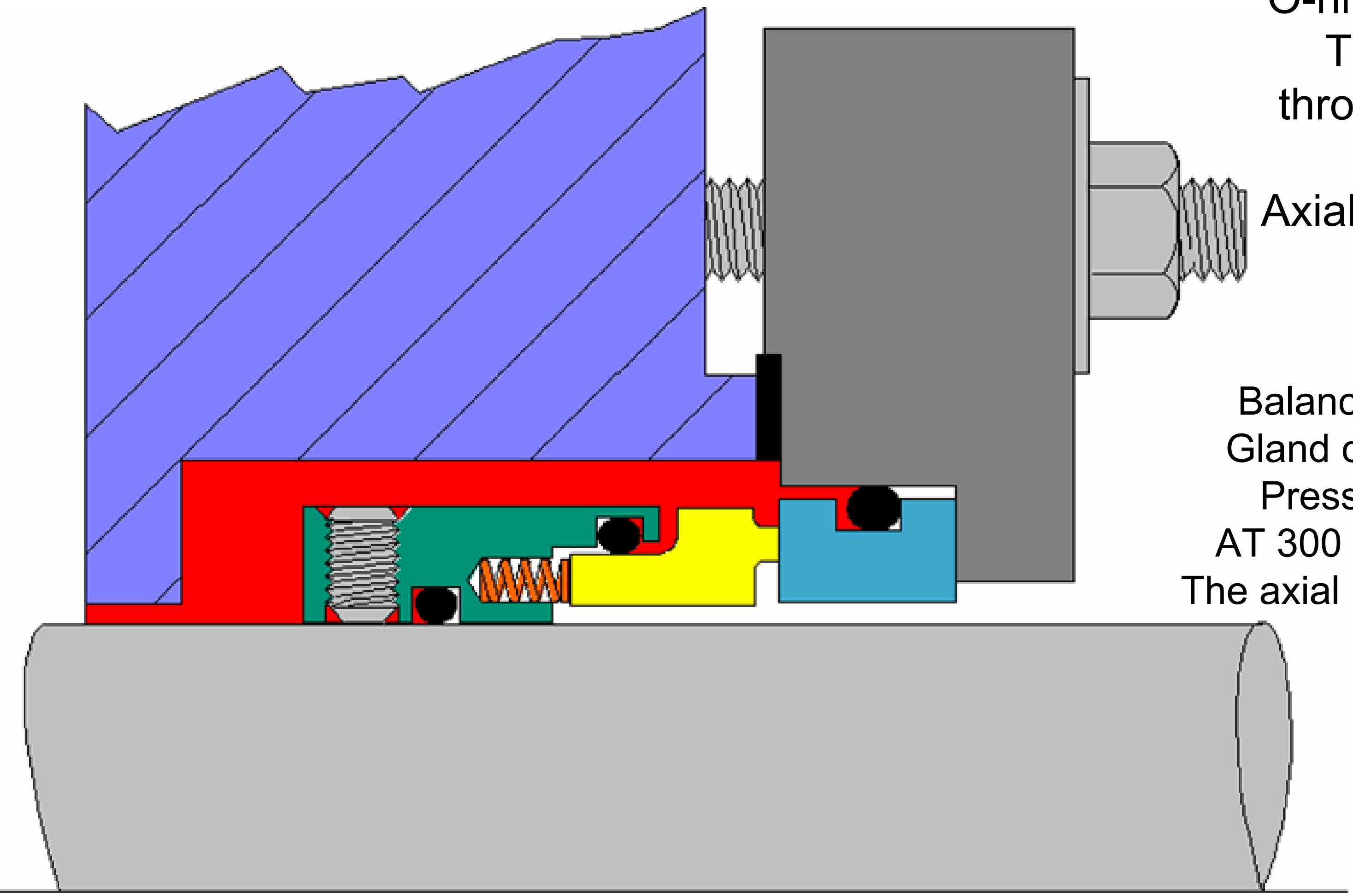
Face Design

Face distortion



Clamped Stationary Design found with Component seals
Extremely sensitive to Gland bolt tightening
Prone to leakage

Face Design
Face distortion

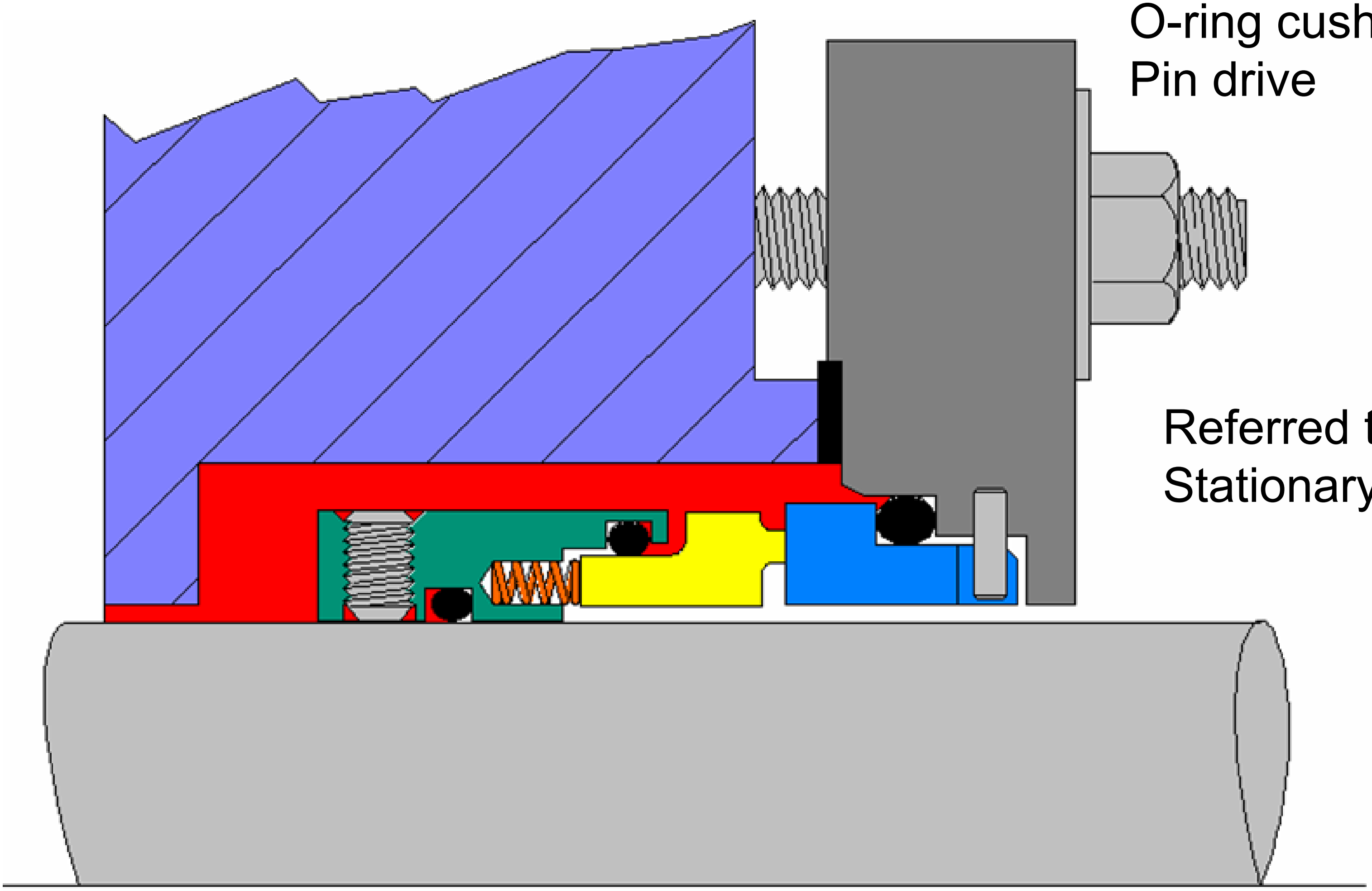


O-ring Mount Stationary
Torque resistance through friction against the gland
Axial pressure loads can Be significant

Example

Balance Diameter = 5.000”
Gland counter bore = 6.000”
Pressure area= 8.639in^2
AT 300 PSI process pressure
The axial load on the seal face is 2,591.8 lbs

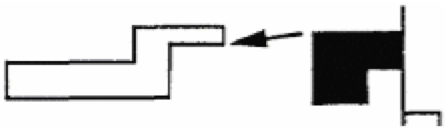
Face Design



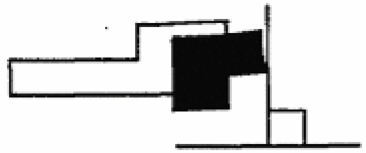
O-ring cushioned stationary
Pin drive

Referred to as VDMA Stationary

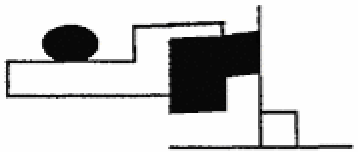
Face Design
Pressed in Faces



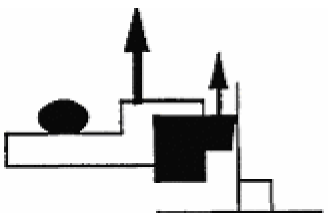
Parts are manufactured. The carbon is larger than the metal part.
The carbon is inserted in the metal.



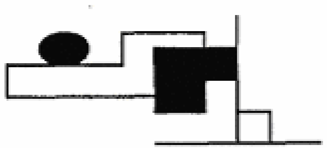
The carbon is shrunk into the holder the face is no longer flat



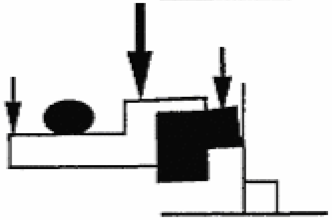
The face is lapped flat



With frictional heat the parts expand, but the metal expands faster than The carbon, typically 9.6 x 10^{-6} in/in/^{0}F(316SS) vs. 2.1 x 10^{-6} in/in/^{0}F (carbon)



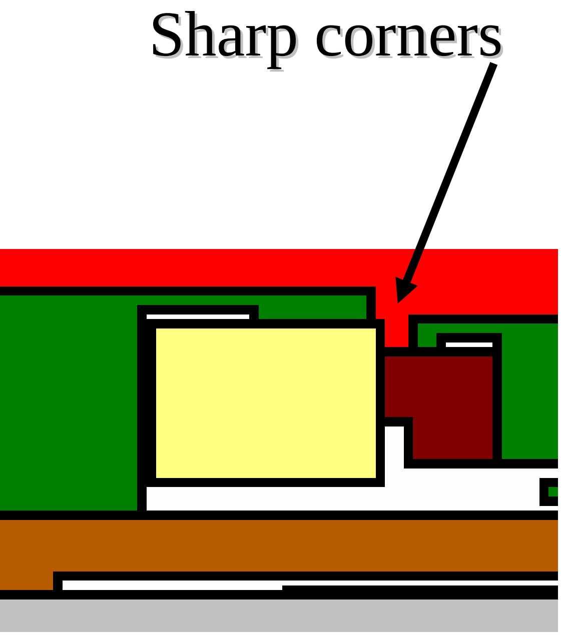
The carbon face wears to conform with the mating face



As the face wears, the fluid film penetrates across the face, the frictional heat is reduced, the temperature decreases, the parts shrink at a different rate, the face further distorts, and if all this is significant enough

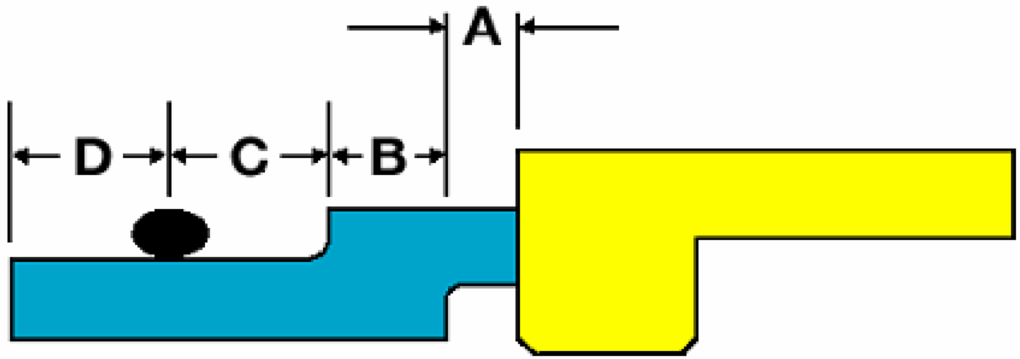
The seal leaks.

Face Design
Pressed in Faces

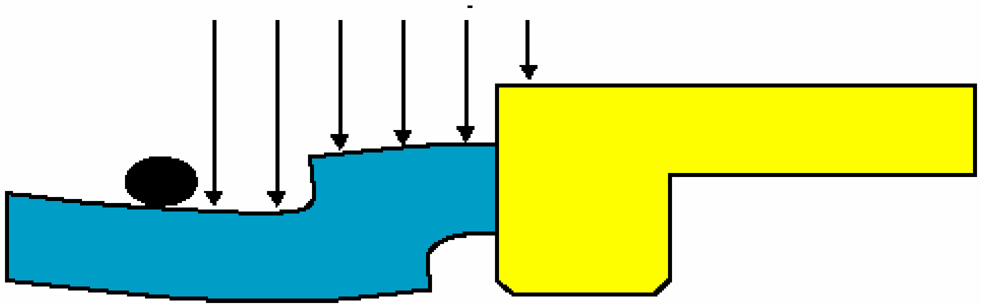


- Besides the difficulty in maintaining face flatness
- Two other factors must be considered:
  - Sharp corners are inherent in the design
  - The interface between the metal part and the seal face outside diameter must seal and prevent product from migrating through

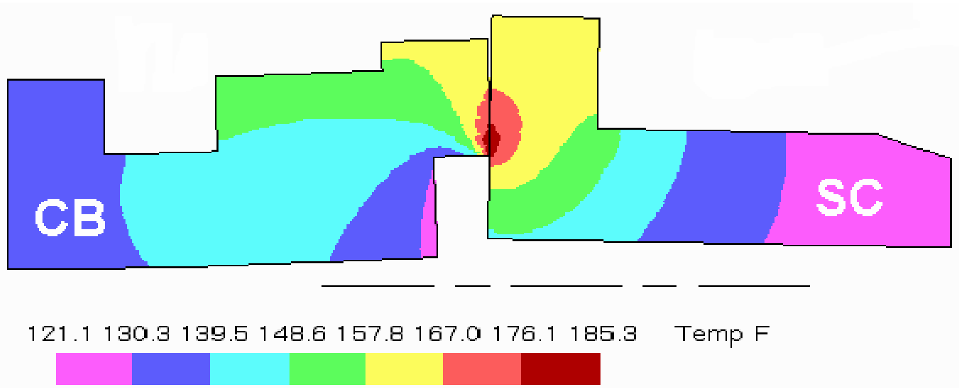
Face Design
Monolithic Seal Faces



Carbon seal face geometry is essential because of the low modulus of the material



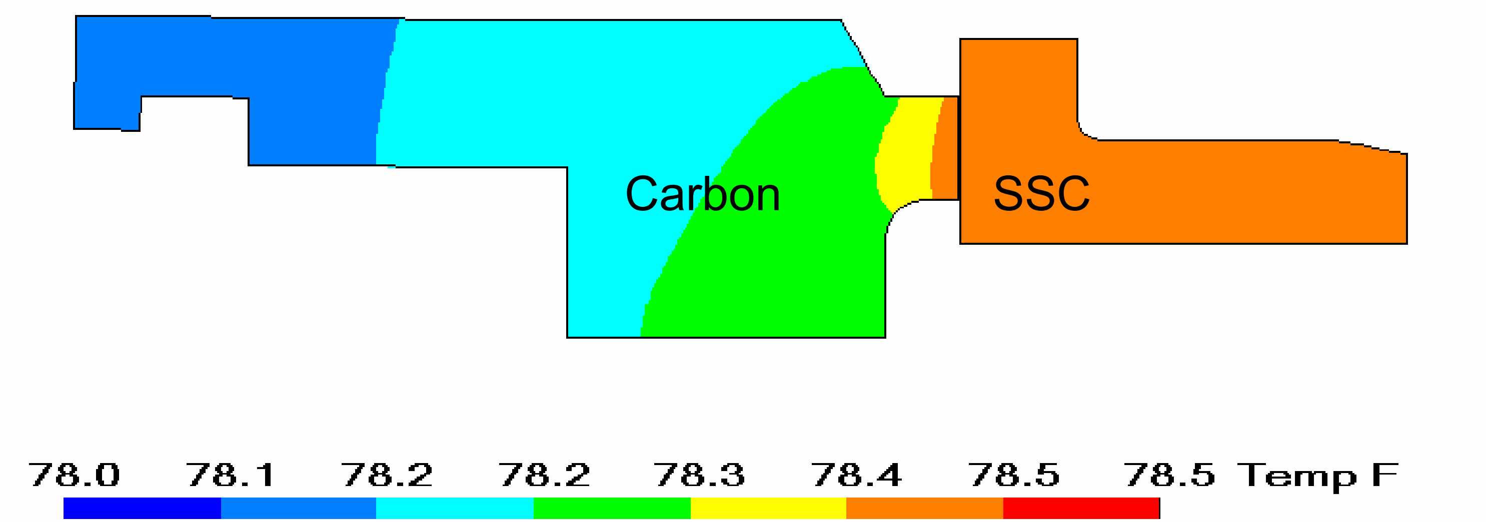
Deflection is controlled, not eliminated



Typical Finite Element Analysis of seal faces under given conditions

Face Design FEA Analysis
Contacting Seal, C/SSC, Water

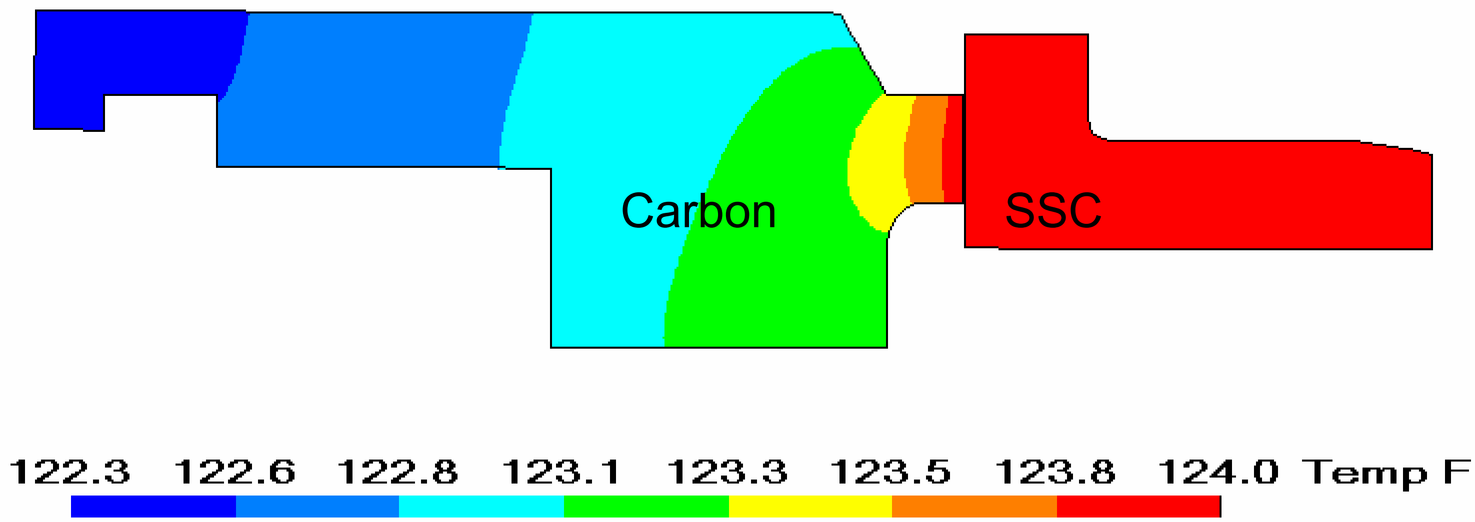
- Operating conditions:
  - 15 rpm
  - 30 psia, process pressure
  - 4.6 µin, RMS surface roughness
  - 78 F, process temperature
  - 0.10, boundary coefficient of friction
  - Water, process fluid
- Performance parameters:
  - 1.96 Btu/h, total frictional heat input
  - 79 F, average face temperature
  - 3.3 µrad., pressure distortion
  - 1.2 µrad., thermal distortion
  - 4.5 µrad. (0.1 LB), total face distortion
  - 0.40 grams/hr, leakage rate



Face Design FEA Analysis
Contacting Seal, C/SSC, Oil

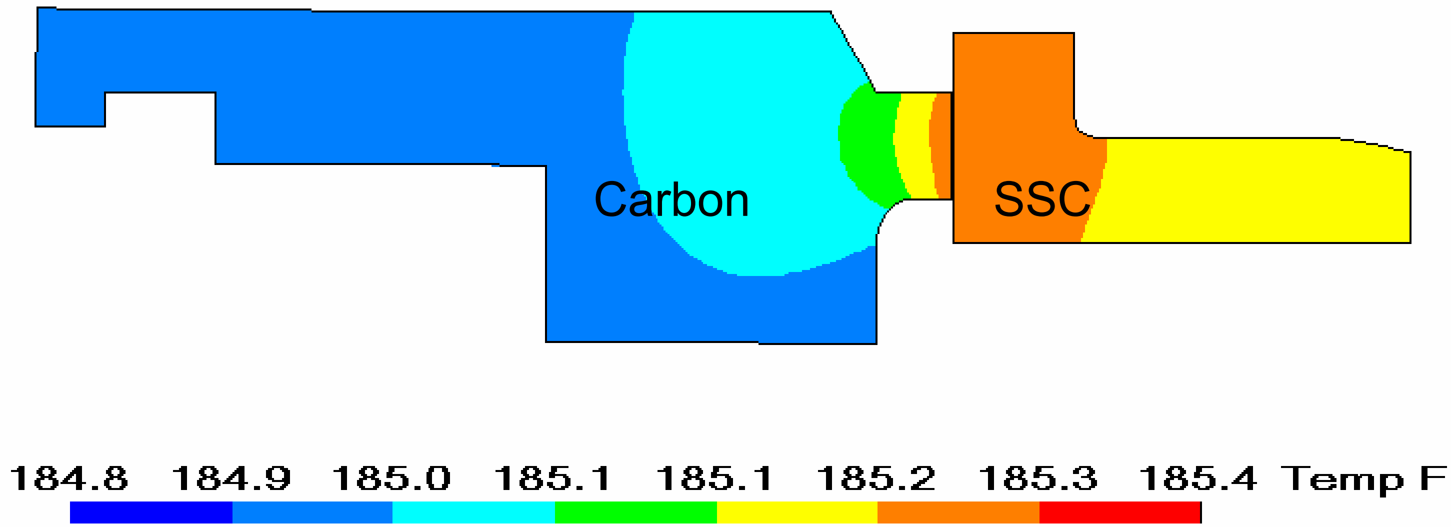
- Operating conditions:
  - 50 rpm
  - 15.7 psia, process pressure
  - 4.6 μin, RMS surface roughness
  - 113 F, process temperature
  - 0.10, boundary coefficient of friction
  - Oil, process fluid

- Performance parameters:
  - 8.19 Btu/h, total frictional heat input
  - 124 F, average face temperature
  - -4.6 μrad., pressure distortion
  - 5.9 μrad., thermal distortion
  - 1.3 μrad. (0.0 LB), total face distortion
  - 0.01 grams/hr, leakage rate



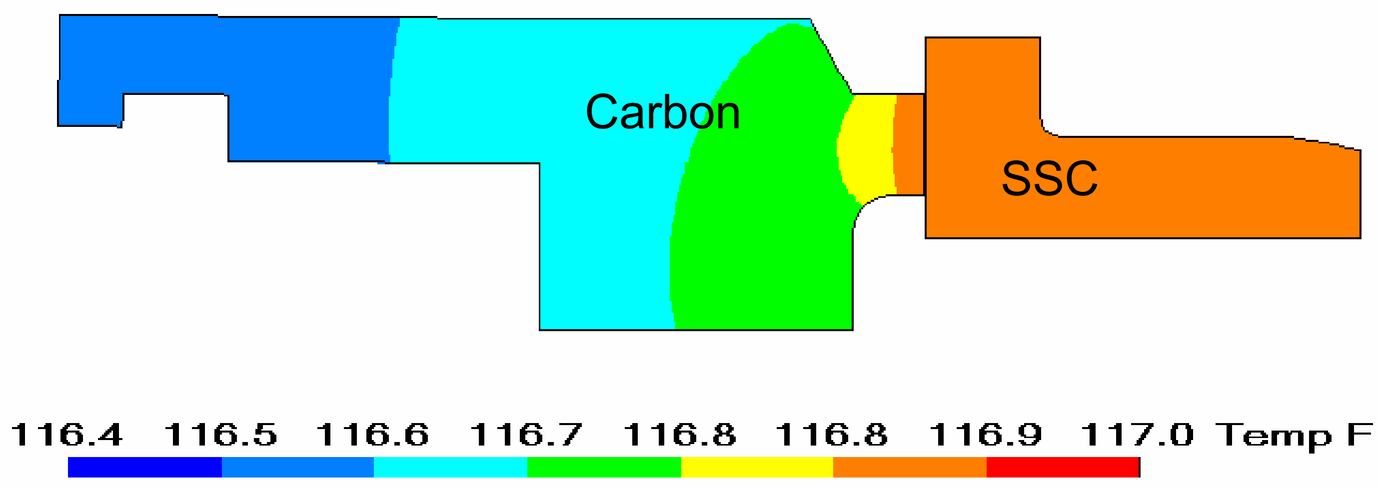
Face Design FEA Analysis
Contacting Seal, C/SSC, Wash

- Operating conditions:
  - 50 rpm
  - 15.7 psia, process pressure
  - 4.6 μin, RMS surface roughness
  - 185 F, process temperature
  - 0.10, boundary coefficient of friction
  - Water, process fluid
- Performance parameters:
  - 5.79 Btu/h, total frictional heat input
  - 185 F, average face temperature
  - -3.2 μrad., pressure distortion
  - 1.2 μrad., thermal distortion
  - -2.0 μrad. (0.0 LB), total face distortion
  - 0.07 grams/hr, leakage rate



Face Design FEA Analysis
Contacting Seal, C/SSC, Air

- Operating conditions:
  - 15 rpm
  - 30 psia, process pressure
  - 4.6 μin, RMS surface roughness
  - 78 F, process temperature
  - 0.125, boundary coefficient of friction
  - Air, process fluid
- Performance parameters:
  - 2.34 Btu/h, total frictional heat input
  - 117 F, average face temperature
  - 3.2 μrad., pressure distortion
  - 1.3 μrad., thermal distortion
  - 4.5 μrad. (0.1 LB), total face distortion

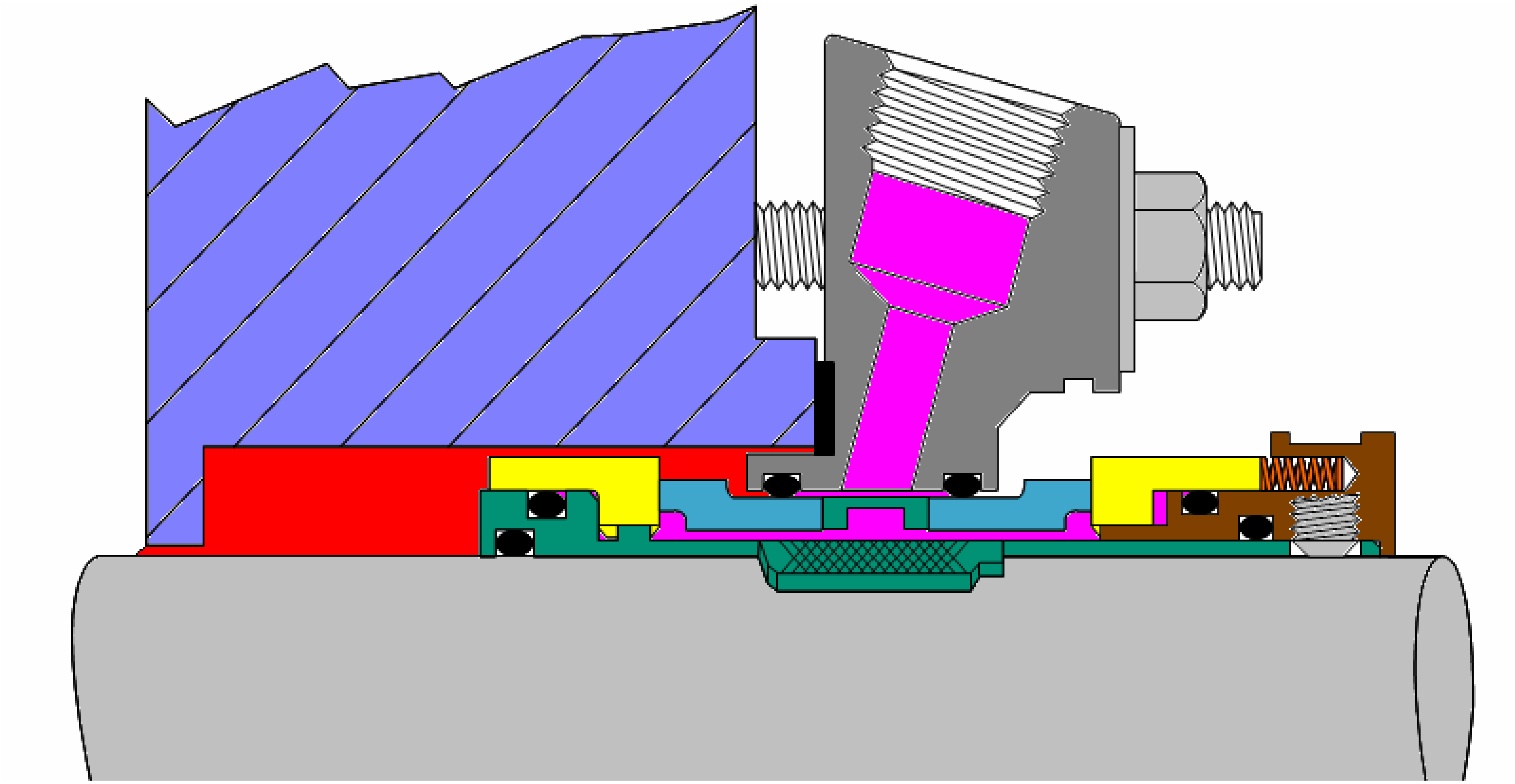


Face Design
Seal Interface

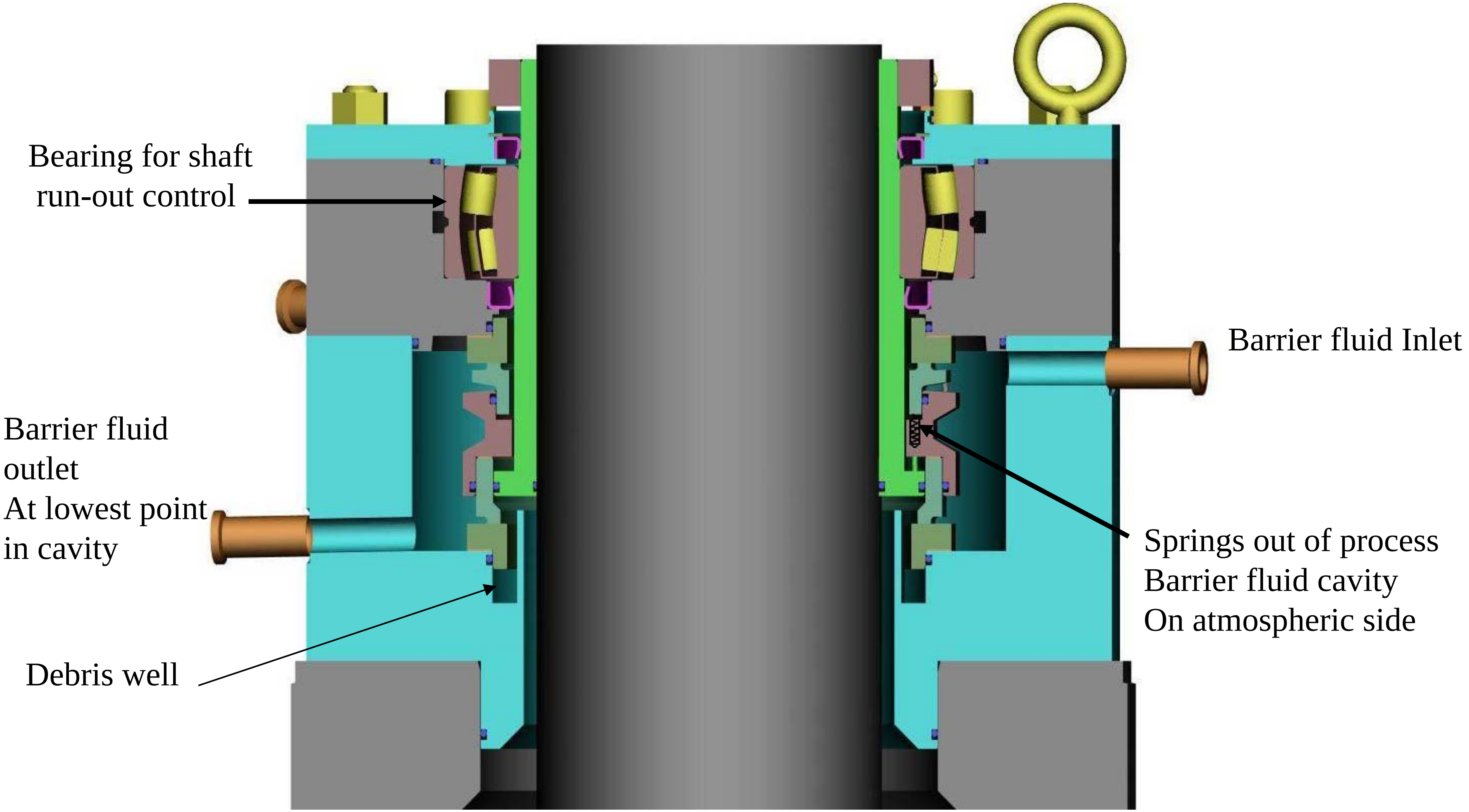
- Film thickness approximation
- Combined face roughness = $\sqrt{\sigma_1^2 + \sigma_2^2}$
- If $\sigma_1^2 = \sigma_2^2 = 4.6$ µin, then the combined face roughness = 6.5 µin
- Full liquid fluid film thickness is then approximated at 3 x 6.5 = 19.5 µin
- In reality the seal operates in mixed contacting mode
  - The actual gap between the faces is smaller and not uniform
  - This is a limit for contacting liquid seals

Do not seal the product

- Dual seals can seal a clean fluid

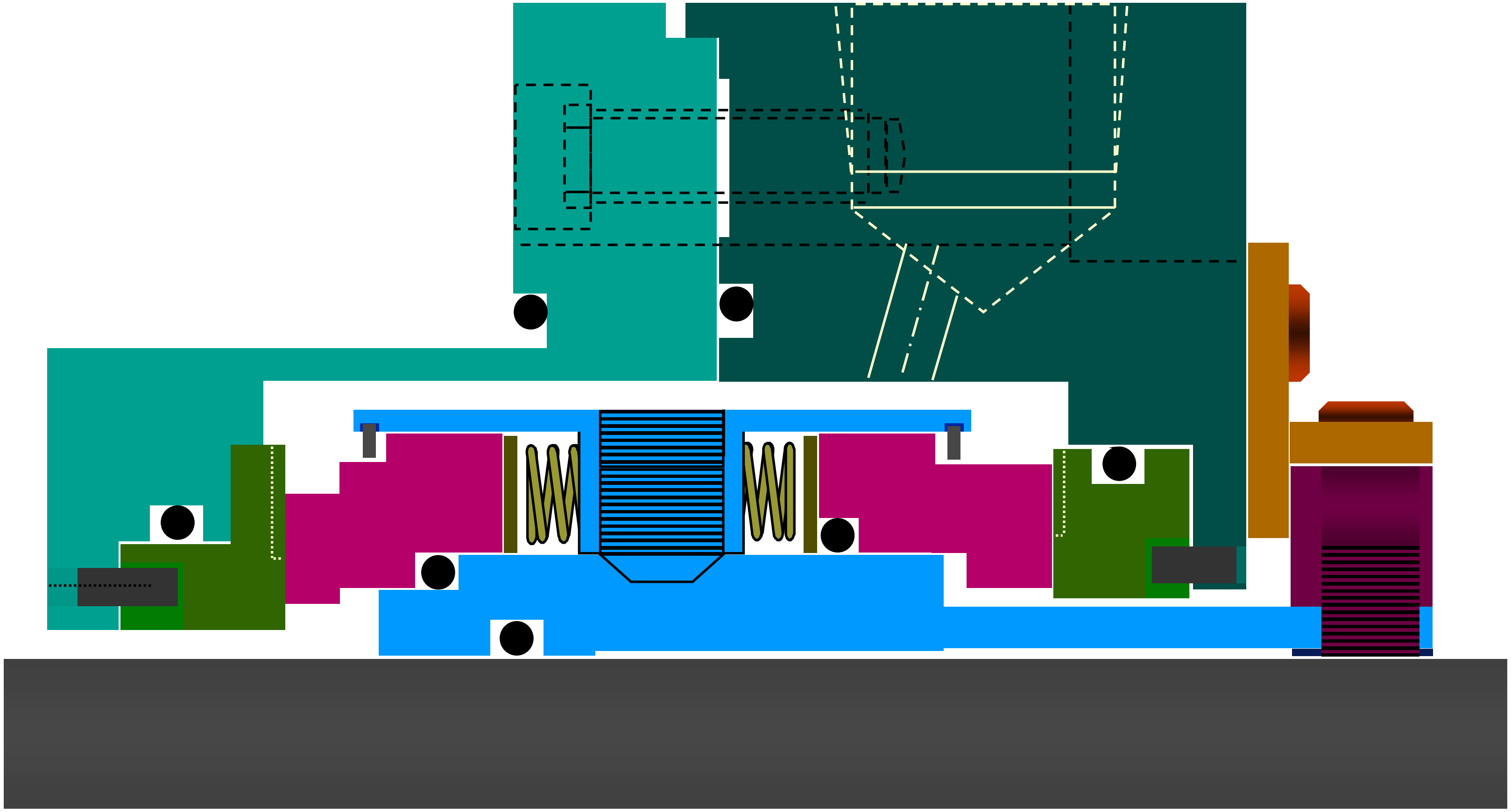


Dual Seal Optimized for Mixer Application



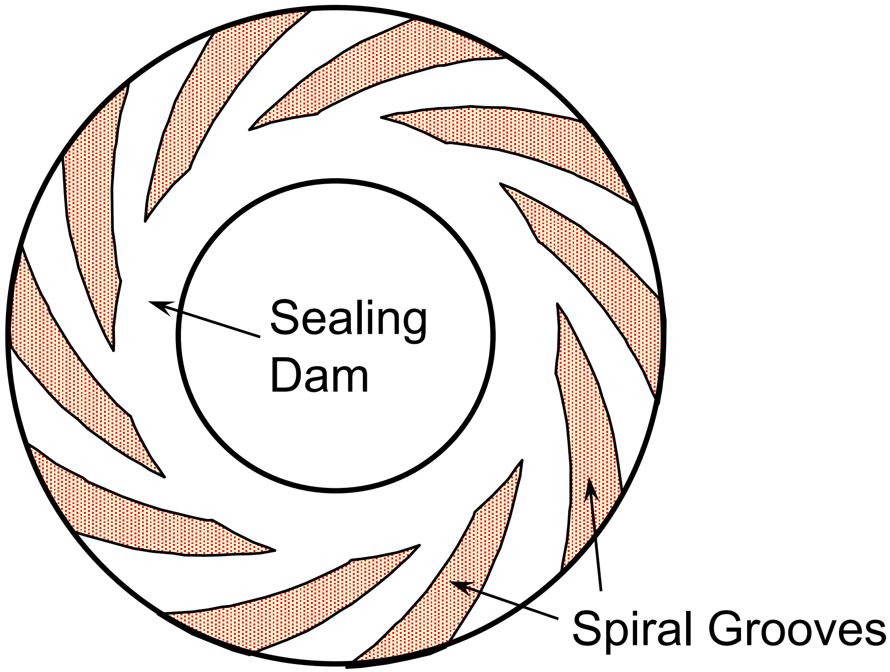
Do not seal the product
Gas seals

- Gas seals can seal sterile air or nitrogen

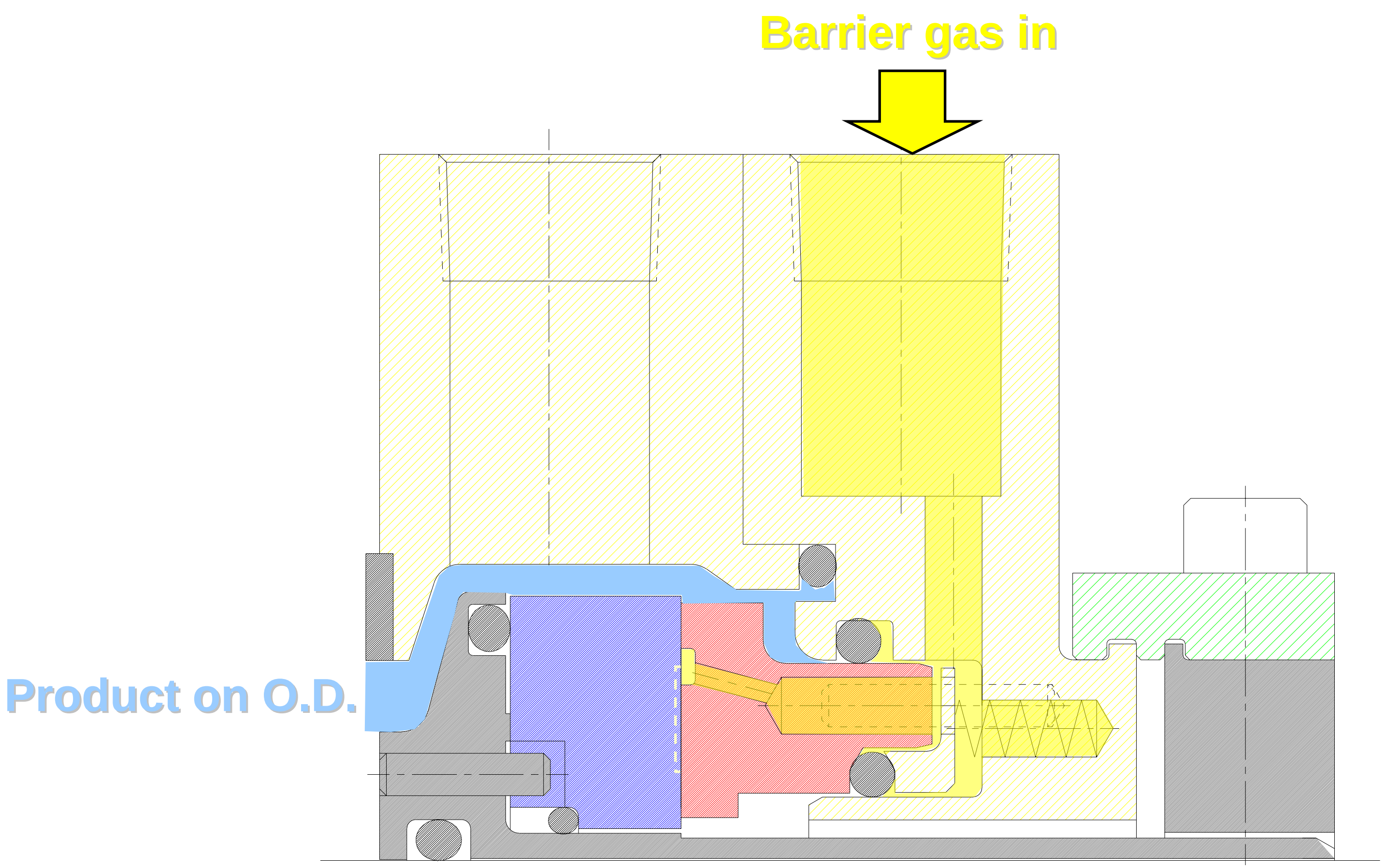


Hydrodynamic Operation

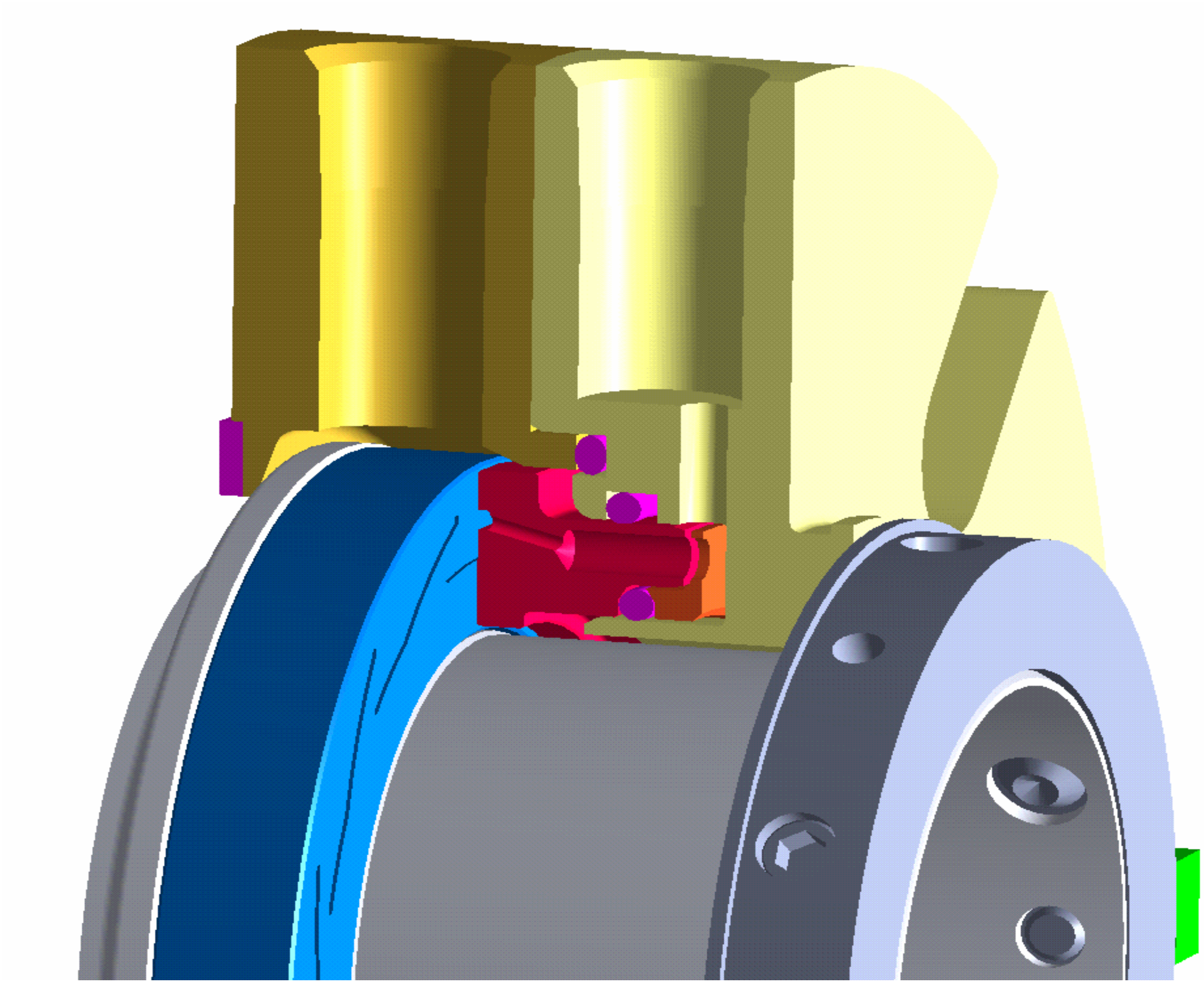
- Spiral Groove



Gas Seal
Product on the OD



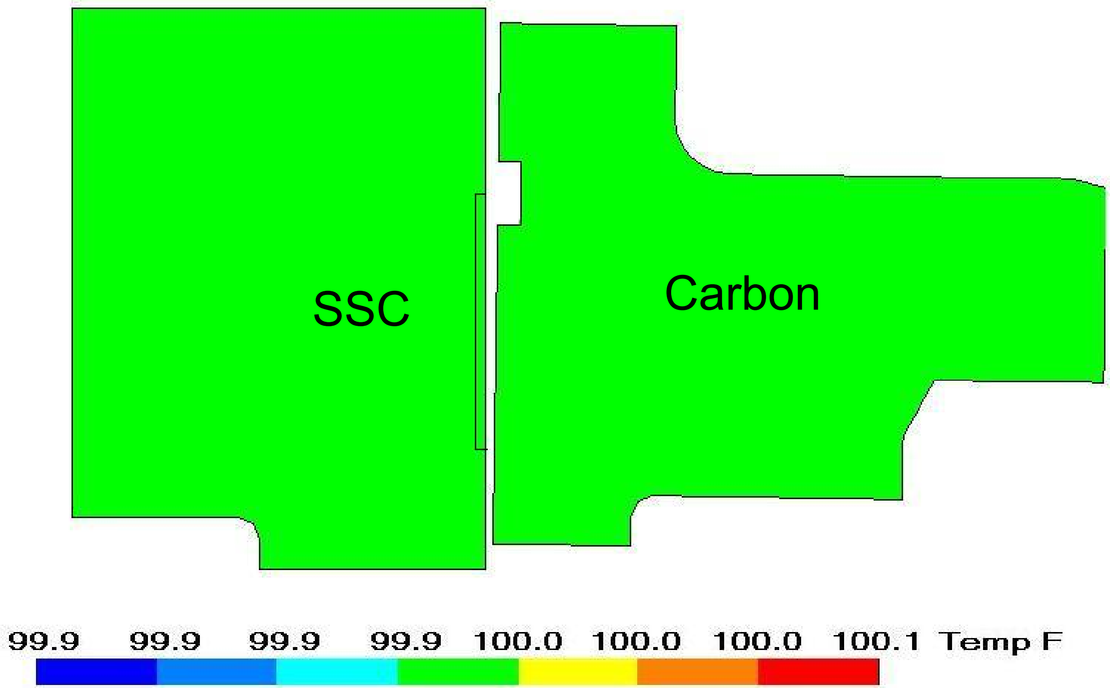
Enclosed Lift Off Grooves



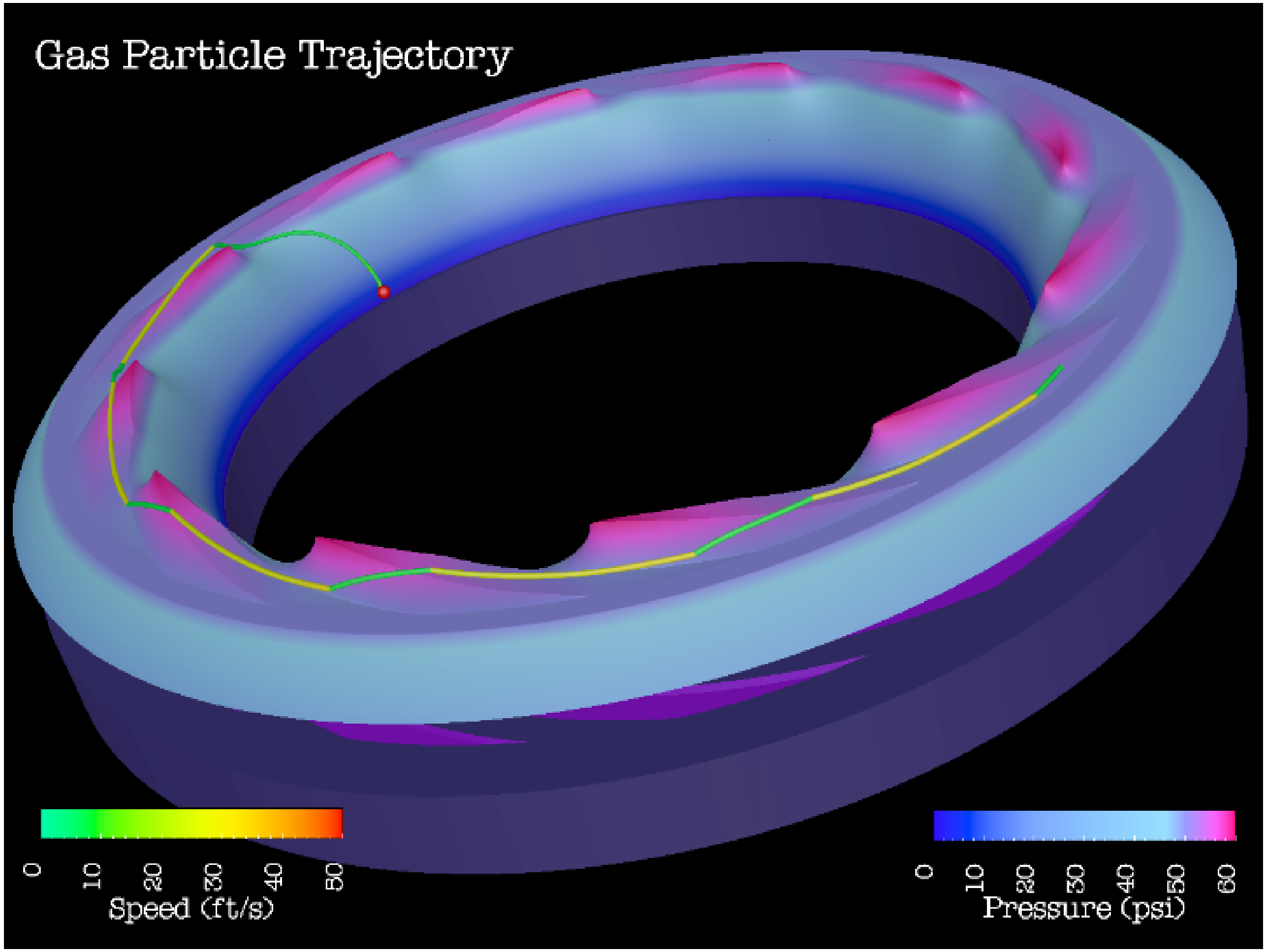
Gas Seal, C/SSC, Nitrogen

- Operating conditions:
  - 5, 15, 50 rpm
  - 15.7, 30 psia, process pressure
  - 4.6 μin, RMS surface roughness
  - 100 F, process temperature
  - 0.10, boundary coefficient of friction
  - Nitrogen, barrier fluid, 23 psi higher

- Performance parameters:
  - 147 – 171 μrad. Face deflection
  - 66 -77 μin., minimum film thickness
  - 0.93 – 0.98 scfh, barrier gas consumption rate



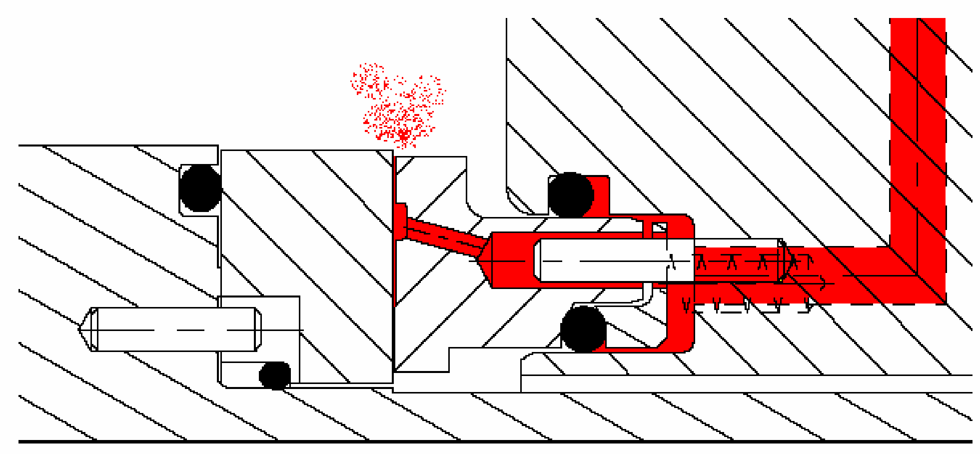
Computational Flow Analysis
Gas Particle Trajectory



Non Contacting Seals
Steam is a gas

Barrier gas connection and flow path

Barrier gas can be sterile air
Steam can also be used for sterilization



Conclusion

- Seals need to work under arduous conditions
- Seal designs vary to allow them to work in different applications
- There are many, many different seal configurations
- Knowing alternatives, you can choose designs to achieve a particular goal