Leader in Vacuum Valves

Vacuum Sealing Technology

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Sealing techniques in vacuum systems

STATIC

- **Non detachable connections:**
  - Welding
  - Brazing
  - Glass and Ceramic feed through
  - Gluing – epoxy resin (pressure > 10^{-7} mbar)
- **Detachable connections:**
  - Flange to flange connections with sealing material
  - Gate to flange connections with sealing material
  - Feed through (elastomer sealed)
  - Feed through (magnetic)

DYNAMIC

- **Non detachable connection:**
  - Feed through (bellows linear or rotary motion)

Difference static and dynamic

Static sealing configuration

Requirements:

- Leak tight
- Low out gassing
- Low permeation
- Bakeable
- Reliable
- Maybe radiation resistant

+

- Repeated reliable sealing

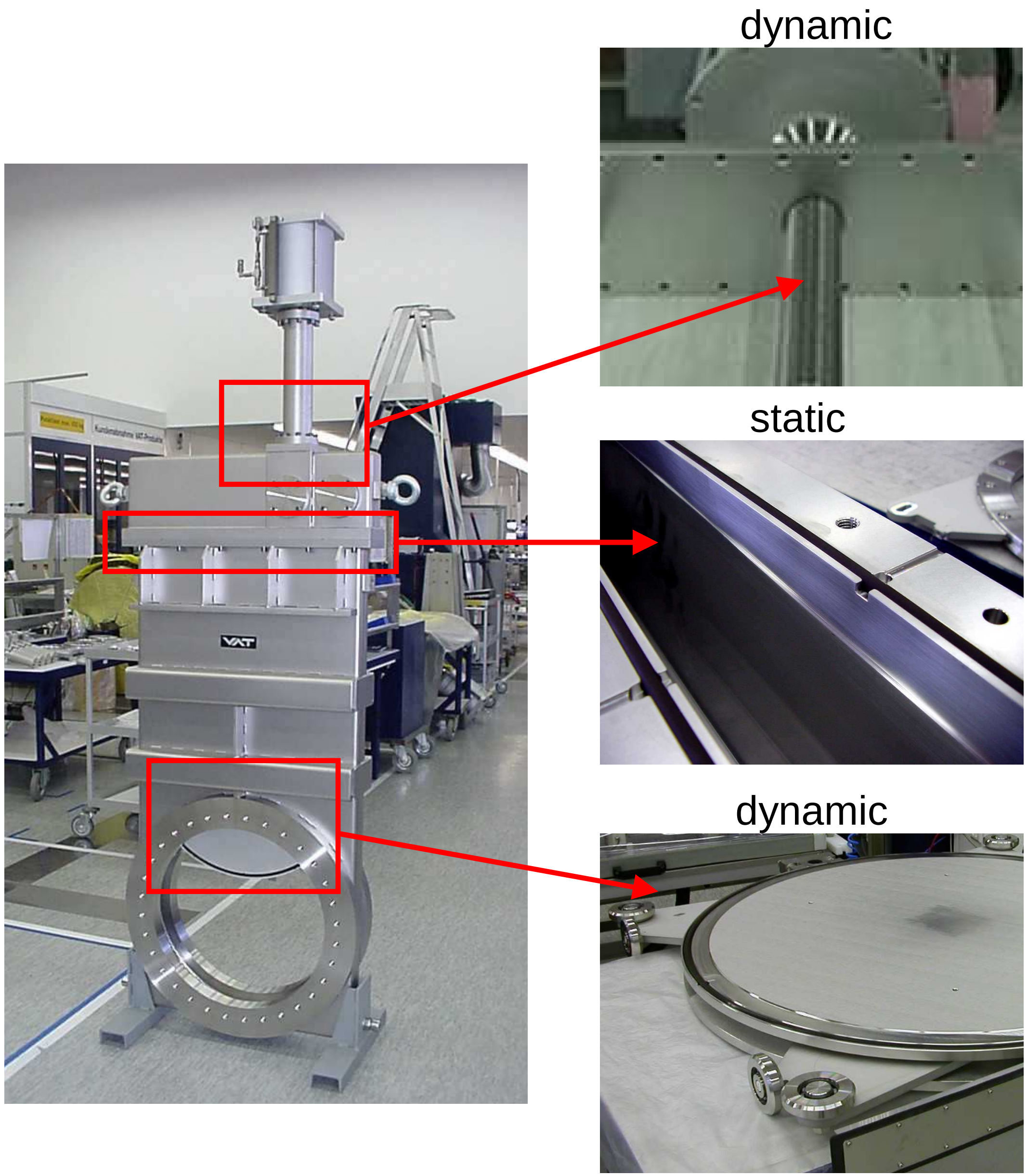
or

- Transfer of movement from atmosphere to vacuum

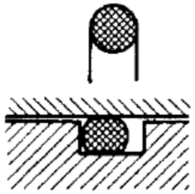
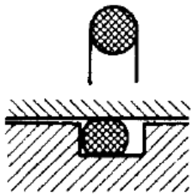
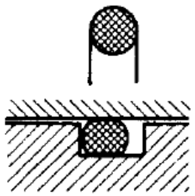
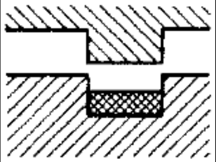
Dynamic sealing configuration

Static and dynamic sealing configuration

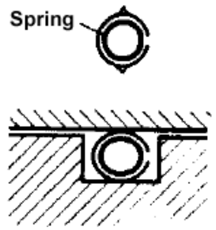
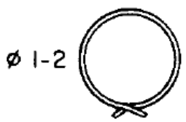
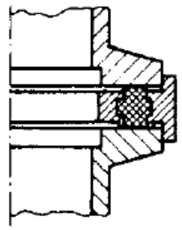
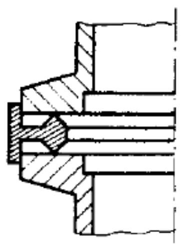
- All types of sealing configuration can be found on a valve



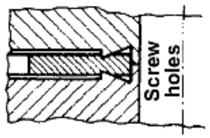
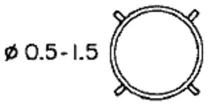
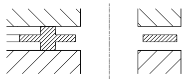
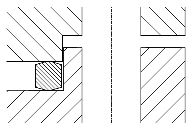
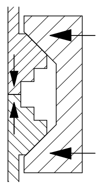
Typical detachable sealing configurations

Static sealing configurations in the Vacuum Technology			
Material	**Max. working temperature**	**Profile**	**Remarks**
Synthetic rubber NBR CR (NEOPREN)	90℃		- X- times usable - Most used seal in fine and high vacuum technology - Relative low priced - Outgassing approx. … 1×10^{-6} (strongly depending on treatment) - Use groove cut-in measure list
Fluoroelastomer FKM (VITON®)	150℃		- X- times usable - Expensive - For demanding purposes (UHV) - Outgassing approx. … 1×10^{-8} (strongly depending on treatment) - Use groove cut-in measure list
Perfluoroelastomer FFKM (KALREZ ® CHEMRAZ ®)	200 - 250℃		- X- times usable -Very expensive - Only for special purposes (UHV, chemical) - Outgassing approx. … 1×10^{-9} (strongly depending on treatment) - Use groove cut-in measure list
Polytetrafluoroethylene PTFE (TEFLON ®)	260℃		- X- times usable - chemically resistant - rarely used - Outgassing approx. … 1×10^{-8} - Needs to be “trapped”

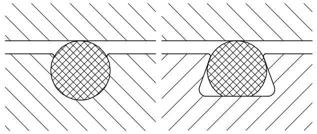
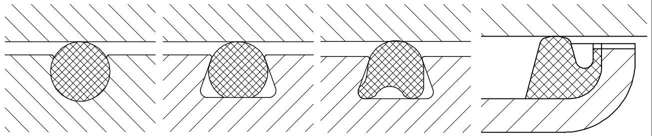
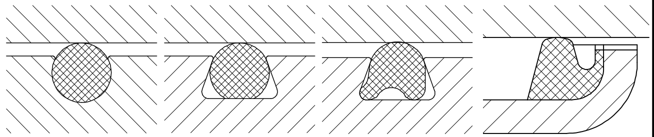
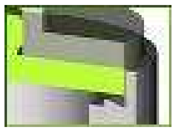
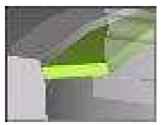
Typical detachable sealing configurations

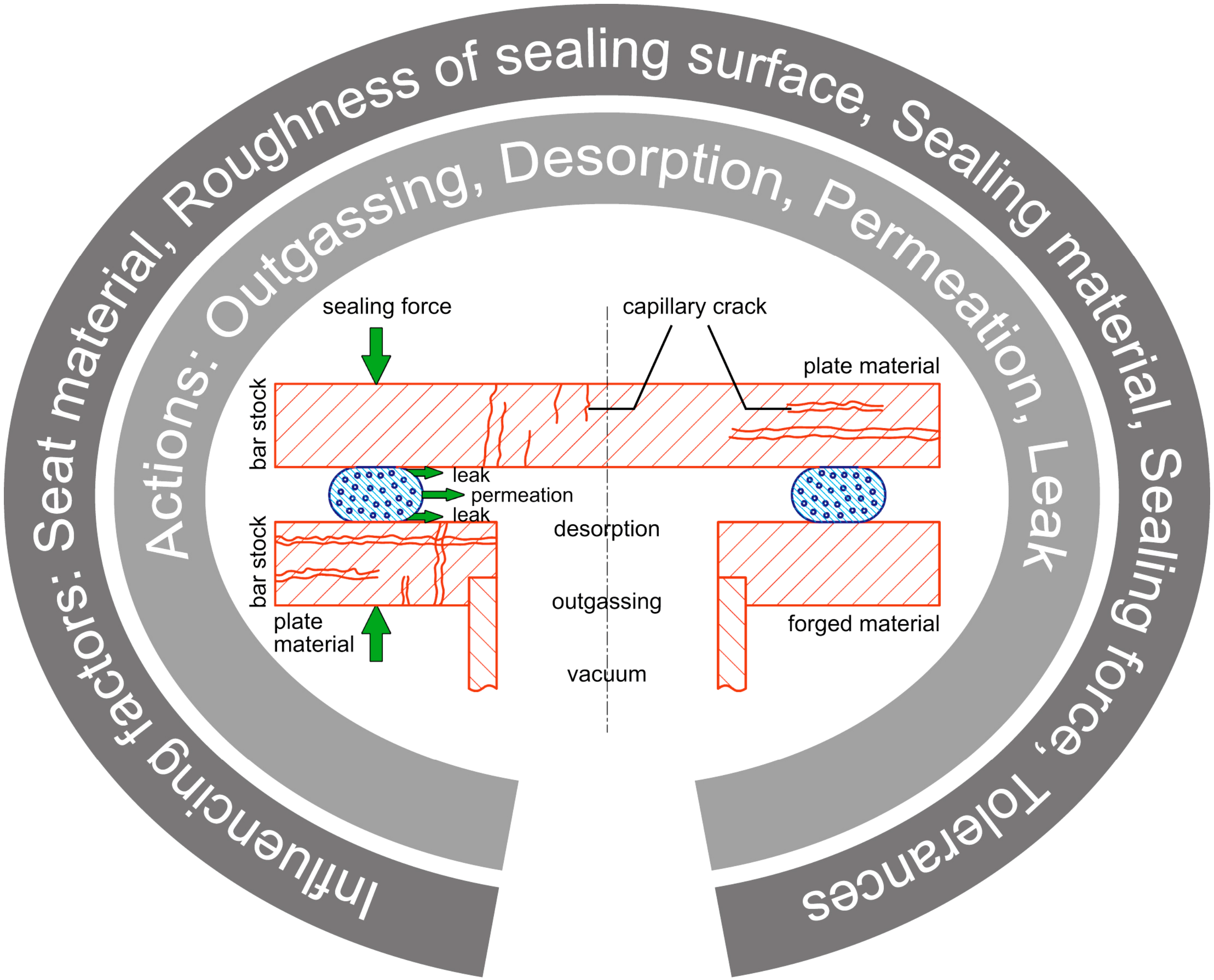
Static sealing configurations in the Vacuum Technology			
Material	**Max. working temperature**	**Profile**	**Remarks**
ALUMINIUM Covering Hélicoflex (Delta)	300℃		- One time usage - Sealing surface R_a 0,4 - Casing also in other materials - Application UHV
INDIUM (or pure tin)	100℃		- One time usage - Soft - Rarely used - Small out gassing
STAINLESS STEEL INDIUM	60℃		- Multiple usage - Suitable for small flange – system (ordinary tension rings) - Minimally out gassing
ALUMINIUM	260℃		- One time usage - Usable with stainless steal small flanges (special tension rings) - Limited UHV suitable

Typical detachable sealing configurations

Static sealing configurations in the Vacuum Technology			
Material	**Max. working temperature**	**Profile**	**Remarks**
COPPER (only usable in OFHC)	400℃		- One time usage - CF - Flange - System - Easy to assemble - Very little out gassing - Application UHV
GOLD	450℃		- Up to approx. 4 times usable (anneal each time) - Instead of CF at larger Ø - High sealing force - Corrosion resistant - Little out gassing - Application UHV
COPPER silver plated VAT VATSEAL	300℃		- One time usage - SS-flanges, flat surface N4 (Ra = 0.2µm) - Application UHV
SS – silver plated edge seal	450℃		-Multiple usage - SS-flanges, flat surface N4 (Ra = 0.2µm) - Application UHV
SS – SS RHP – Flat seal Flowmeca ™	- 100℃ + 500℃		- Multiple usage - SS weld fittings or even the tube itself, plane surface - Application UHV

Typical detachable sealing configurations

Dynamic sealing configurations in the Vacuum Technology			
Material	**Max. working temperature**	**Profile**	**Remarks**
Synthetic rubber NBR CR (NEOPREN)	90℃		For Vacuum application
Fluoroelastomer FKM (VITON®)	150℃		For High Vacuum and Ultra High Vacuum application
Perfluoroelastomer FFKM (KALREZ ®, CHEMRAZ ®)	200 - 250℃		For High Vacuum and Ultra High Vacuum application
SS – CU	450℃ with special precautions		For XUHV application
SS – SS silver plated VATRING	350℃		For XUHV application


Influencing factors: Seat material, Roughness of sealing surface, Sealing material, Sealing force, Tolerances
Actions: Outgassing, Desorption, Permeation, Leak
sealing force
capillary crack
plate material
bar stock
leak
permeation
leak
bar stock
desorption
outgassing
plate
material
forged material
vacuum

- **Outgassing / Outgassing rate**

The outgassing rate ($mbarls^{-1}$) is the sum of all gas loads caused by:

- Desorption
- Diffusion
- Permeation
- Outgassing of voids and crevices
- Disintegration of surface layers

A small outgassing rate is essential for efficient pump down and low base pressure and is achieved by:

- Use of materials with as small desorption, diffusion and permeation rates as possible
- Preventing crevices and unvented voids
- Vacuum compatible cleaning

The outgassing rate of very well degassed surfaces (baked) at room temperature:

- Stainless steel $2 \times 10^{-13}\ mbarls^{-1}cm^{-2}$
- VITON® (without permeation) $2 \times 10^{-11}\ mbarls^{-1}cm^{-2}$

Desorption, Leak (vacuum)

- **Desorption**

The desorption of physically or chemically bound gasses from the interior surfaces of a vacuum container is the last step of the processes «diffusion» and «permeation». A small desorption rate is achived by:

- Selection of material
- Surface treatment
- Cleaning
- Vacuum bake

- **Leak (vacuum)**

A leak is an opening where air or other substances are sucked into the vacuum camber. This may be a defect in the material or in the sealing surface or a not properly loaded seal.

Permeation

- Swelling decreases permeation rate
- High pressures decrease permeation rate (reduction of free volume)
- Higher temperatures increase diffusion rate and permeation rate (asymptotically)
- Larger molecules of gas lower diffusion rate

Permeation is a multi stage process. Gas adsorbed at the outer wall is dissolved in the material, diffuses through the material and desorbs from the inner wall. For stainless steel gas flows due to permeation can be neglected for temperatures used in the vacuum technology. These gas flows have however to be taken into account for elastomer and plastomer gaskets.

For VITON® the permeation rates «P» have approx. the following values after a long time at room temperature:

- He P $= 10 \times 10^{-8}$ cm^2s^{-1}
- O_2 P $= 1 \times 10^{-8}$ cm^2s^{-1}
- N_2 P $= 0.6 \times 10^{-8}$ cm^2s^{-1}

For a body with the area «A» (cm^2) and the average diffusion length «l» (cm) the gas flow «Q» due to permeation at a pressure differential «Δp» (mbar) is around:

$Q = P \times A / l \times \Delta p$ ($mbarls^{-1}$)

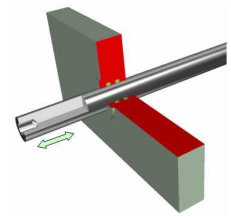
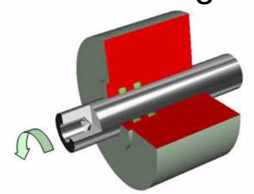
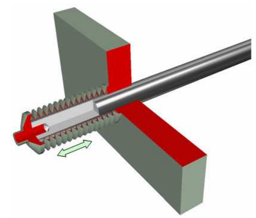
For air at atmospheric pressure the partial pressures «p» of the relevant gas are

- He P $= 5.0 \times 10^{-3}$ mbar
- O_2 P $= 2.1 \times 10^{2}$ mbar
- N_2 P $= 7.8 \times 10^{2}$ mbar

For well degassed O-rings the permeation of nitrogen and oxygen of the air through the VITON® is the major contributor to outgassing.

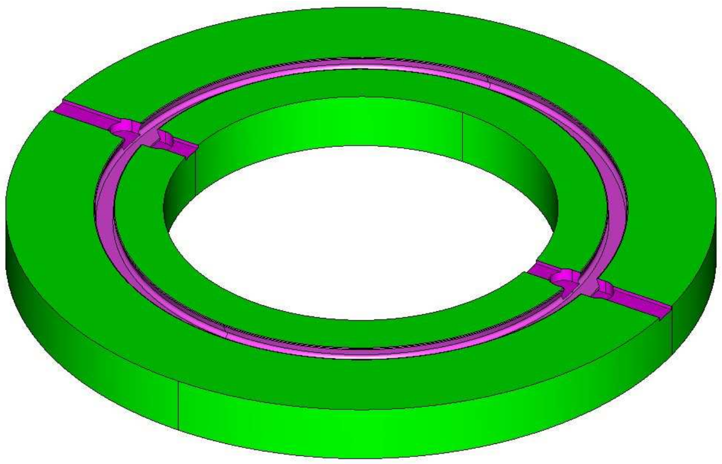
The helium gas flow due to permeation can simulate large leaks during leak testing after a test time depending on the gasket.

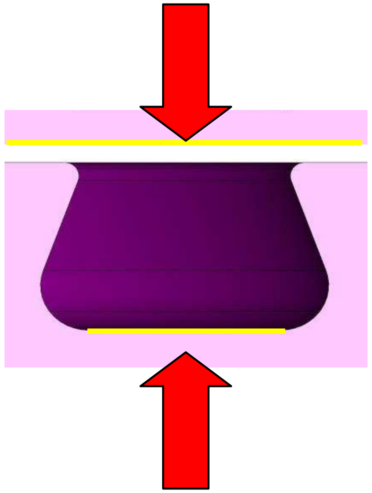
Vacuum levels

Vacuum level	Pressure range (mbar)	Maximum Temperature (℃)	Seals		
			Inside vacuum	To the outside	Feedthrough
Vacuum	to $1 * 10^{-7}$	150	NBR / VITON®	NBR / VITON®	O-ring shaft seal 
HV (high vacuum)	to $1 * 10^{-8}$	150	VITON®	VITON®	Rotary feedthrough 
UHV (ultra high vacuum)	to $1 * 10^{-10}$	200/250	VITON® / Kalrez® vulcanized preferred	Metal	Bellows / magnetic feedthrough 
XHV (extreme UHV)	better than 10^{-10}	300/450	Metal	Metal	

Sealing surface

- Not all surfaces of an O-Ring groove are sealing surfaces.
- Ideally they are in the load pass of the sealing force!

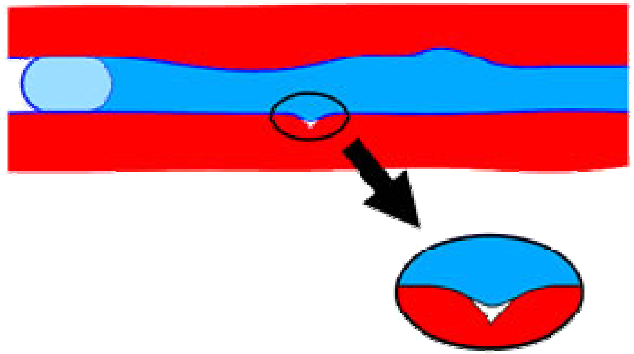




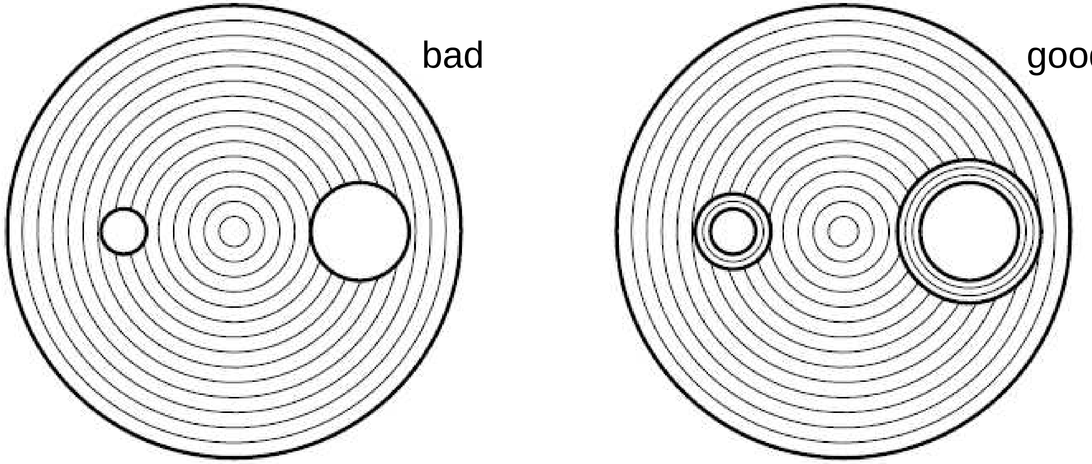
Yellow marked surface = sealing surface

Sealing surface

- Sealing surfaces require special roughness, flatness and surface finish
- To a certain degree (depending on the sealing material) it is possible to compensate unevenness
- It’s not possible to seal sharp grooves
- Make sure that machining grooves are in line with the sealing line and not crossing them



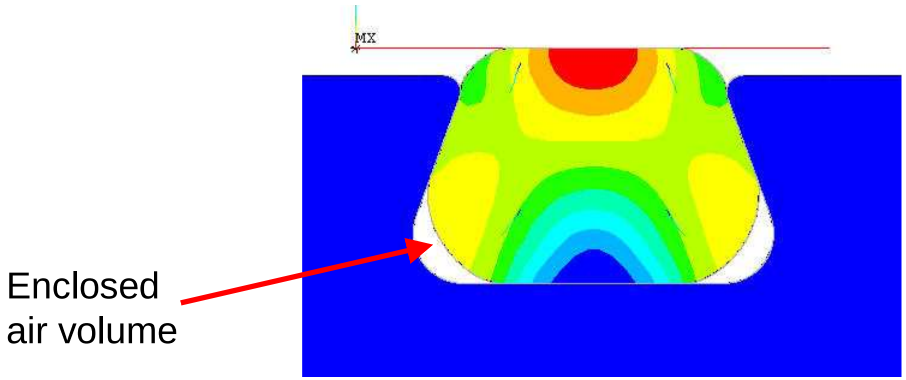
Impossible to seal

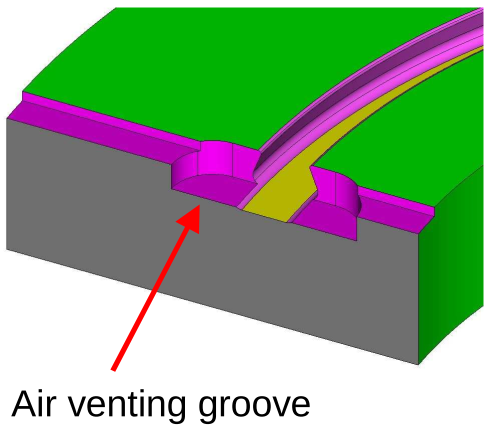


Concentric machining grooves

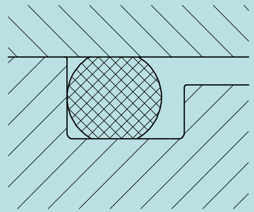
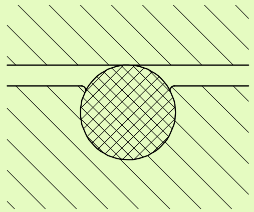
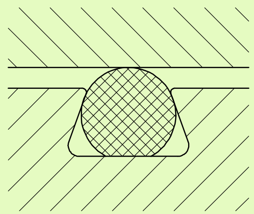
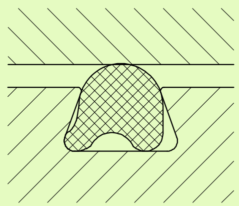
Venting of O-ring grooves

- To get a low pressure in the vacuum system venting of O-Ring grooves is a must!
- Make sure that the depth of the venting groove is just above sealing ground level

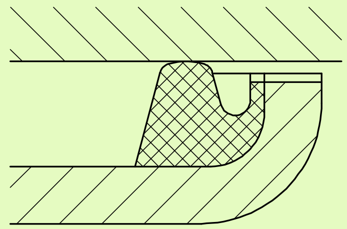




O-ring groove shape

Static seal Holding of O-ring in place Definition of O-ring compression		**U shaped**
Dynamic seal Holding of O-ring in place Definition of sealing force No metal contact (flange/gate) Prevent a sticking O-ring from being released from the O-ring groove.		**Ball shaped**
		**dovetail shaped**
		**dovetail shaped** **with TriLobe™ Seal**

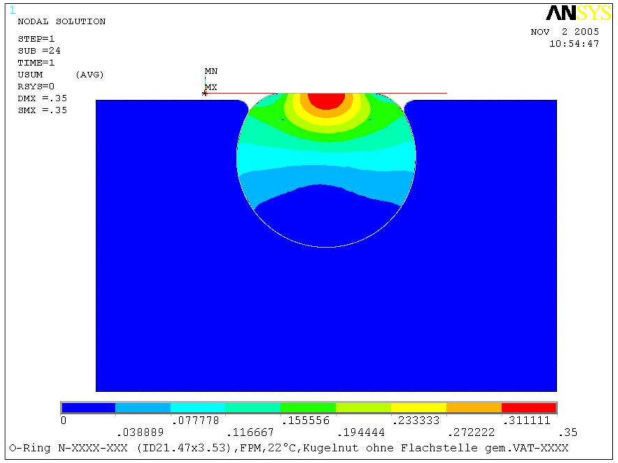
Vulcanized seals

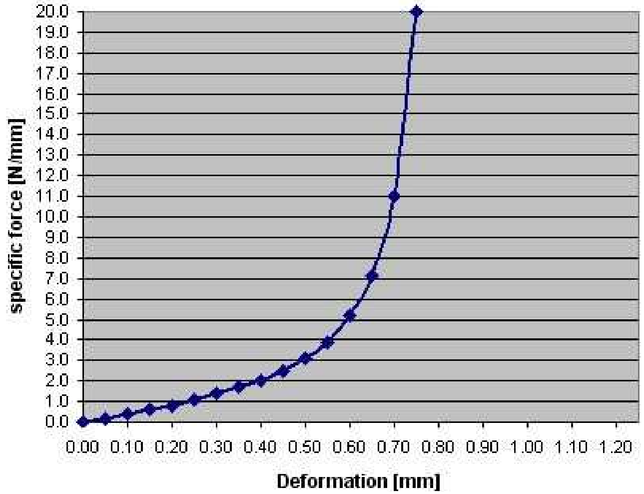
dynamic seal Definition of sealing force No trapped volume No metal contact (flange/gate) No lost gasket when sticking Optimum sealing performance for UHV	

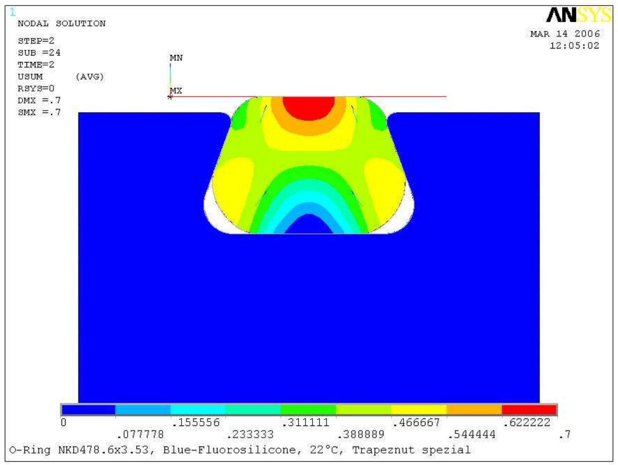
Stiffness impact of the groove shape

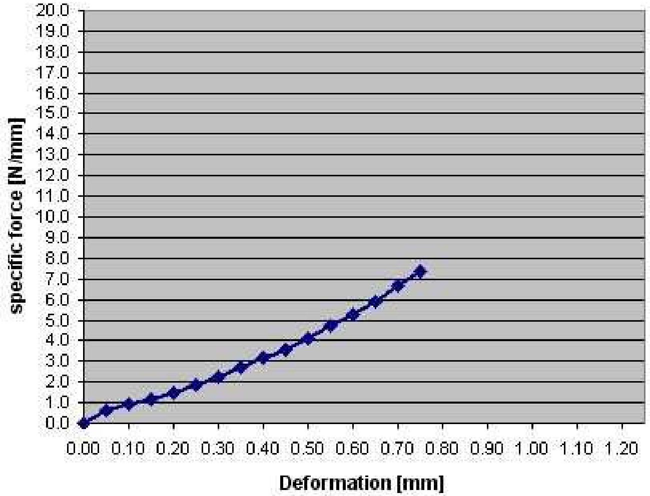
- Ball shaped
  - High stiffness
  - Small deformation capabilities
  - Avoid metal to metal contact (Particle generation)
  - Big influence of geometric tolerances

- Dovetail shaped
  - Low stiffness
  - Large deformation capabilities
  - Metal to metal contact possible (design measures)





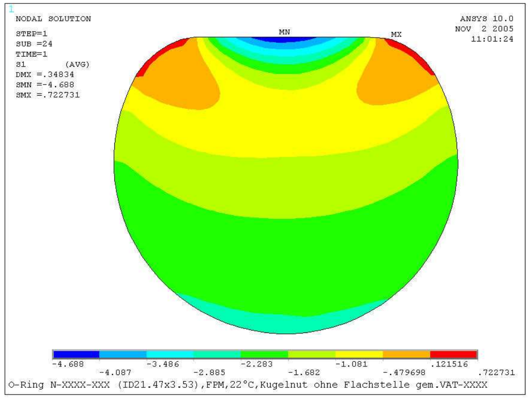




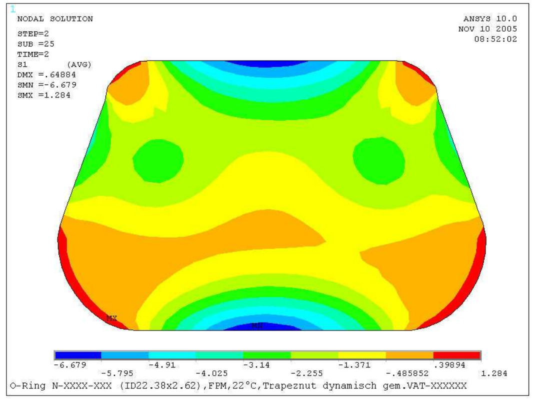
Stress plots of O-ring / Vulcaniced seal configuration

- Important for lifetime capabilities of the rubber (particles etc.)
- aggressive process gases will destroy the rubber especially at areas with high stresses
- Sticking on sealing surface can extract the O-ring out of the groove (advantage of vulcanized sealing)

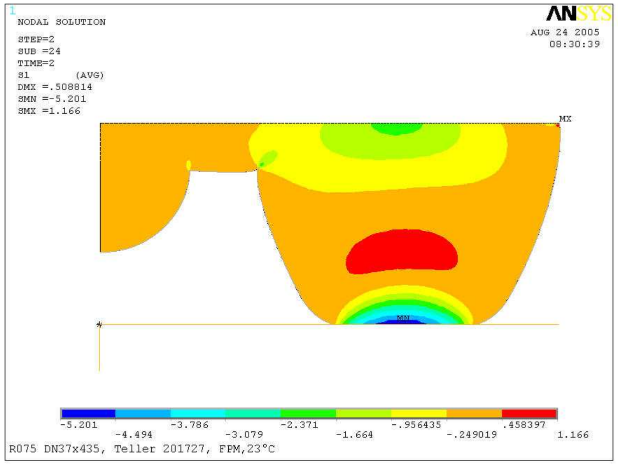
Ball shaped



Dovetail shaped

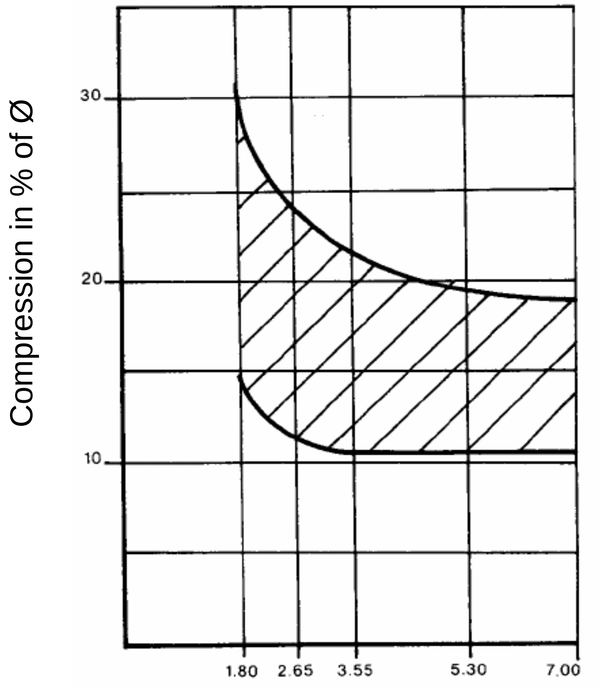


Vulcanized



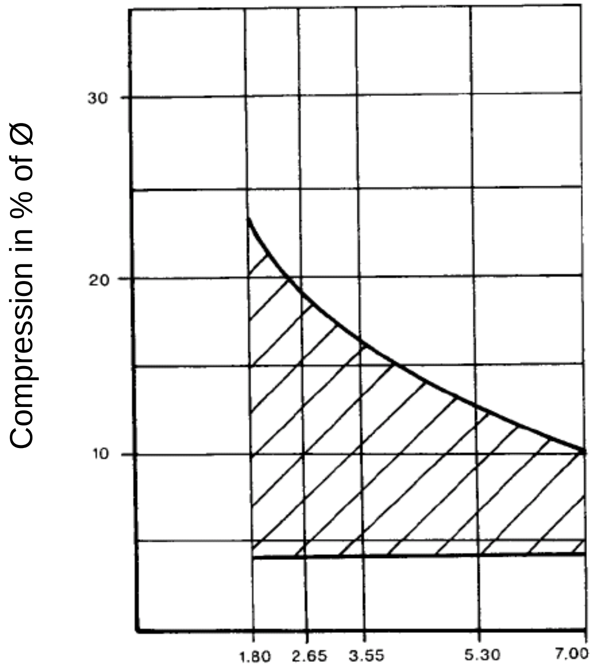
Compression of O-rings

Static seal	Dynamic seal



O-ring diameter [mm]

Allowable deformation plotted against O-ring cross section – static seal in rectangular groove



O-ring diameter [mm]

Allowable deformation plotted against O-ring cross section – dynamic seal in rectangular groove

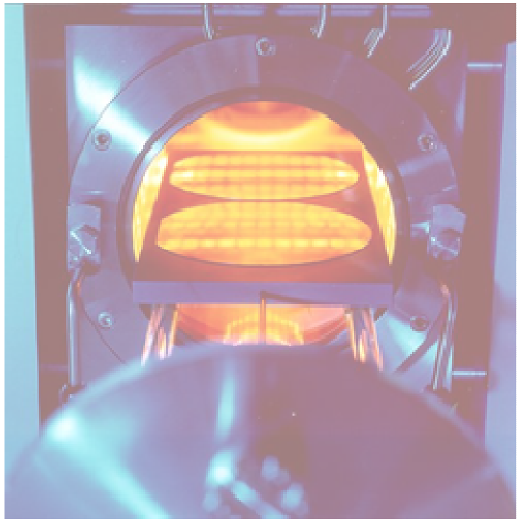
source: Parker Hanninfin GmbH, Prädifa – Packing Division Europe

Compression of O-rings

- Recommendation from the elastomer suppliers, usage from 25℃ to 200℃
- Reduce the initial values by around 2 % with applications over 200℃ in the static case

O-ring diameter	static	dynamic
1.78 mm	18 %	12 %
2,62 mm	17,5 %	11,5 %
3,53 mm	17 %	11 %
5,33 mm	16,5 %	10,5 %
6,99 mm	16 %	10 %

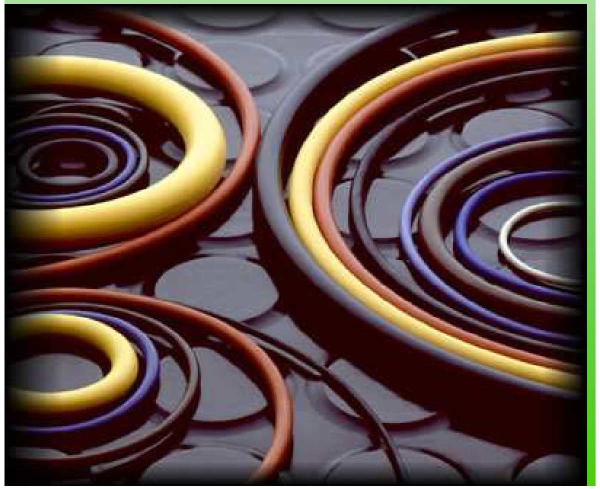
For U-shaped groove, dimensions acc. supplier recommendation



O-ring tolerances

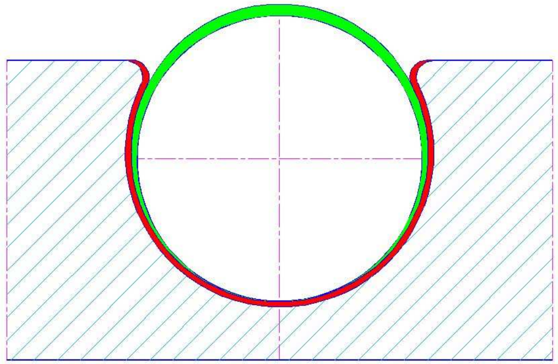
O-ring diameter	I.D.	Ø tolerance (mm)
1.78 mm	small ± 9 % large ± 0.75 %	± 0.08
2.62 mm	small ± 10 % large ± 0.6 %	± 0.08
3.53 mm	small ± 1.7 % large ± 0.47 %	± 0.1
5.33 mm	small ± 1.24 % large ± 0.46 %	± 0.13
6.99 mm	small ± 0.74 % large ± 0.46 %	± 0.15

permitted tolerances up to 7mm are defined in DIN 3771 and ISO3601/I



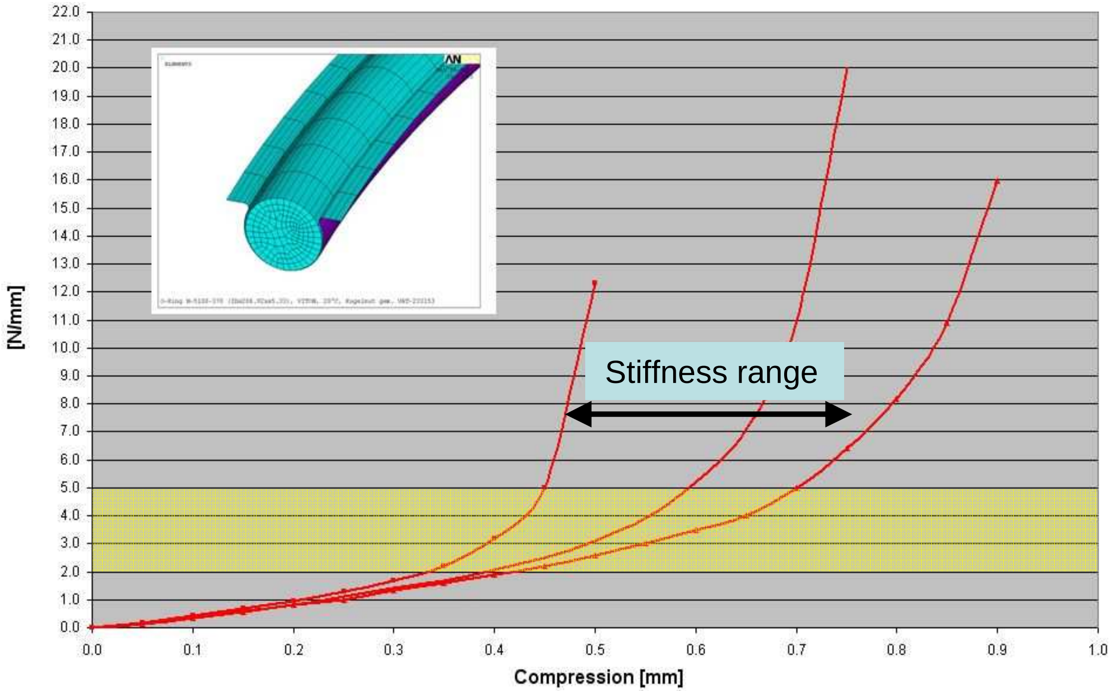
Effect of tolerances

- Dramatic effect on Force / compression ratio of the seal!
- With 2 N/mm the compression is between 0.33 and 0.42 mm
- With 5 N/mm the compression is between 0.45 and 0.7 mm



Machining tolerance of groove (ball shape) -> red

Manufacturing tolerance of O-ring -> green



Stretching and compressing of O-rings

Many time the O-ring ID doesn’t fit exactly the O-ring groove. This is design driven.

Maybe there is no other space available or it is a wanted design feature. For example it is possible to hold the O-ring easily in place if we have a little tension on the ID of the O-ring in a rectangular groove. However there are limits.

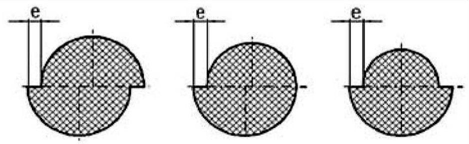
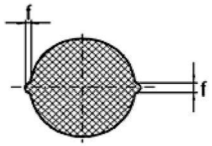
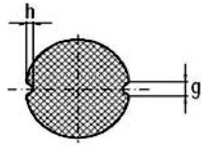
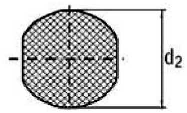
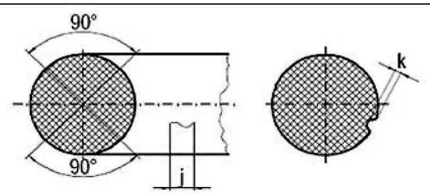
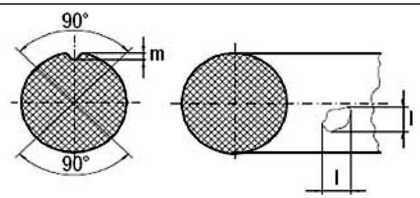
- Maximum stretching at assembly = 25 to 30% (FKM)
- Maximum stretching after installation = 6% (FKM)

- Maximum stretching at assembly = 20 to 25% (FFKM)
- Maximum stretching after installation = 3 to 5% (FFKM)

- Maximum compressing after installation = 3% (FKM)
- Maximum compressing after installation = 3% (FFKM)

O-ring quality

VAT - limits of acceptable shape and surface deviation

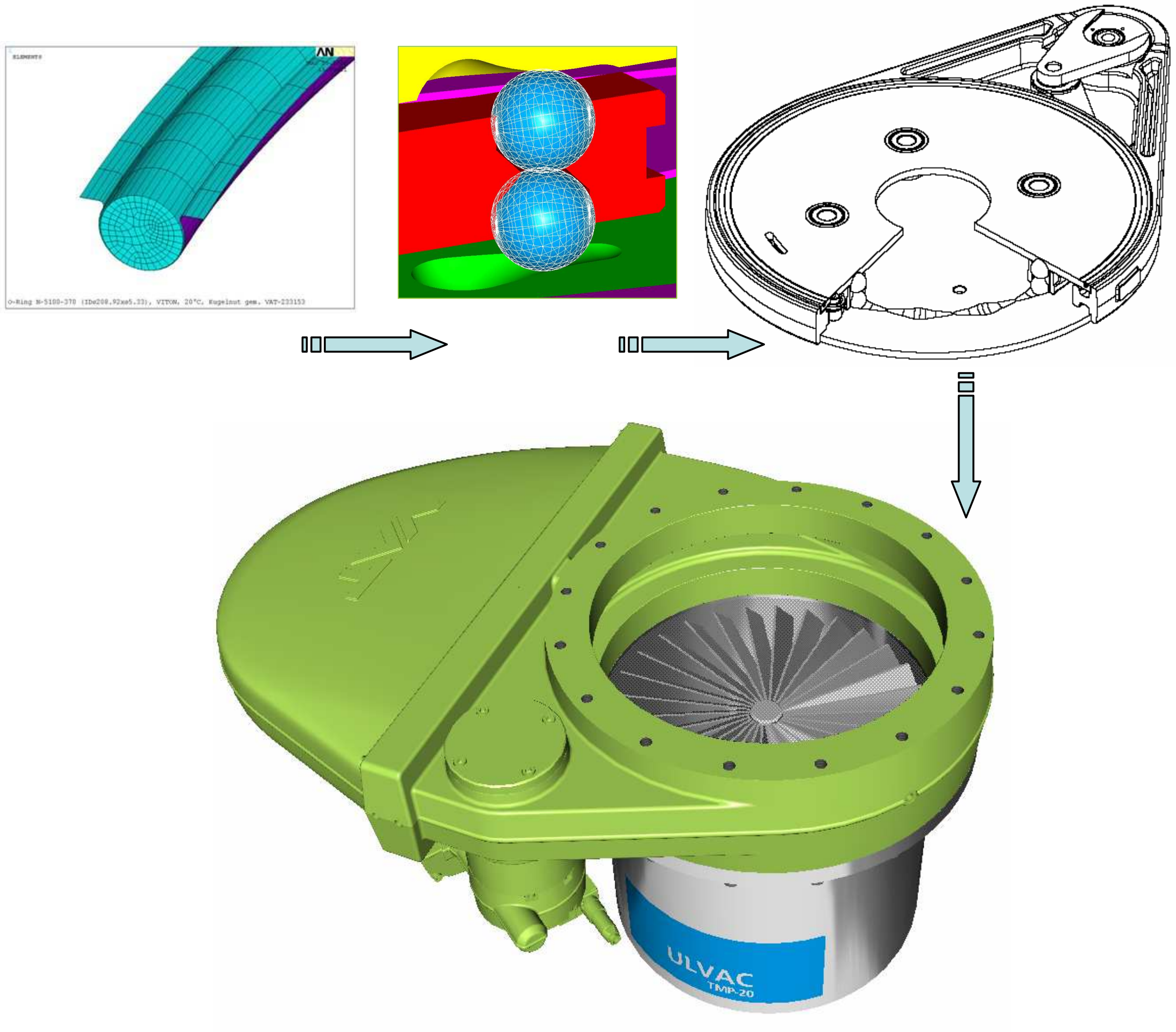
Kind of deviation	Schematic illustration	Dim.	Dimension at d_2 =					
			1.78	2.62	3.53	5.33	6.99	
Displacement and shape deviation		e	0.08	0.10	0.13	0.15	0.15	
Bulb/shoulder/ displacement combined		f	0.05	0.06	0.07	0.08	0.10	
Indentation		g	0.18	0.27	0.36	0.53	0.70	
		h	0.08	0.08	0.10	0.10	0.13	
Area of deburring		-	Deviations from the circular cross section are allowed when the flattening seamlessly merges with the circle and the tolerance d_2 is met.					
Flow lines (radial extension is prohibited)		j	1.00	1.00	1.00	2.00	3.00	
		k	0.05					
Indentations, recesses		m	0.05	0.05	0.10	0.10	0.10	
		l	0.15	0.25	0.30	0.50	1.00	
Foreign substance		-	not allowed					

Origin: VAT standard N-2046

Stiffness of the overall system

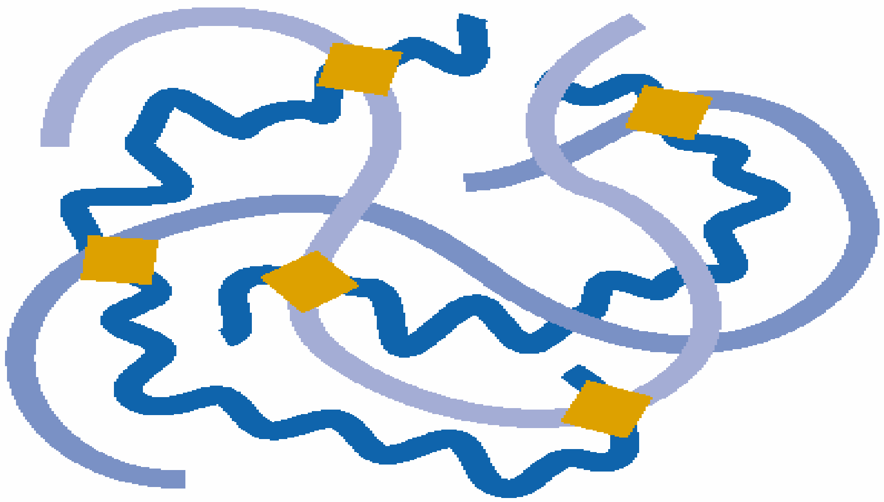
- Reliable function of the hole valve and system depends on several points:
  - Sealing stiffness
  - Gate and counterplate stiffness
  - Body stiffness
  - Actuator

→ Force flow!

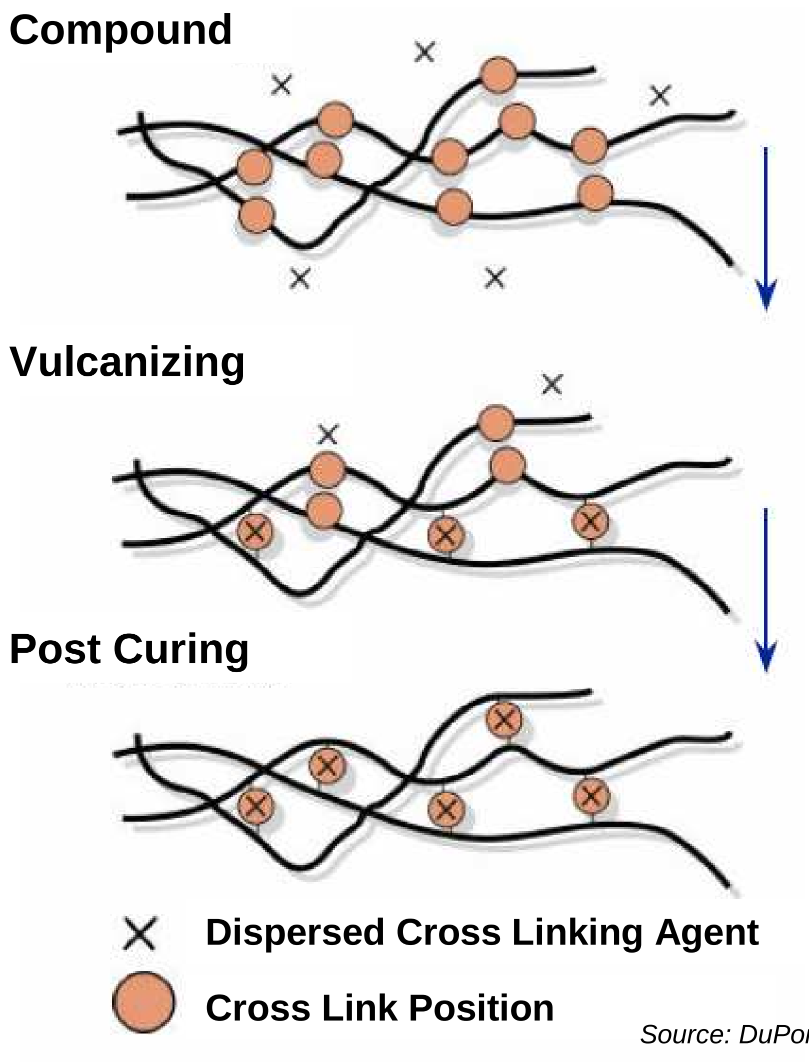


Elastomer Basics

- Elastomers are flexible long-chain polymers which are capable of cross-linking.
- The cross-link is the key to the elastic properties of these materials. The elasticity provides resiliency in sealing applications.



Elastomer Basics



Source: DuPont Performance Elastomers

Relaxation / Temperature

- Stress relaxation show the reduction of stress in a component (elastomer seal), when the deformation of a component is constant.
- The deformed component shows the irreversible flow of the elastomer.
- The rate of stress relaxation is being impact by the stress and very strong by temperature.
- Arrhenius can be used as a easy rule of thumb. The reaction rate is increased by factor 2 when the temperature is increased by 10 ℃. The analysis of the measured ch arts shows a reaction rate of 2.5 – 4.

Relaxation / Temperature

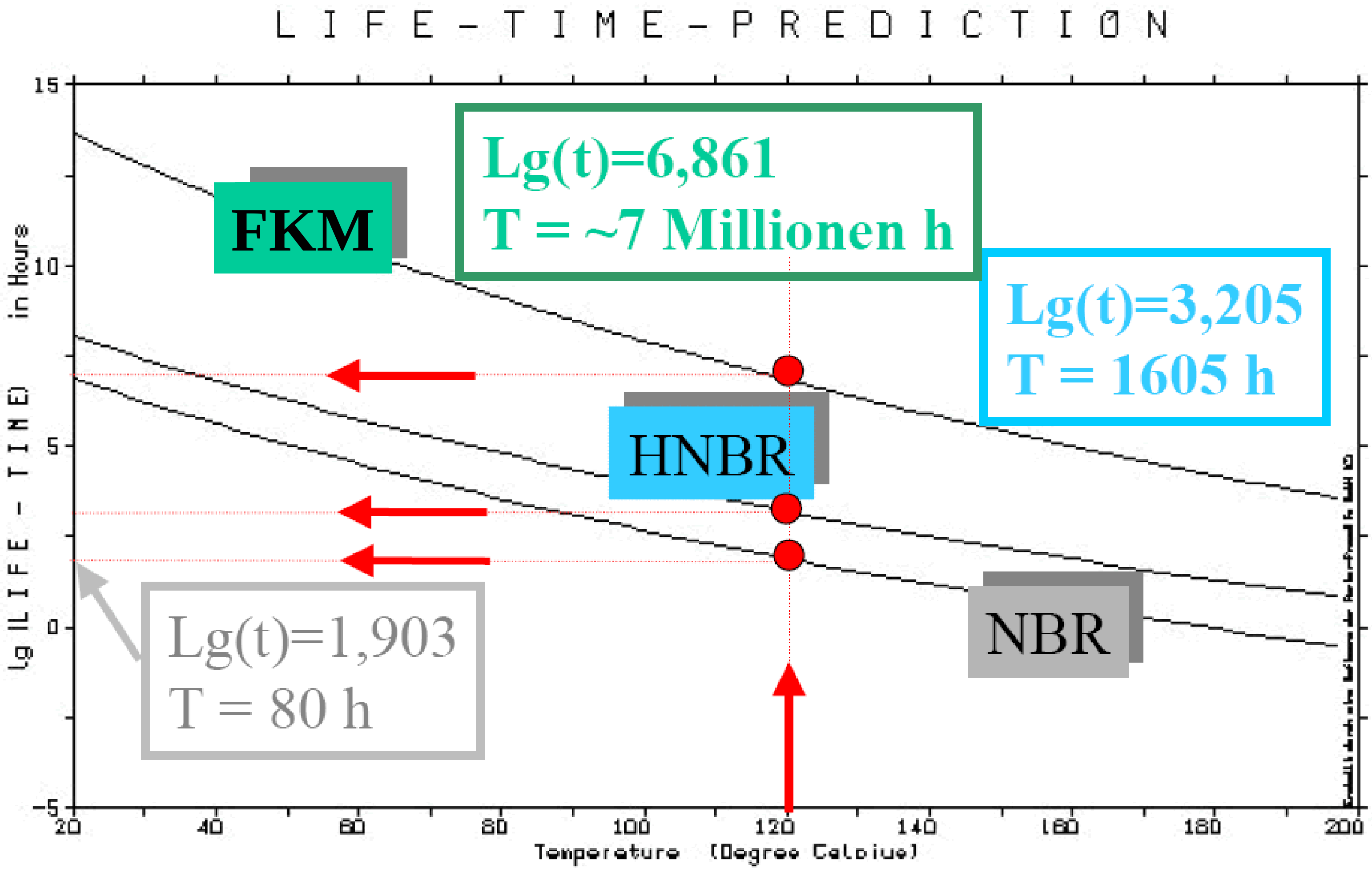
Test setting:

- The sample was extended by 20 % in a hot cabinet.
- Analyzed was the time, when the residual stress was 40 % of initial stress.
- To guarantee the function of the seal a residual stress of 40 % was defined.
- Post cure reactions of the elastomer at higher temperatures are not considered.
- The impact of seal design to the life time is not considered.

Test result:

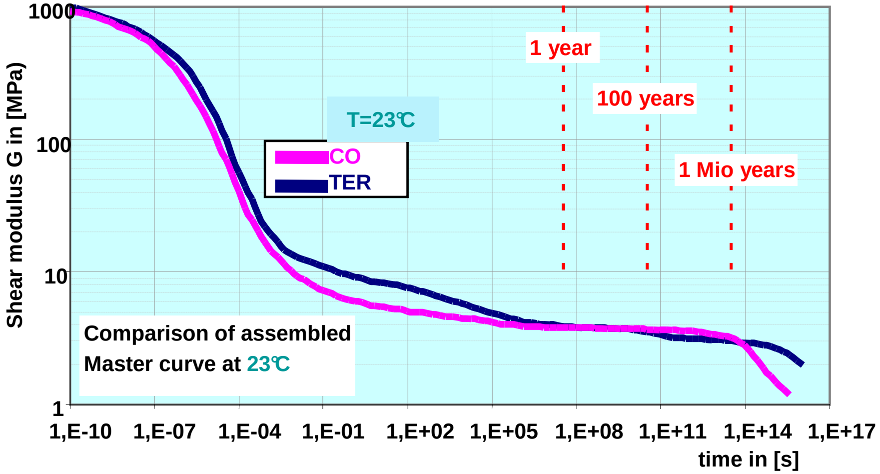
- The graph shows the life time as function of temperature

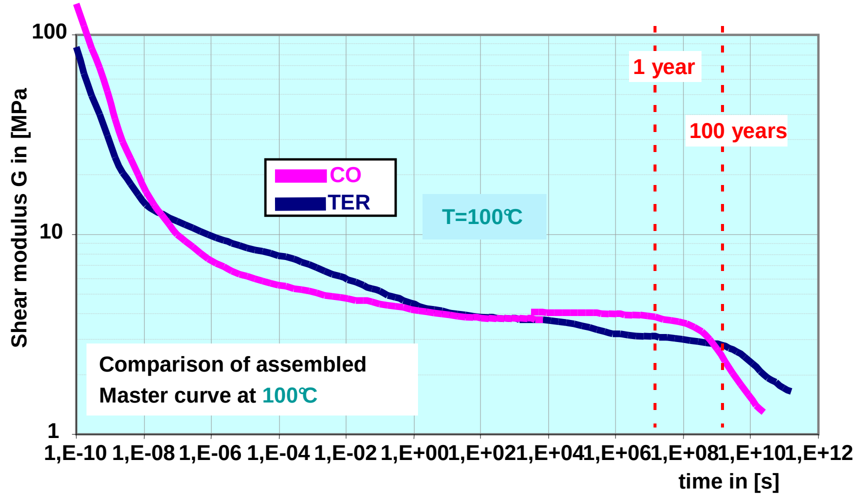
Relaxation / Temperature

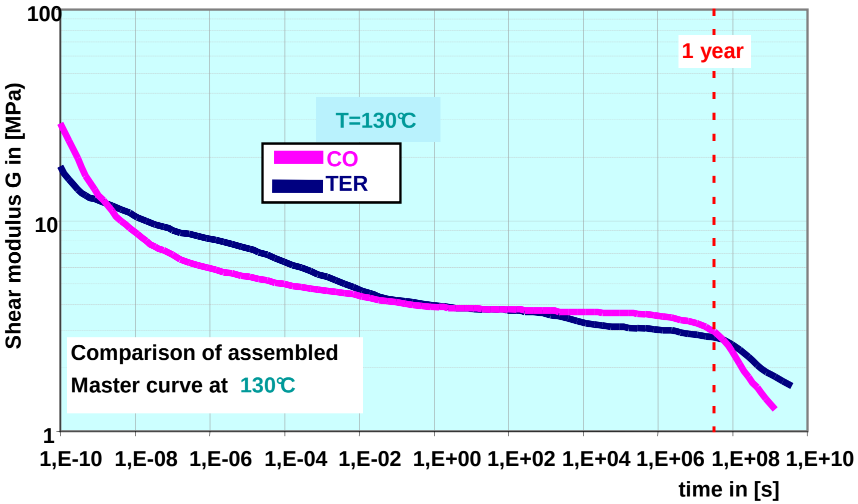


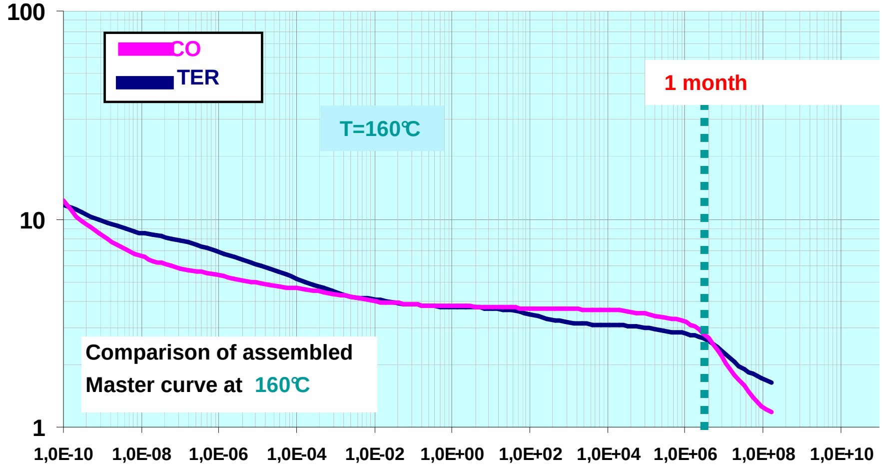
- CO - Cofluoropolymermaterial
- TER - Terfluoropolymermaterial

Relaxation / Temperature FKM





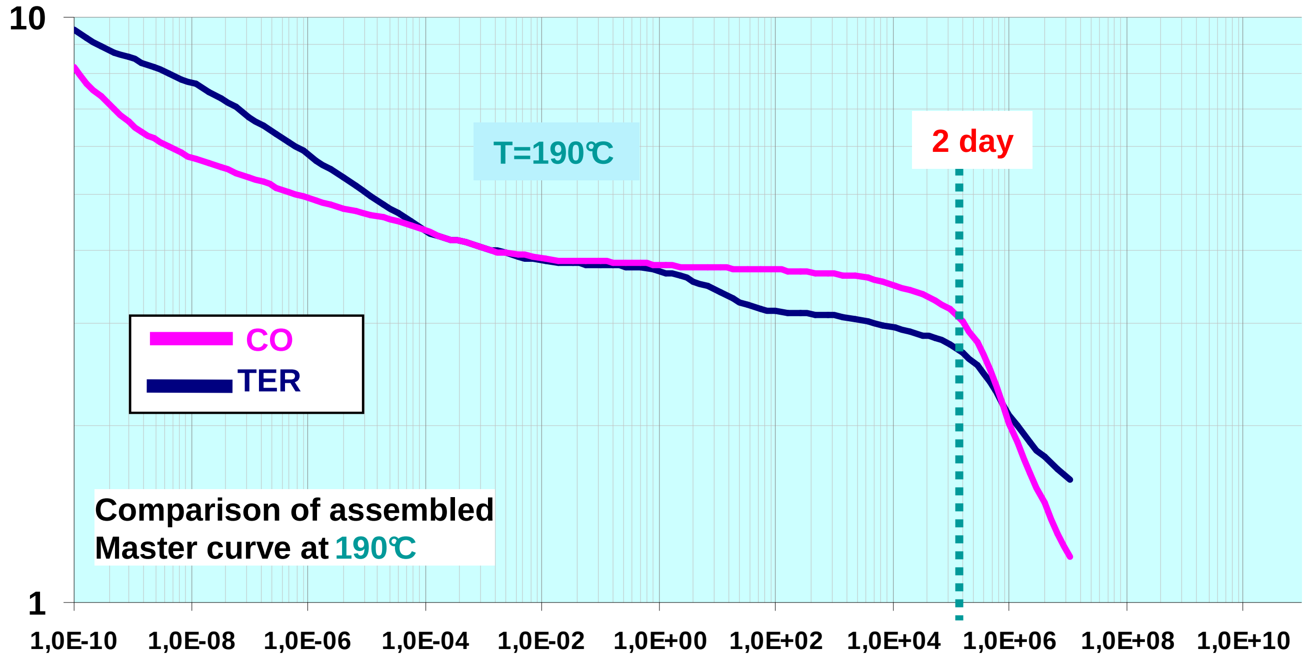




Source: Parker Hanninfin GmbH, Prädifa – Packing Division Europe

Relaxation / Temperature FKM

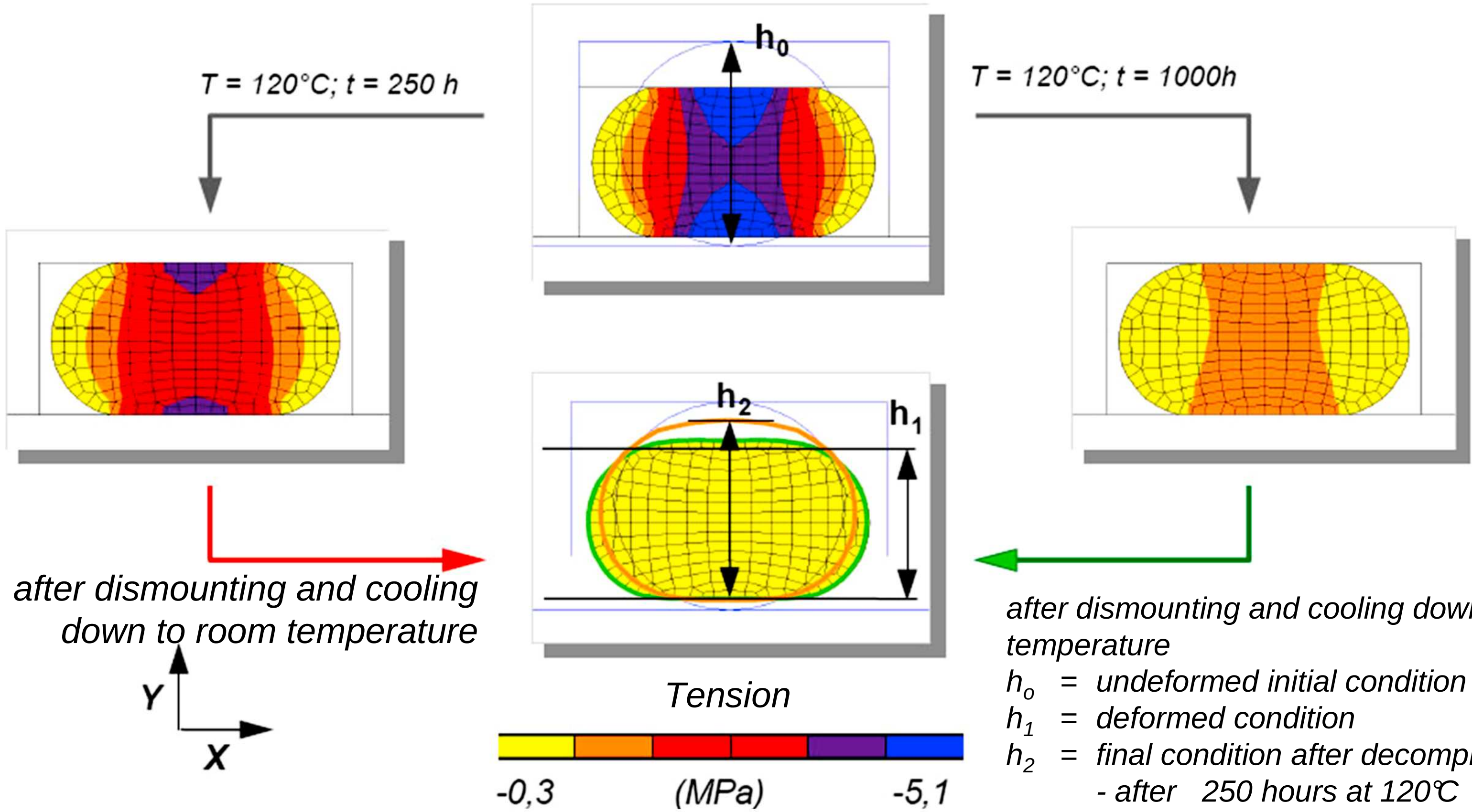
- CO - Cofluoropolymermaterial
- TER - Terfluoropolymermaterial



Source: Parker Hanninfin GmbH, Prädifa – Packing Division Europe

Compression Set

Initial condition: T = 120°C; t ~ 0



after dismounting and cooling down to room temperature

h_o = undeformed initial condition

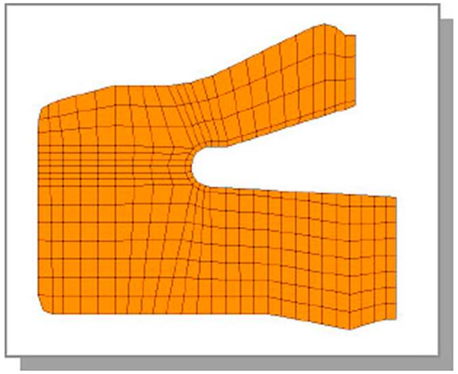
h_1 = deformed condition

h_2 = final condition after decompression
- after 250 hours at 120°C
- after 1000 hours at 120°C

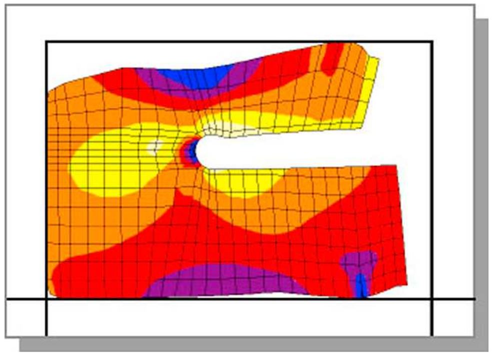
Due to the relaxation in the elastomer the compressive stress in the sealing element diminishes and the residual sealing force decreases. Simultaneously, crosslinking in the elastomer continues and the seal adopts the shape of the groove. After cooling down, the seal maintains its shape. This settling behavior is called COMPRESSION SET.

Compression Set

Example of a piston seal

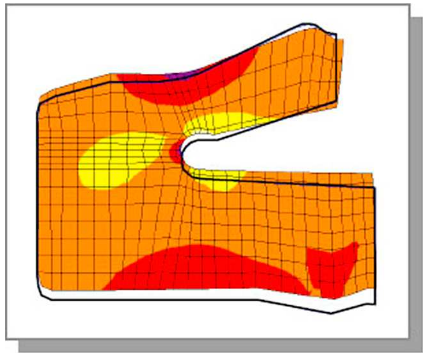


Piston seal for the pneumatic actuator



Deformation of the installed and compressed seal at 120℃

Comparison of the geometries after 1500 hours at 120℃ after cooling down to room temperature and dismounting



Seal Failures – vacuum seals

COMPRESSION SET

Description: The seal exhibits a flat-sided cross-section, the flat sides corresponding to the mating seal surfaces .

Contributing Factors: Excessive compression. Excessive temperature. Incompletely cured elastomer. Elastomer with high compression set .

Suggested Solutions: Proper gland design for the specific elastomer. Confirm material compatibility .

ABRASION

Description: The seal or parts of the seal exhibit a flat surface parallel to the direction of motion. Loose particles and scrapes may be found on the seal surface.

Contributing Factors: Rough sealing surfaces. Excessive temperature. Process environment containing abrasive particles. Dynamic motion. Poor elastomer surface finish.

Suggested Solutions: Use recommended gland surface finishes. Consider internally lubed elastomers. Eliminate abrasive components.

Seal Failures – vacuum seals

CONTAMINATION

Description: The seal exhibits foreign material on the surface within the cross section.

Contributing Factors: Process environment deposition.

Suggested Solutions: Specify contamination level including manufacturing and packaging of the seals.

INSTALLATION DAMAGE

Description: The seal or parts of the seal may exhibit small cuts, nicks or gashes.

Contributing Factors: Sharp edges on glands or components. Improper sizing of elastomer. Low-modulus/hardness elastomer. Elastomer surface contamination.

Suggested Solutions: Remove all sharp edges. Proper gland design.

Seal Failures – vacuum seals

OVERCOMPRESSION

Description: The seal exhibits parallel flat surfaces (corresponding to the contact areas) and may develop circumferential splits within the flattened surfaces.

Contributing Factors: Improper design—failure to account for thermal or chemical volume changes, or excessive compression.

Suggested Solutions: Gland design should take into account material responses to chemical and thermal environments.

SPIRAL FAILURE

Description: The seal exhibits cuts or marks which spiral around its circumference.

Contributing Factors: Difficult or tight installation (static). Slow reciprocating speed. Low-modulus/hardness elastomer. Irregular O-ring surface finish (including excessive parting line). Excessive gland width. Irregular or rough gland surface finish. Inadequate lubrication.

Suggested Solutions: Correct installation procedures. Higher-modulus elastomer. Internally-lubed elastomers. Proper gland design. Optimise gland surface finish.

Seal Failures – vacuum seals

THERMAL DEGRADATION

Description: The seal may exhibit radial cracks located on the highest temperature surfaces. In addition, certain elastomers may exhibit signs of softening—a shiny surface as a result of excessive temperatures.

Contributing Factors: Elastomer thermal properties. Excessive temperature excursions or cycling.

Suggested Solutions: Selection of an elastomer with improved thermal stability. Evaluation of the possibility of cooling sealing surfaces.

Radiation resistance

With the radiation resistance of an elastomer it is similar to a cup. The cup has a specific capacity, you can fill it with a small water jet or with a heavy water jet as soon as it is full, it is full. Only the time is the question.

An elastomer is able to take a certain amount of radiation, it will degrade until the point where it is no more able to fulfill the requirements we have to the elastomer seal. Therefore the time is given by the radiation level which is seen by the elastomer seal. The radiation levels are given in Gy.

- As a rough guide line we are able to use sealing materials to the following radiation levels
  - Viton® E5 Gy
  - BunaN E6 Gy
  - EPDM E6 Gy

Attention: Degradations due to temperature, aging etc. will additionally reduce the seal life time!

Why all metal seals?

Everywhere where I have to have the following it's recommended to use metal seals:

- Low desorption
- Nearly no permeation of light gases
- Lowest outgassing
- High temperatures
- Long term radioactive resistance

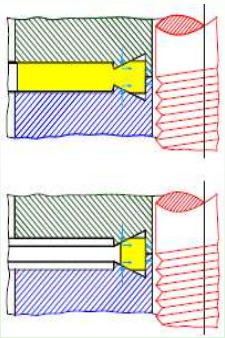
What type of seals?

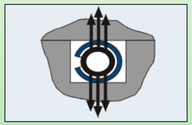
On the beginning when all metal sealing technology was "born" no standard was available. Every institue started to develop it's own seal ("flange war" of the 60's and 70's). Therefore we find even today many different kind of metal sealing concepts all around the world. Most of them are no more used for new vacuum systems.

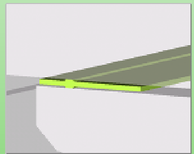
There are still new developments for metal seals, driven by e.g. cryogenic technology (flange materials) or metal seals which should be able to replace O-ring seals by keeping everything around the seal as it is with an O-ring.

Many time these sealings have a certain field where they are able to work fine. Mostly they are not the solution if they have to cover the wide range of requirements for an all metal seal.

Is there any standard?







I would say there is, at least for a wide range of UHV and XUHV application.

For static seals we have one main standard it's the Conflat Flange system which has proven to be a very reliable sealing method up to DN 250.
Side developments found solutions which are able to seal a CF connection with damaged knife edge.

Partly, where chain clamps are used (radiation environment) we are able to find the Helicoflex seal as a static seal.

In synchrotrons we see more and more the VATSEAL for specific RF apertures.

For dynamic seals we find the combination of copper pad and knife edge ("soft on hard") or the VATRING system ("hard on hard") in the field.

Sealing Details / Metal seals

”Soft on hard“ sealing

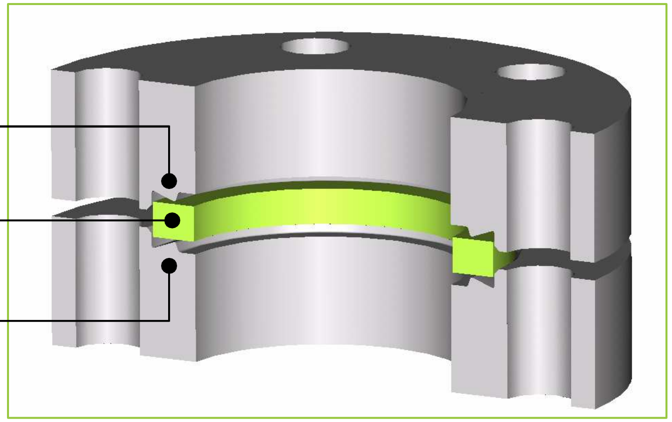
At least one sealing partner is plastically deformed to a considerable degree

Soft copper seal and knife edge

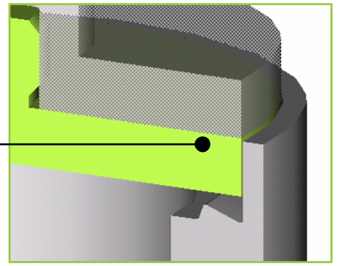
KNIFE EDGE

COPPER PAD

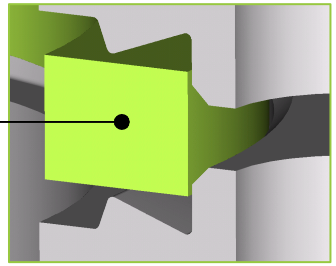
KNIFE EDGE



DETAIL OF DYNAMIC SEAL



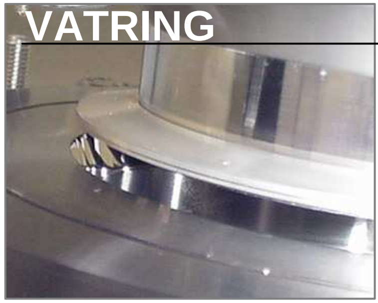
DETAIL OF STATIC SEAL



Sealing Details / Metal seals

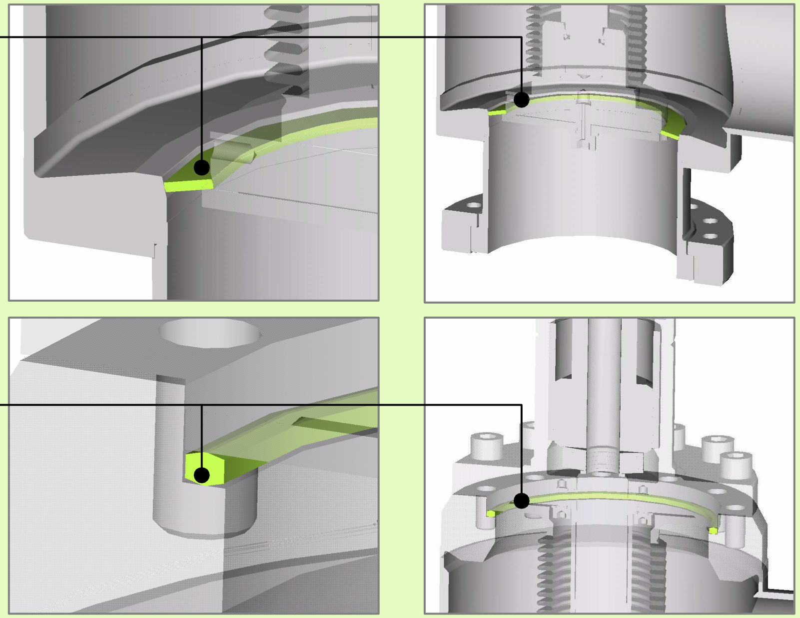
”Hard on hard“ sealing

All sealing partners are mainly deformed in the elastic area



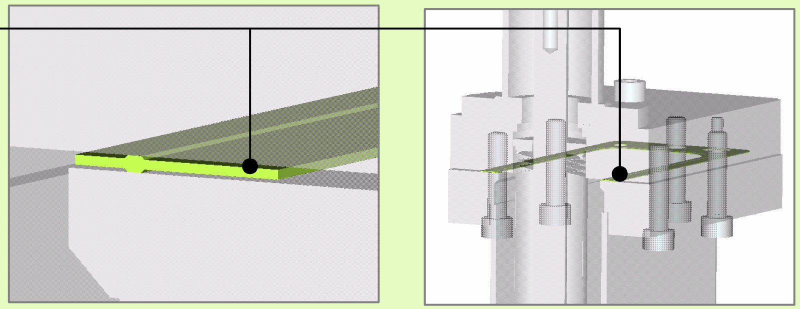
EDGE SEALING

Seat and seal SS



VATSEAL

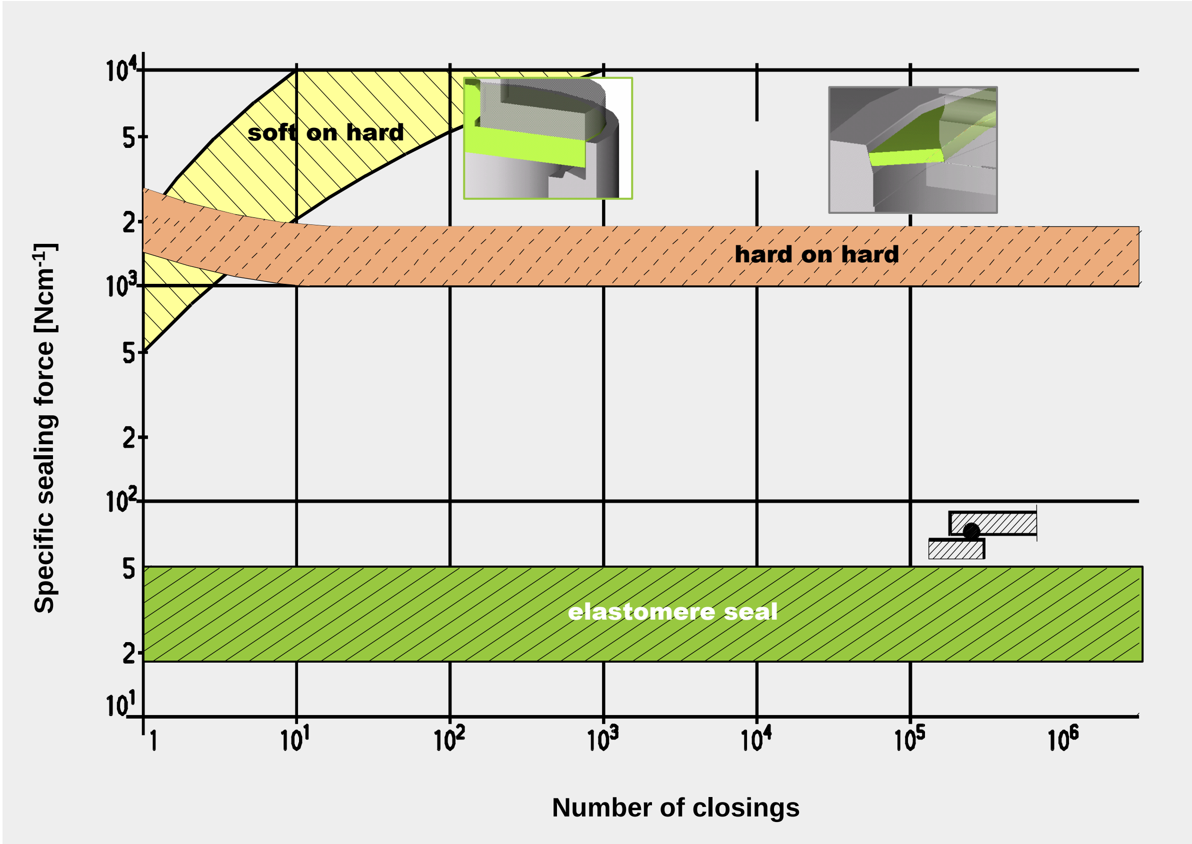
Seat SS
Seal SS or OFHC



Sealing Details / Elastomer seals

Advantages of ”hard on hard“ sealing against ”soft on hard“ sealing

Diagram showing sealing force requirements



At least for dynamic vacuum seals VAT uses the “hard-on-hard“ sealing method because of numerous advantages against the “soft-on-hard“ sealing method.

Key for a reliable metal seal

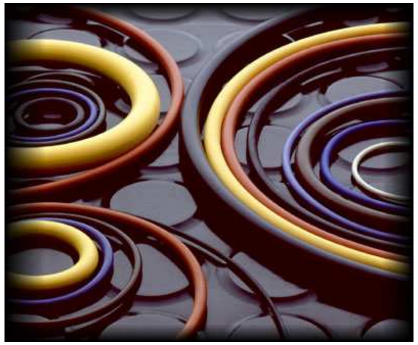
The key is very simple

Make your sealing joint leak tight and then never ever change anything.

To do this is not so easy, because we will have to handle

- forces from the system
- thermal movements
- different thermal expansions
- settings of metal seals (soft seals)

For dynamic seals we additionally have to be able to get repeatable stable conditions (on every closure) otherwise we will not reliable seal.



Try always to use the correct sealing for your application

- You will not get lucky when you use an elastomer seal where you would better have used a metal seal!
- On the other hand it doesn’t make sense to use metal seals where elatomer seals would be sufficient!

O-rings are much easier in handling then metal seals

- Not so demanding in respect of sealing surface quality
- Can’t easily get scratched
- Demand much lower sealing force
- Are less expensive

O-rings are mostly the largest gas source in a sealed vacuum system

Don’t rely to much on property values you get for elastomers, the vacuum performance differs strongly from supplier to supplier but also from batch to batch.

Never forget, elastomer seals are a kind of rubber and they are really rubbery!

Thank you for your attention!