COG

C. OTTO GEHRCKENS

SEAL TECHNOLOGY

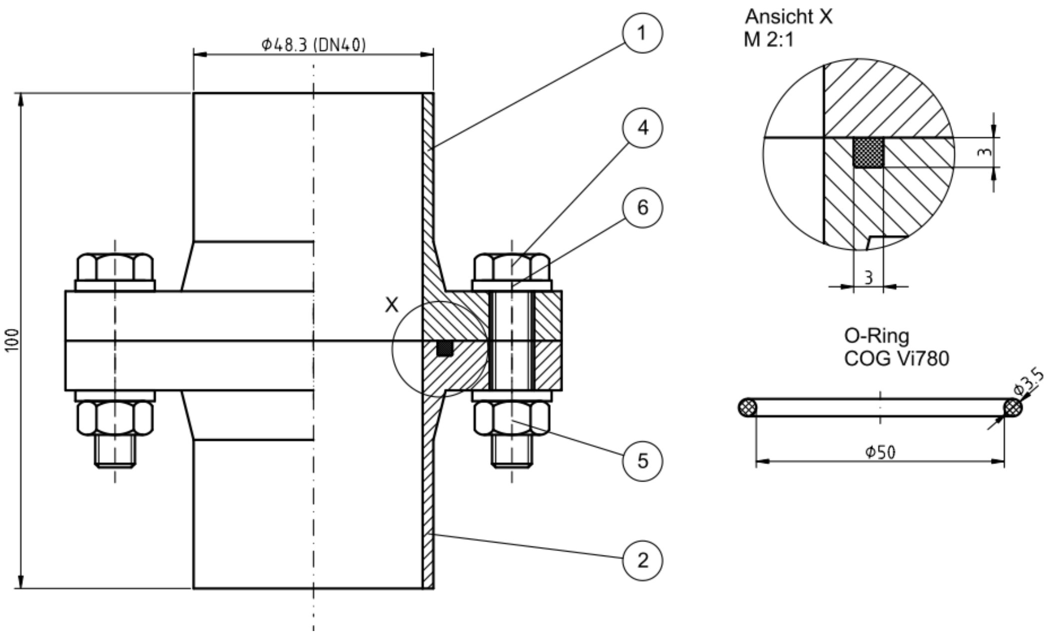
A major challenge:
Designing and sealing with O-rings

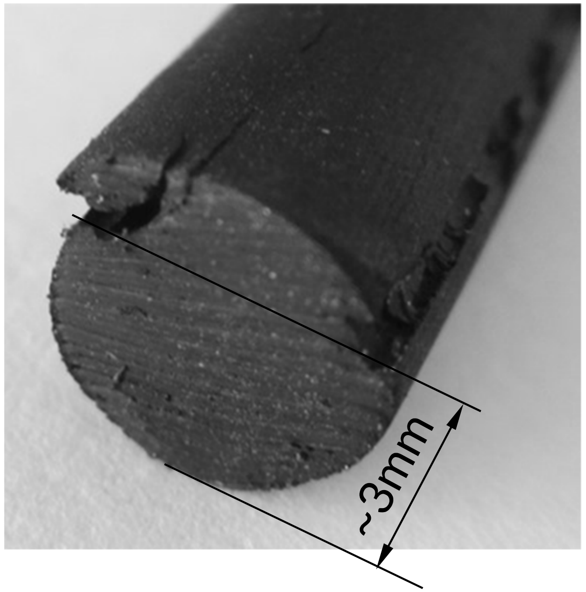
Using the example of a piston seal

O-ring damage

WE'RE NOW BUYING HIGH-QUALITY
FKM/FPM O-RINGS FROM YOU, AND OUR
EQUIPMENT STILL LEAKS!
WHY IS THIS, MR. LUCHT?

O-ring damage





O-ring damage due to incorrectly designed O-ring groove

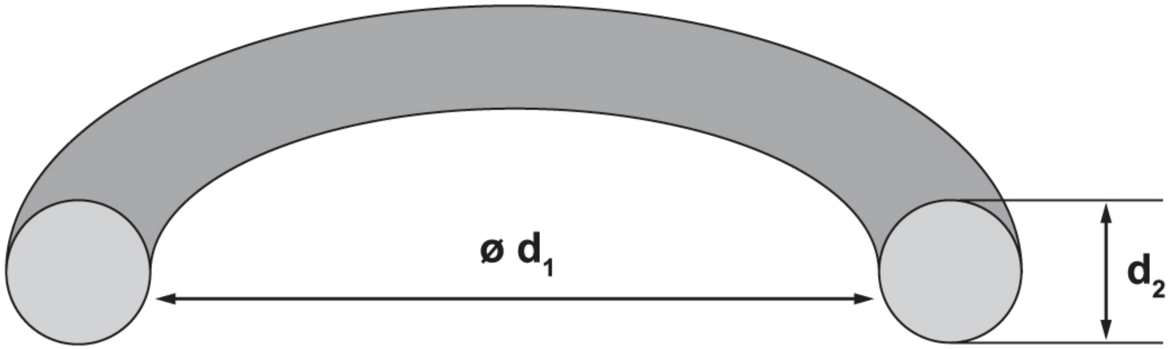
Question 1

Have you ever had failures due to a wrongly designed O-ring groove?

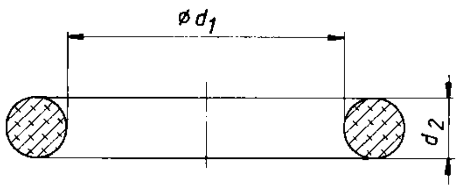
- *Yes*
- *No*

Contents

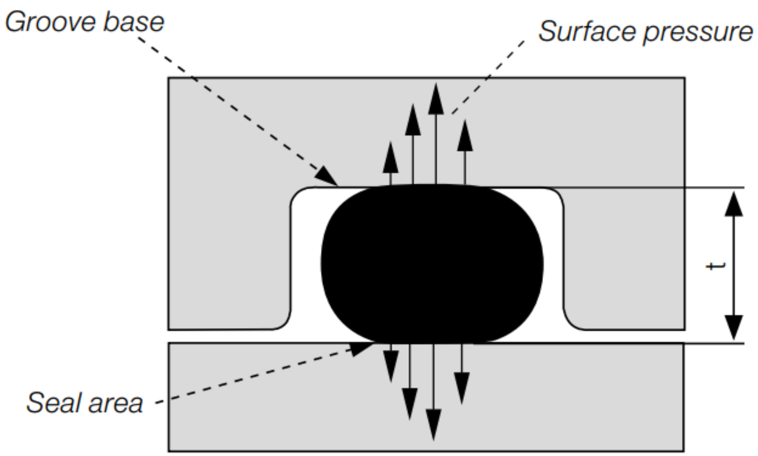
O-ring description



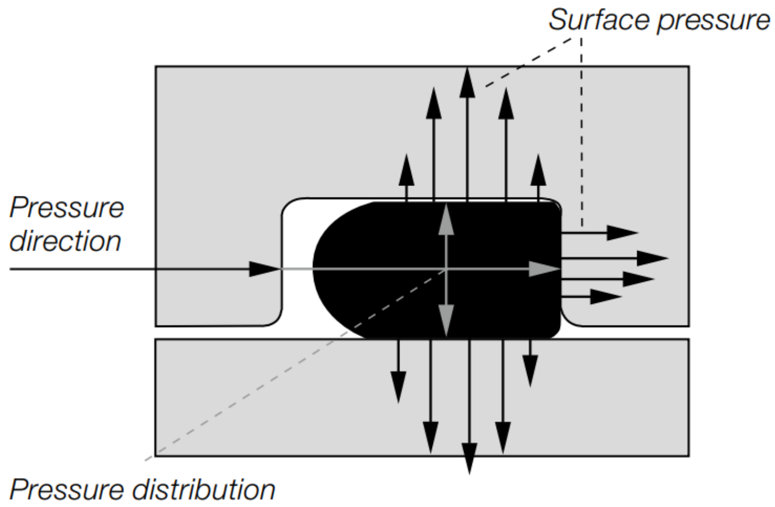
or pictured here:



O-ring seal function



Compressed O-Ring in installation space without pressure



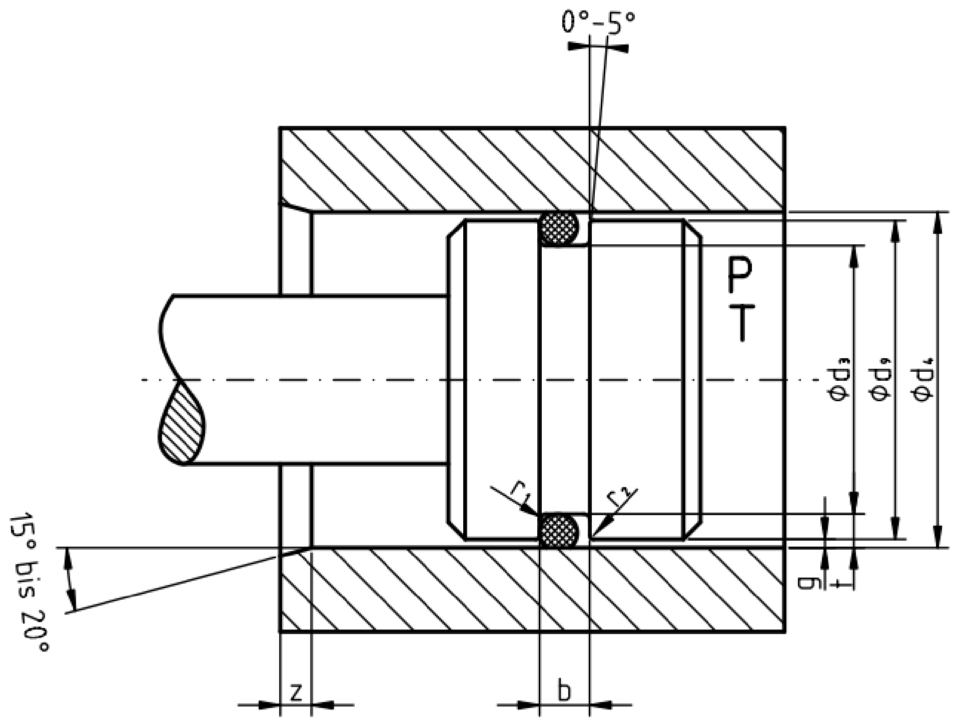
Compressed O-Ring in installation space under pressure

Benefits of an O-ring seal

- Low space requirement
- Simple seal design
- Easy fitting
- Wide operating temperature range, from approx. -100 °C to +325 °C
- Full pressure range from high vacuum to approx. 3000 bar
- Excellent (worldwide) availability
- Relatively low-cost

Design of installation spaces

Piston seal

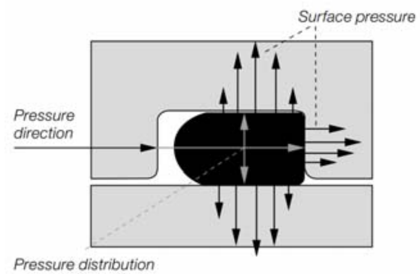


D3	groove base diameter
d4	drill hole diameter
d9	shaft diameter
b	groove width
t	groove depth
g	sealing gap
z	lead-in chamfer
r1	radius in groove base
r2	radius on upper edge of groove
P	Pressure
T	Temperature

Design of installation spaces

$$Compression = \frac{cross\ section - groove\ depth}{cross\ section} \cdot 100\ \%$$

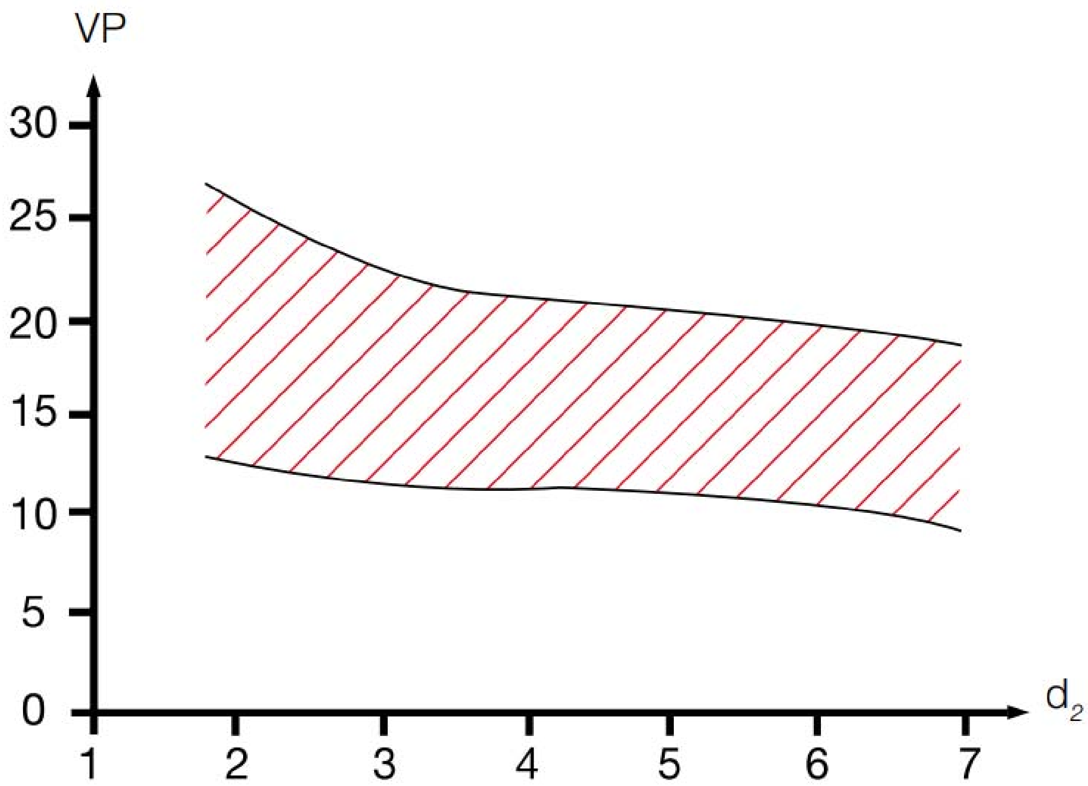
$$QV\ [\%] = \frac{d_2 - t}{d_2} \cdot 100\%$$



Compressed O-Ring in installation space under pressure

Warning! The real cross section must be used here, i. e. the cross-sectional alteration after expansion and the thermal expansion of the ring must be considered, cf. ISO 3601-2. All tolerances must also be factored in.

Design of installation spaces



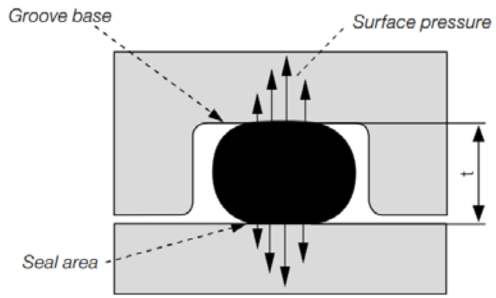
Compression diagram for a hydraulic dynamic application.

Design of installation spaces

$$Groove\ fill = \frac{O - ring\ surface}{groove\ cross\ section} \cdot 100\ \%$$

$$F = \frac{d^2 \cdot \pi}{4 \cdot b \cdot t} \cdot 100\ \%$$

$$F \leq 85\ \%$$



Compressed O-Ring in installation space without pressure

Warning! The real cross section must be used here, i. e. the cross-sectional alteration after expansion and the thermal expansion of the ring must be considered, cf. ISO 3601-2. All tolerances must also be factored in.

Design of installation spaces

Piston seal

Input values						
	Nominal dimension	Fit	Upper tolerance	Lower tolerance	Maximum dimension	Minimum dimension
Shaft diameter d9 [mm] =	50	h8	0,000	-0,039	50,000	49,961
Drill hole diameter d4 [mm] =	50	H8	0,039	0,000	50,039	50,000
Groove base diameter d3 [mm] =	44,4	h8	0,000	-0,039	44,400	44,361
Groove width b [mm] =	4,5	Suggested	0,250	0,000	4,750	4,500
Radius in groove base r1 [mm] =	0,3	Suggested	0,100	-0,100	0,400	0,200
O-ring inside diameter d1 [mm] =	43	ISO 3601	0,431	-0,431	43,431	42,569
O-ring cross section diameter d2 [mm] =	3,53	ISO 3601	0,100	-0,100	3,630	3,430
Material:	NBR					
Pressure P [bar] =	5					
Temperature T [°C] =	20	OK				
Expansion coefficient a [10^-6/K] =	175					
Hardness [Shore A] =	70					
O-ring inside diameter [mm] at 20 °C =	43,00					
O-ring cross section diameter [mm] at 20 °C =	3,53					
Results						
	nominal	max	min	test		
Compression including cross section reduction [%] =	19,21	21,43	15,69	i.o.		
Compression including cross section reduction [mm] =	0,67	0,76	0,53			
Groove fill [%] =	75,10	79,60	67,05	i.o.		
Expansion [%] =	3,26	4,30	2,14	i.o.		
Groove depth t [mm] =	2,8	2,84	2,80			
Lead-in chamfer at 15° z [mm] =	3,1					
Lead-in chamfer at 20° z [mm] =	2,4					
Gap g [mm] =	0	0,08	0,00	i.o.		
Max. recommended sealing gap g [mm] =	0,10			i.o.		
				-		

Design of installation spaces

Permissible deviations for O-ring cross section in accordance with ISO 3601-1.

Cross section d2 [mm]	0,80 < d2 ≤ 2,25	2,25 < d2 ≤ 3,15	3,15 < d2 ≤ 4,50	4,50 < d2 ≤ 6,30	6,30 < d2 ≤ 8,40
Permissible deviation ± [mm]	0,08	0,09	0,1	0,13	0,15
Estimated deviation [mm]	0,16	0,18	0,2	0,26	0,3
Rel. estimated deviation [%]	20 -> 7,1	8 -> 5,7	6,3 -> 4,4	5,8 -> 4,1	4,8 -> 3,6

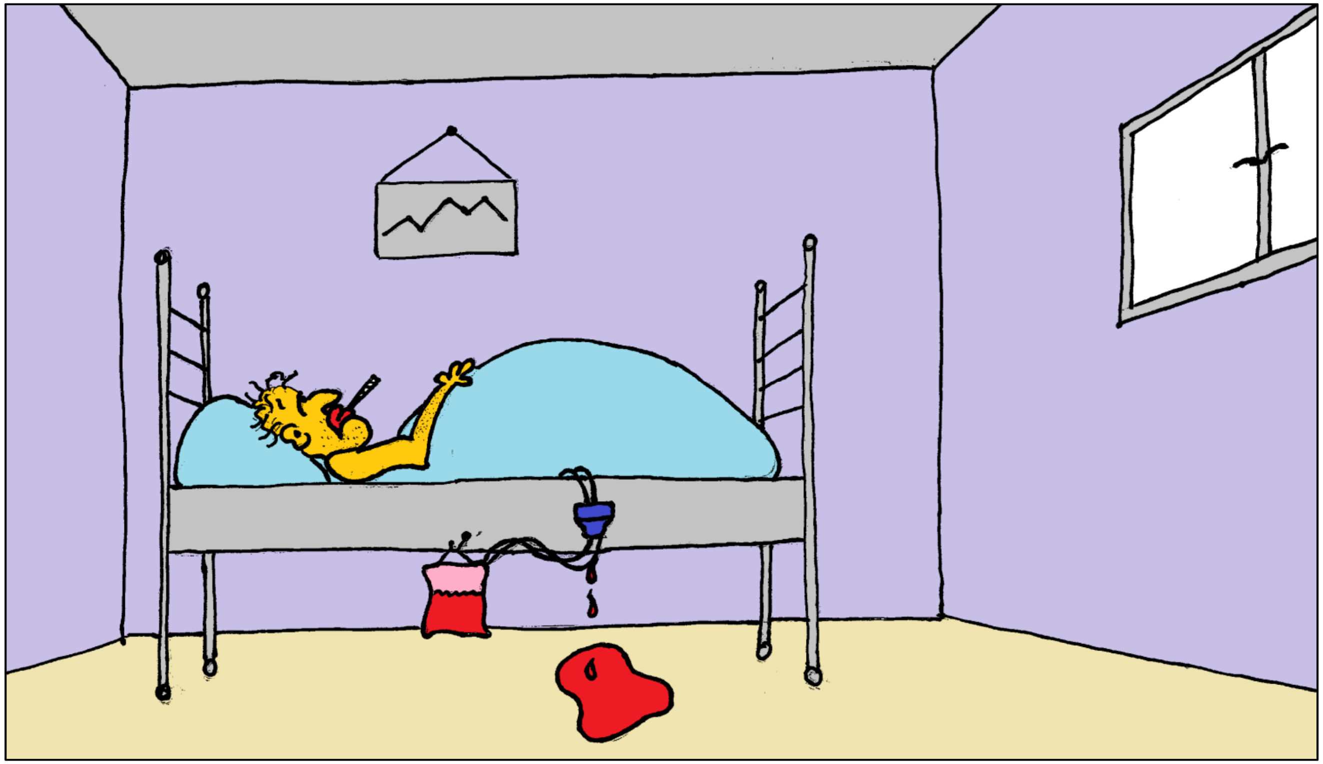
Always work with the largest possible cross section.

Question 2

Do you consider all tolerances <u>of all components</u> when designing the O-ring seal?

- *Yes*
- *No*

Coupling example



Coupling for drainage bags

Coupling example

- Problem: Some couplings are sealed, some not
- Two O-rings are used: 2.35 x 1 and 5.5 x 1.5
- O-rings are made from EPDM 70 perox. + FDA
- Medium: Blood, various bodily fluids
- Pressure: Slight vacuum
- Temperature: Body temperature approx. 35 °C
- Sterilisation: ETO (ethylene oxide)
- Coupling is new on the market

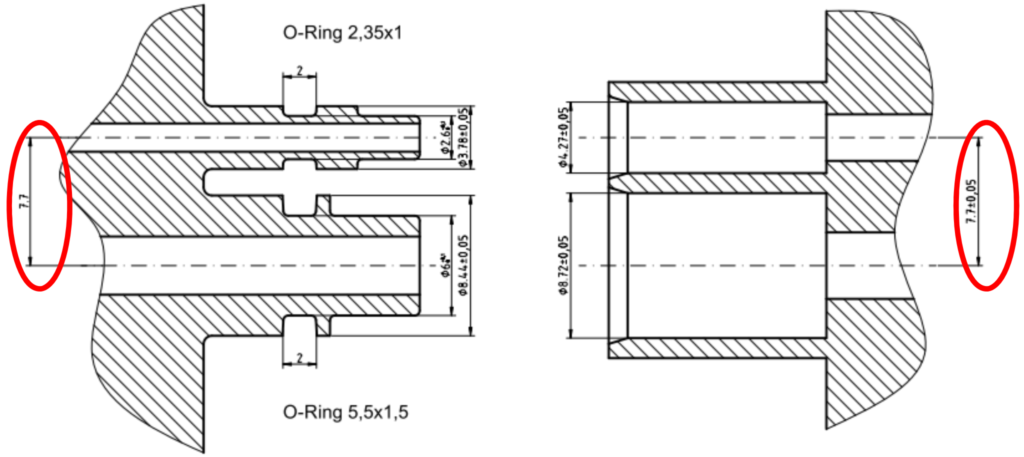
Coupling example

- Tests on used O-rings showed no significant changes
- EPDM perox. is highly resistant to blood and various bodily fluids within the stated temperature range
- EPDM perox. is relatively resistant to ETO

CONCLUSION

No lack of resistance observed

Coupling example



7,7 ±0,20 (ISO 2768m)

7,7 ±0,05 (drawing)

Pin not centrally positioned in the drill hole

Coupling example

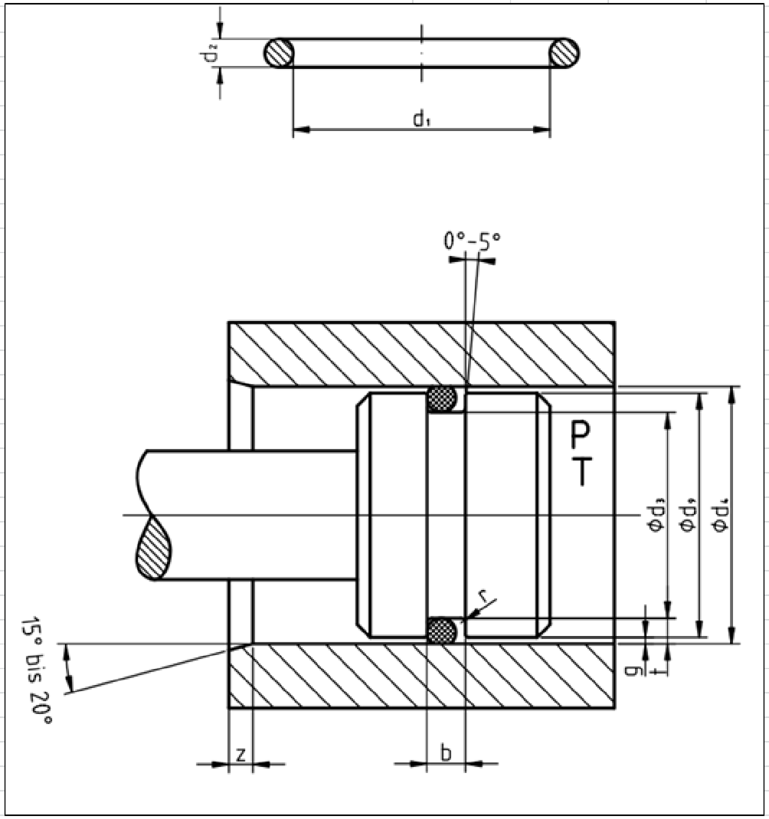
Suspected cause: Tolerance issue?

- Some couplings are sealed, some not
- Thin cords
- Good resistance

Permissible deviations for O-ring cross section in accordance with ISO 3601-1

Cross section d2 [mm]	0,80 < d2 ≤ 2,25	2,25 < d2 ≤ 3,15	3,15 < d2 ≤ 4,50	4,50 < d2 ≤ 6,30	6,30 < d2 ≤ 8,40
Permissible deviation ± [mm]	0,08	0,09	0,1	0,13	0,15
Estimated deviation [mm]	0,16	0,18	0,2	0,26	0,3
Rel. estimated deviation [%]	20 -> 7,1	8 -> 5,7	6,3 -> 4,4	5,8 -> 4,1	4,8 -> 3,6

Coupling example



Input values

	Nominal dimension	Fit	Upper tolerance	Lower tolerance	Maximum dimension	Minimum dimension
Shaft diameter d9[mm]=	3.78	Loose	0.050	-0.050	3.830	3.730
Drill hole diameter d4[mm]=	4.27	Loose	0.050	-0.050	4.320	4.220
Groove base diameter d3[mm]=	2.6	Loose	0.100	0.000	2.700	2.600
Groove width b[mm]=	2	Suggested	0.250	0.000	2.250	2.000
Radius in groove base r1[mm]=	0.3	Suggested	0.100	-0.100	0.400	0.200
O-ring inside diameter d1[mm]=	2.35	DIN ISO 3601	0.130	-0.130	2.480	2.220
O-ring cross section diameter d2[mm]=	1	DIN ISO 3601	0.080	-0.080	1.080	0.920

Material:	EPDM	
Pressure P [bar]=	1	
Temperature T [°C]=	20	OK
Expansion coefficient α [10^-6/K]=	175	
Hardness [Shore A]=	70	
O-ring inside diameter[mm] at 20°C =	2.35	
O-ring cross section diameter[mm] at 20°C =	1.00	

Results

	nominal	max	min	test
Compression including cross section reduction [%]=	13.64	27.22	-5.57	Compression < 6%
Compression including cross section reduction [mm]=	0.13	0.28	0.03	
Groove fill [%]=	45.00	59.01	36.71	OK
Expansion [%]=	10.64	21.64	4.83	Expansion >6.5%
Groove depth t [mm]=	0.835	0.86	0.76	
Lead-in chamfer at 15° z [mm]=	1.2			
Lead-in chamfer at 20° z [mm]=	0.9			
Gap g [mm]=	0.245	0.59	0.39	OK
Max. recommended sealing gap g [mm]=	0.08			Sealing gap too great Change hardness or fit, otherwise use support rings

- In some cases, no compression when centred
- Gap is 59 % of the cord thickness
- Expansion too great

Summary of the coupling example

- No chemical attack
- Not centred
- O-ring not compressed in some cases
  - Good or no sealing depending on position of actual dimensions
- Sealing gap too great

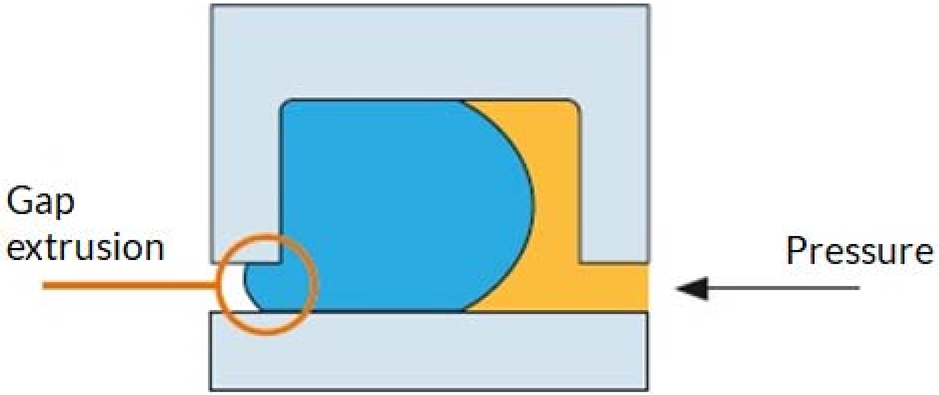
CONCLUSION

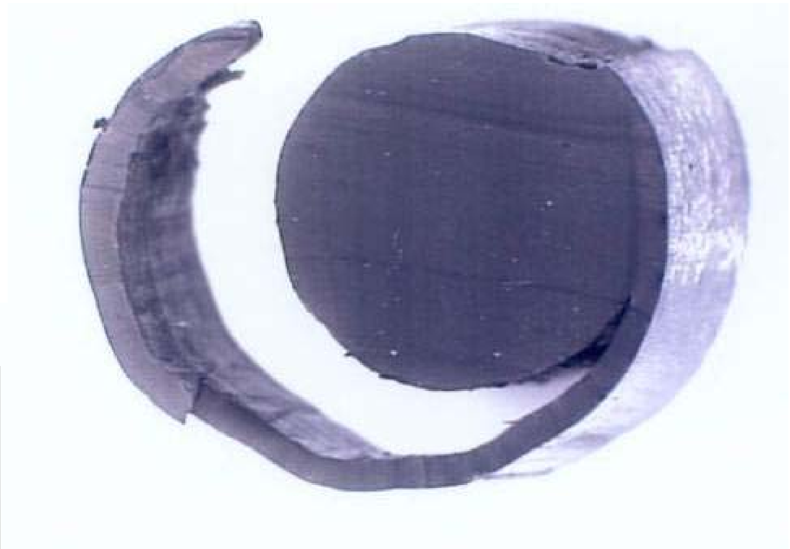
- Poor design → ISO 3601
- Must adhere to tolerances for all components involved

Coupling example, suggested solutions

- Adapt the groove ISO 3601
  - Problems
    - o Injection-moulded parts (completed => high costs)
- Cord thickness +0.1 mm
  - Problems
    - o Max. compression too high
    - o Fitting force too high (hospital staff)
    - o Gap extrusion when fitting
- Cord thickness +0.1 mm plus PTFE coating
  - Trials required

Design of installation spaces

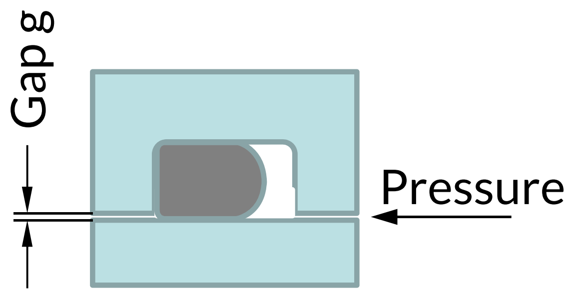




Design of installation spaces

Cross-section d_2	up to 2	2.01 – 3	3.01 – 5	5.01 – 7	over 7.01
	O-Ring hardness 70 Shore A				
Pressure (bar)	**Gap g**				
≤ 35	0.08	0.09	0.10	0.13	0.15
≤ 70	0.05	0.07	0.08	0.09	0.10
≤ 100	0.03	0.04	0.05	0.07	0.08
	O-Ring hardness 90 Shore A				
Pressure (bar)	**Gap g**				
≤ 35	0.13	0.15	0.20	0.23	0.25
≤ 70	0.10	0.13	0.15	0.18	0.20
≤ 100	0.07	0.09	0.10	0.13	0.15
≤ 140	0.05	0.07	0.08	0.09	0.10
≤ 175	0.04	0.05	0.07	0.08	0.09
≤ 210	0.03	0.04	0.05	0.07	0.08
≤ 350	0.02	0.03	0.03	0.04	0.04

All measurements in mm



O-Ring Basics, page 10

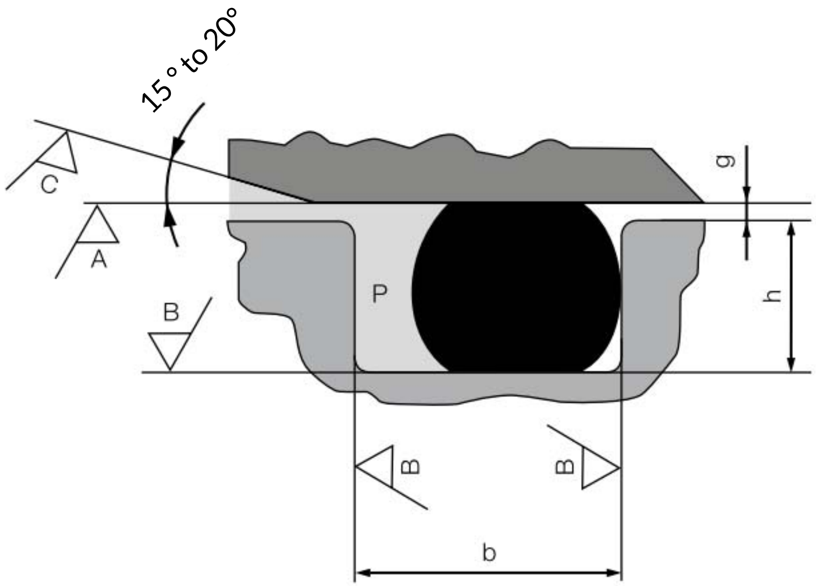
Design of installation spaces

Recommended O-ring cord diameter

Drill hole diameter d4	O-ring cord diameter nominal size d2
4 to 12	1,78
> 12 to 24	2,62
> 24 to 46	3,53
> 46 to 124	5,33
> 124 to 500	6,99

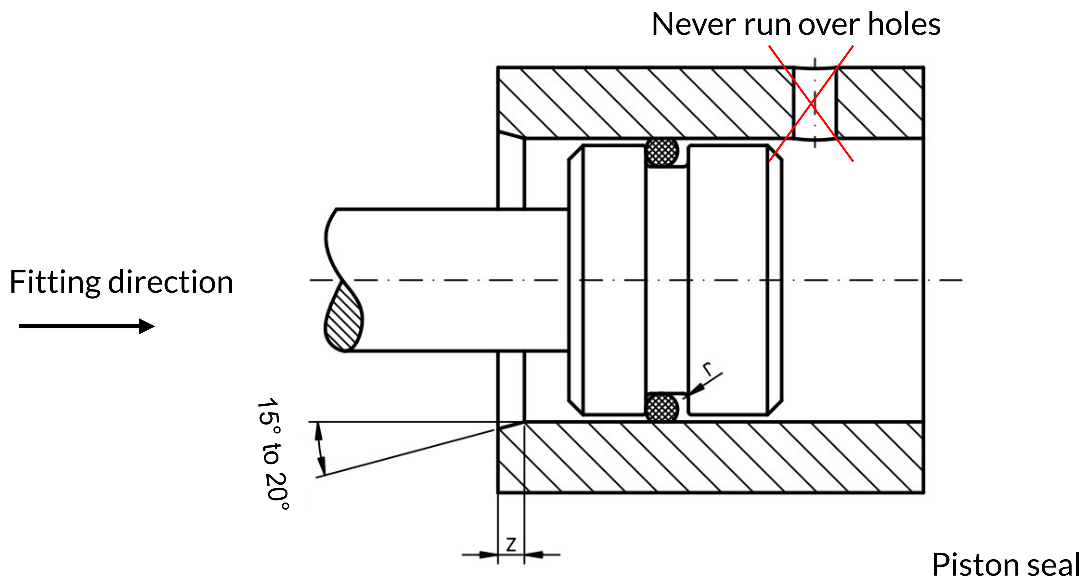
Design of installation spaces

Surface	Application	Rz (µm)	Ra (µm)
Groove base (B)	Static	6,3	1,6
Groove flank (B)	Static	6,3	1,6
Seal area (A)	Static	6,3	1,6
Groove base (B)	Dynamic	6,3	1,6
Groove flank (B)	Dynamic	6,3	1,6
Seal area (A)	Dynamic	1,6	1,6
Lead-in chamfer (C)	---	6,3	1,6



Design measures

- Never draw O-rings over sharp edges



Design measures

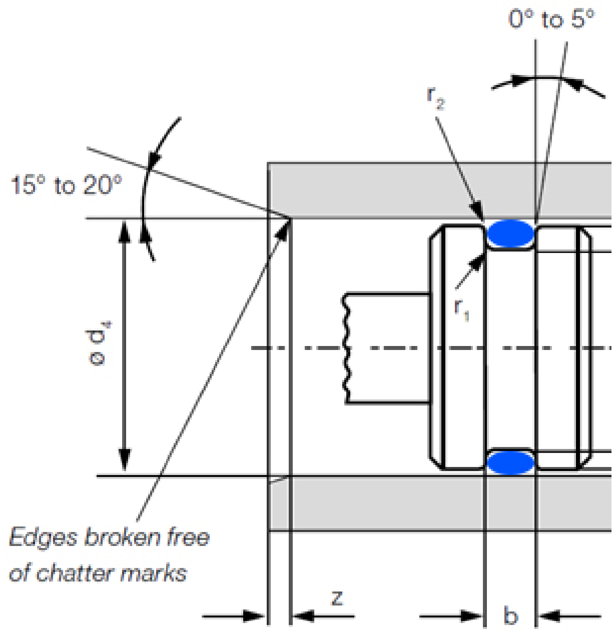
Damage to the O-ring caused by sharp-edged components.

Design measures

- Provide lead-in chamfers

d	z at 15°	z at 20°
bis 1,80	2,5	2
1,81 – 2,62	3	2,5
2,63 – 3,53	3,5	3
3,54 – 5,33	4	3,5
5,34 – 7,00	5	4
over 7,01	6	4,5

Lead-in chamfer minimum length



Design of installation spaces

- The O-ring needs about 20 % clearance in the groove
- Compression should not be more than 30 % depending on the cord thickness
- Observe all tolerances
- Do not choose a cord thickness that is too thin
- The fit between shaft and drill hole must match the pressure
- Do not expand O-rings more than 20 % temporarily and no more than 6 % permanently
- Avoid sharp edges, cross holes, etc.

O-RING AKADEMIE®

Question 3

How do you select your sealing materials? After …

- *Chemical resistance list*
- *Laboratory tests*
- *Experience*
- *Recommendations*
- *Others*

Material selection

Medium	NR	IIR	EPDM	NBR	HNBR	CR	AU	ACM	VMQ	FVMQ	TFE/P	FKM	FFKM
Calcium acetate (watery solution)	A	A	A	B	B	B	D	D	D	D	A	D	–
Calcium carbonate sulphur solution	D	A	A	D	A	A	–	D	A	A	–	A	A
Calcium chloride (watery solution)	A	A	A	A	A	A	A	A	A	A	A	A	A
Calcium hydrogen sulphite (watery solution)	D	D	D	D	A	A	A	D	A	A	–	A	A
Calcium hydroxide (watery solution)	A	A	A	A	A	A	A	D	A	A	A	A	A
Calcium hypochlorite (watery solution)	C	A	A	B	B	C	D	D	B	B	A	A	A
Calcium nitrate (watery solution)	A	A	A	A	A	A	A	A	B	A	A	A	A
Calcium sulphide (watery solution)	B	A	A	A	A	A	A	D	B	A	A	A	A
Carbamate	D	B	B	C	–	B	D	D	–	A	–	A	A
Carbitol (ethyldiglycol)	B	B	B	B	–	B	D	D	B	B	–	B	A
Carbolic acid (phenol)	D	B	B	D	D	C	C	D	D	A	–	A	A
Carbon dioxide	B	B	B	A	A	B	A	–	B	A	–	A	–
Carbon disulphide	D	D	D	C	D	D	–	C	D	A	A	A	A
Carbon monoxide	B	A	A	A	A	B	A	A	A	B	–	A	A

A = 0 to 5 % volume swelling, elastomer shows zero to small swelling.

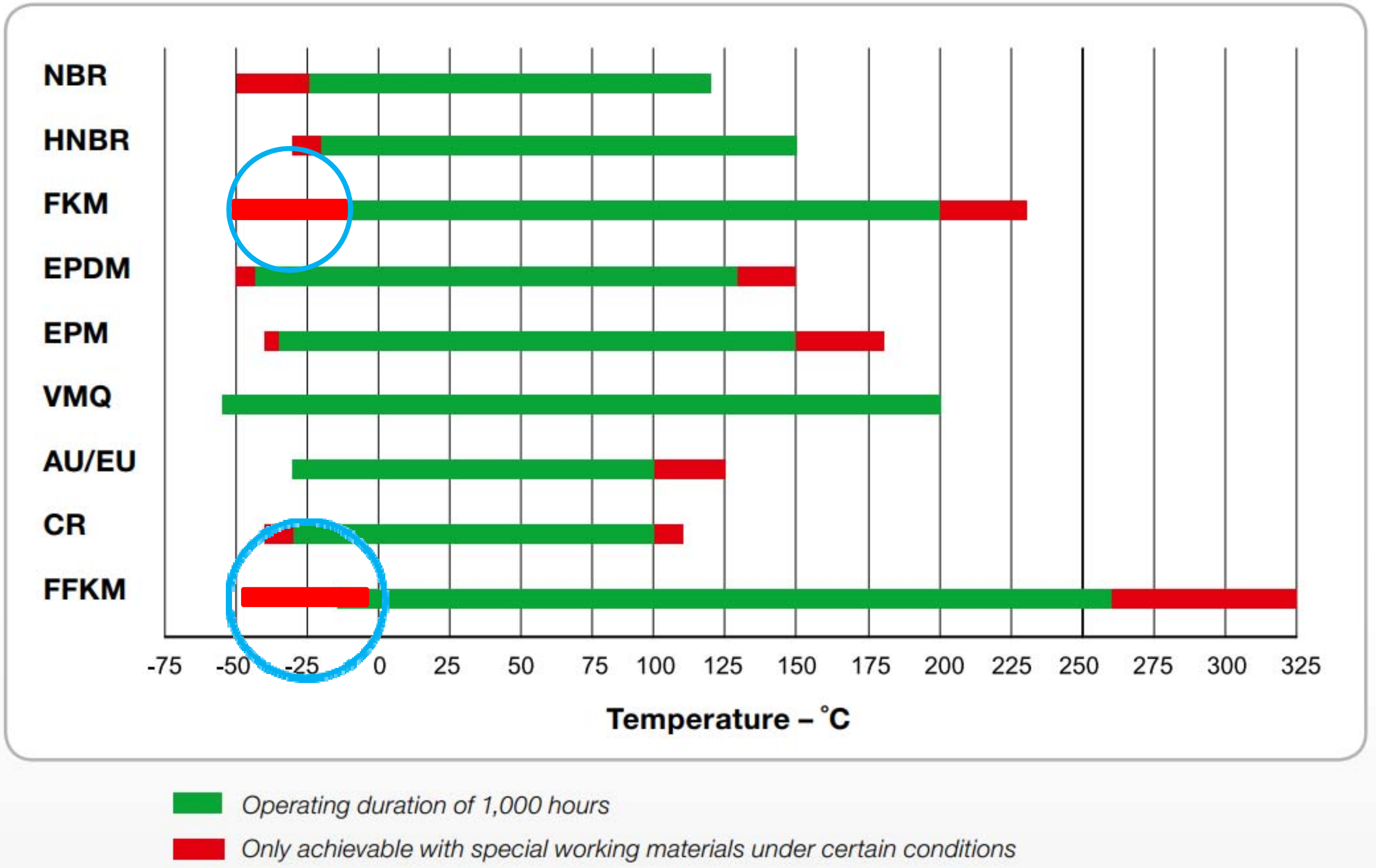
B = 5 to 10 % volume swelling, elastomer shows small to moderate swelling.

C = 10 to 20 % volume swelling, elastomer shows moderate to strong swelling.

D = Not recommended

E = Unknown / Not checked

Material selection



Material selection

- **NBR:** Oil, hydraulic oil, lubricating grease, petrol, aliphatic hydrocarbons, diluted acids and alkaline solutions
- **Standard FKM/FPM (Copolymer):** Mineral oil, aliphatic and aromatic hydrocarbons, chlorinated hydrocarbons, concentrated acids, weak alkalines
- **Special FKM/FPM (Tetrapolymer):** As standard FPM, plus exceptional resistance to hot water, steam, biogenic substances (biodiesel, E10, etc.).
- **FFKM/FFPM:** Resistance comparable to PTFE (Teflon)
- **EPDM:** Highly resistant to hot water and steam, resistant to ageing and ozone, excellent chemical resistance to oxidising agents
- **VMQ:** Wide operating temperature range (-55 °C to +200 °C), air, oil resistance similar to NBR, no hot water and steam

Material selection

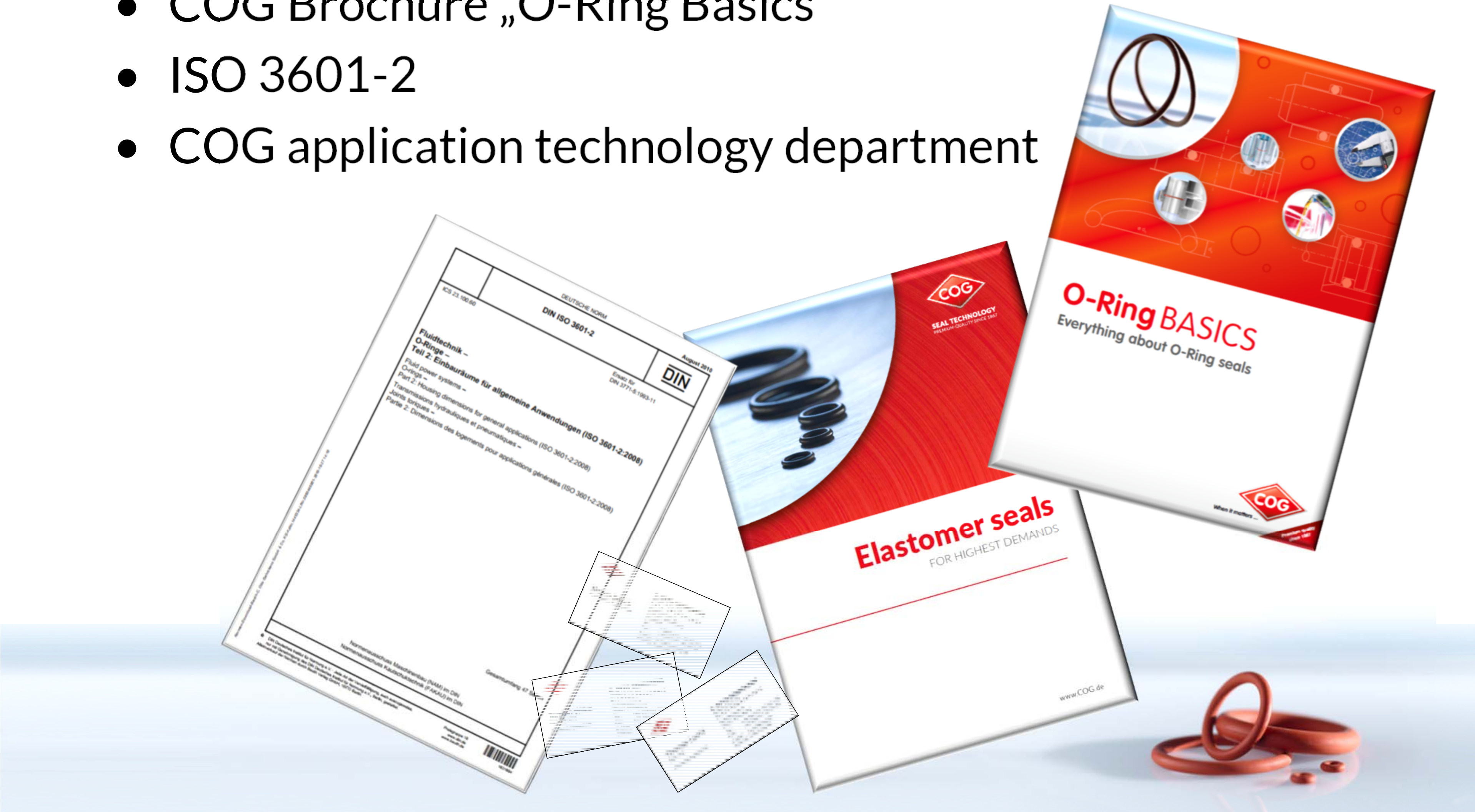
O-RING AKADEMIE®

Summary:

- Resistance table
- Temperature ➔ Use the Arrhenius equation
- Empirical values
- Suitability tests in borderline cases
- If in doubt, use a higher quality material,
  NBR ➔ FKM ➔ FFKM

Further Information

- COG Brochure „Elastomer seals for highest demands“
- COG Brochure „O-Ring Basics“
- ISO 3601-2
- COG application technology department



Questions?

Many thanks for your attention!

Contact

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