

# Diaphragms

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# Diaphragms

For certain applications, components must be flexibly connected to each other and at the same time ensure that a tightly sealed separating wall is provided for. These demands can generally best be fulfilled with diaphragms. Simrit offers more than 400 different compounds for diaphragm applications. These can be utilised based on individual projects and for customer-specific requirements.

## Requirements

- Operational safety for widely varied media deployments
- Solutions for control, accumulator or pump functions
- Fabric insert and/or layer, depending on the pressure load
- Allowance for unilaterally or bilaterally applied pressure
- Optimum design of stroke to bore ratio.





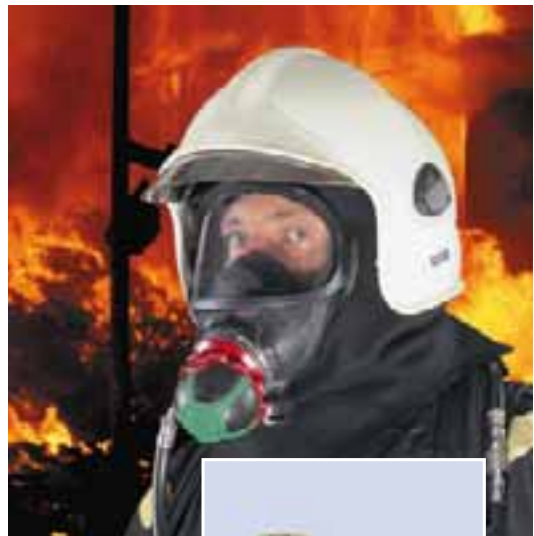
### Features

- Customised solutions based on the 4 basic types: flat diaphragm, dished diaphragms, convoluted diaphragms and rolling diaphragms
- Ultimate precision, thanks to the most advanced FEM calculations when designing
- Optional PTFE/TFM foil layers against aggressive media
- Special metal or plastic inserts for load transmission and bracing
- Qualitative high-grade material constructions, contingent upon the operating conditions (e.g. NBR, HNBR, ECO lead-free, AU, FKM, FFKM, etc.).

### Application ranges

The application spectrum of diaphragms extends from conventional control and seal elements for valve technology through to sophisticated tasks for aerospace.

- Valves and fittings
- Actuators
- Pumps and compressors
- Accumulator diaphragms in hydraulics
- Aerospace industry
- Plumbing technology
- Respirator masks
- Foodstuffs industry
- etc.



# Basic Principles

Diaphragms made of elastic rubber materials have the task of establishing a sealed and, at the same time, flexible partition between two component chambers and to enable volumetric changes of the separate chambers.

By virtue of their basic function, they can also be characterised as flexible sealing components.

In light of these prerequisites, a diaphragm can fulfil 3 main functions:

- **Controlling/switching function:**  
hydraulic or pneumatic pressure applied to the effective area of the diaphragm is transformed into a linear shaft force and operates a switching, controlling or display device.
- **Pump function:**  
with the pump function, an introduced linear shaft force or a hydraulic or pneumatic pressure on the effective area of the diaphragm is transformed into a delivery pressure.
- **Separating function:**  
this function simply involves separating chambers – which have virtually the same pressure level – from each other by means of a slightly movable and flexible partition. A good example of this are applications in the area of accumulators.



Diaphragms offer several advantages compared with contact seals:

- Leak-free
- There is no requirement for lubrication, therefore they are maintenance-free
- No frictional losses
- Minimal hysteresis with the appropriate constructive design
- No breakaway force ("stick-slip effect")
- Minimal wear due to clear roll-away movement
- Substantially reduced demands for tolerances and surface quality of the adjacent components make cost savings in component manufacturing possible.

The fundamental interrelationships can be best explained using the example of the pump or control diaphragms depicted in → Fig. 1.

## Mode of operation and main dimensions

The operating area of the diaphragm is restricted outwardly by the housing diameter and inwardly by the piston diameter. The diaphragm is statically fitted in the housing and – if necessary – on the piston, to seal. Located between the housing and piston there is a rolling gap, over which the flexed area of the diaphragm is more or less tightly "stretched". If there is a pressure differential between the upper and lower side, then the flexed area is depressed into the rolling gap by the pressure load, initially taking on an arched form. As with a thin-walled pipe under internal pressure, pressurising forces and forces running tangential to the arch in the diaphragm wall are kept in balance. The radius of the curve in the flexed zone is dependent on the length of the freely available surface line between the clamping point on the housing and piston, as well as the clearance between clamping point and the position of the piston at the clamping plane. Consideration should be given to an adequate flexed zone surface length when making the design. When travelling through the stroke, the flexed area "rolls" up in the rolling gap. When doing so, areas of the diaphragm wall move from the piston to the housing and vice versa, thereby undergoing an enlargement or, respectively, reduction in diameter.

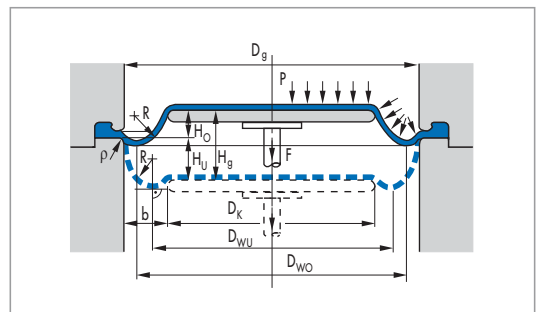


Fig. 1 Main dimensions/mode of operation

### Basic diaphragm types

The multitude of designs can be traced back to just a few basic types:

- Flat diaphragms
- Dished diaphragms
- Convoluted diaphragms
- Long-stroke rolling diaphragms.

An essential distinguishing feature is the, with a respective specified housing diameter of  $D_g$ , attainable absolute stroke travel  $H_{max}$ . Another is the type of permissible pressure applied (unilaterally, bilaterally) as well as the measure of dependence of the effective diameter  $D_w$  from the stroke.

#### Flat diaphragms

Flat diaphragms (→ Fig. 3) can only be utilised with relatively short strokes but can, of course, have pressure applied bilaterally. As a rule, the effective diameter change greatly with the stroke.

The low stroke heights often still permit so-called "swaged installation" to reduce the component stress under pressure load (→ Fig. 2). The compression should be selected high enough that the necessary elongation compensates for the free diaphragm surface at the end position of the piston. This avoids an elongation of the diaphragm surface. If sheets or rolled goods are used as semi-finished products, then the manufacturing of an expensive, item-specific vulcanisation tool can be dispensed with.

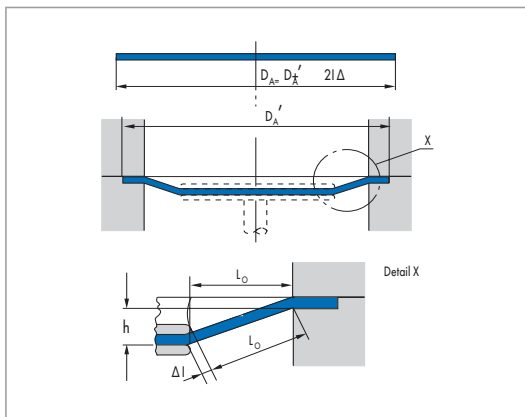


Fig. 2 Swaged installation of flat diaphragms

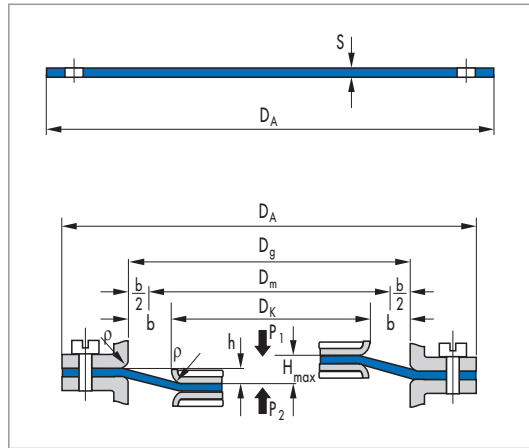


Fig. 3 Flat diaphragms

#### Dished diaphragms

Dished diaphragms (→ Fig. 4) can, like the flat diaphragms, have pressure applied bilaterally, yet allow substantially longer strokes. With this design type also the effective diameter is extremely dependent upon the stroke.

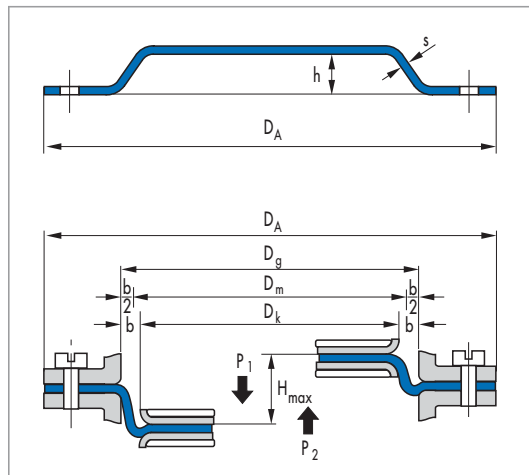


Fig. 4 Dished diaphragms



### Convoluted diaphragms

This design type (→ Fig. 5) involves a rolling convolution with an arched cross-sectional area, even in an unloaded state. As long as limitations in the stroke height are taken into consideration, then an almost stroke-independent effective diameter can be attained.

Convoluted diaphragms always require a pressure differential toward the rolling convolution in order to preclude a folding over of the rolling convolution.

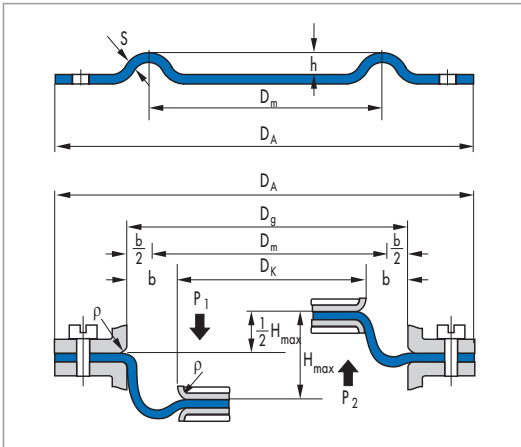


Fig. 5 Convoluted diaphragms

### Long-stroke rolling diaphragms

To be considered a special case amongst dished diaphragms is the long-stroke rolling diaphragm (→ Fig. 6), which is everted during installation. With the design with fabric reinforcement, the potential stroke is limited by the deep drawing quality of the fabric.

Rolling diaphragms must be supported on the outside by the housing and on the inside by the piston. This provides for a quasi stroke-independent, constant effective diameter. Rolling diaphragms always require a pressure differential to the rolling convolution, as do convoluted diaphragms, as otherwise they would be everted by the pressure.

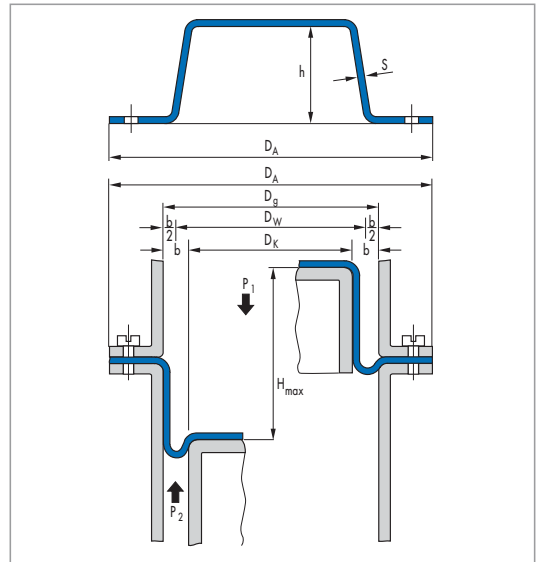


Fig. 6 Long-stroke rolling diaphragms

### Diaphragms with fabric reinforcement

All forms of diaphragms can be made as purely elastomer diaphragms or also with fabric reinforcement. With these, the reinforcing fabric is embedded in the middle of the diaphragm cross-section (insert) or "placed upon" a surface (support). The support must thereby always be on the non-pressurised side (e.g. outside of the rolling convolution), as otherwise the elastomer layer would be separated from the fabric sheet by the pressure and the diaphragm would be destroyed.

It should be kept in mind that the very limited plasticity of the fabric restricts its possibilities for usage from a manufacturing-compatible point of view.

The different fabric types that can be used are addressed in more detail in → Diaphragm fabric page 739.

### Diaphragms with a support made of PTFE

With aggressive ambient media and conveying media, as can be found with pump applications, the chemical resistance of the elastomer can be inadequate. In this case there is the possibility of protecting the basic material of the diaphragm by applying a foil made of PTFE to protect the surface facing the medium, thus increasing the service life.

Forms of diaphragms	Max. stroke $H_{\max}$	Applied pressure	Change of effective diameter $D_w$ by means of stroke $H$
Flat diaphragms	$\leq 0.1 D_g$	bilaterally	very large
Dished diaphragms	$\leq 0.3 D_g$	$P_1 \leq P_2$	large
Convoluted diaphragms	$\leq 0.3 D_g$	unilaterally	small
Rolling diaphragms	$\leq 1.7 D_g$	$P_1 > P_2$	none

Tab. 1 Diaphragm parameters

## Parameters

The behaviour of a diaphragm can be approximately characterised by means of the parameters stroke, effective diameter or, respectively, effective area, mean diameter and elasticity module.

### Stroke

The absolute stroke travel  $H_g$  comprises the portions of  $H_o$  above and  $H_u$  below the clamping plane:

$$[1] \quad H_g = H_o + H_u$$

When dimensioning, the larger of the two values is to be considered to be a critical case. With a view towards optimal function and service life, the stroke should only be deduced from the change in shape of the diaphragm and not, however, from an elongation of the diaphragm surface.

### Effective diameter, effective area

Under a pressure load, the diaphragm braces itself on the piston and thus provides a contribution towards the linear shaft force. The diameter which has an effect on the linear shaft force – the effective diameter  $D_w$  is dependent upon the stroke position and lies between the piston diameter  $D_k$  and the housing diameter  $D_g$ . What is generally applicable is:

$$[2] \quad D_k \leq D_w \leq D_g$$

The effective diameter can be determined as a pitch point of the tangent which is perpendicular to the diaphragm axis on the arch of the flexed area. Only the effective area lying inside of this diameter contributes to generating the linear shaft force. The pressure on the ring surface lying outside of the effective diameter of the diaphragm only acts as a tensile load for clamping in the housing.

### Mean diameter

The mean value of the piston and housing diameter is designated as being the mean diameter. In the home position it coincides well with the effective diameter:

$$[3] \quad D_m = (D_g + D_k)/2 = D_{w(H=0)} \approx D_{w(H)}$$

### Rolling gap

The gap "spanned" by the diaphragm between the housing and piston is designated as the rolling gap  $b$ :

$$[4] \quad b = (D_g - D_k)/2$$

In the first approach it can be established that:

$$[5] \quad b \approx 0,15 D_g$$

### Housing diameter

When specifying parameters, it is preferred to use the housing diameter as it is derived directly from the present housing or, respectively, allows an immediate estimation of the necessary housing. With the arrangement for the rolling gap according to  $\rightarrow$  equation 5, it applies that:

$$[6] \quad D_g = D_m / 0,85 \approx D_w / (0,85)$$

### Elasticity module

The modulus of elasticity (e-module) for elastomers is, in contrast to that of steel, not constant but rather dependent on the hardness of the elastomer, the temperature, the elongation and deformation speed.

- The e-module progresses with increasing deformation speed (dynamic hardening). When dimensioning, one limits one's self to the quasistatic case for the sake of simplicity. Regarding the component stress, this is also considered the "critical case".
- With an increase of the secant between the original state and a 20% elongation of the tension elongation diagram, an approximate value for the modulus of elasticity in the dimensioning area is received.



The dependency of the E20% modulus of elasticity upon the elastomer hardness and temperature is exemplarily depicted in → Fig. 7. As the module depends on the compound, it is recommended to enquire about this characteristic value with the compound manufacturer.

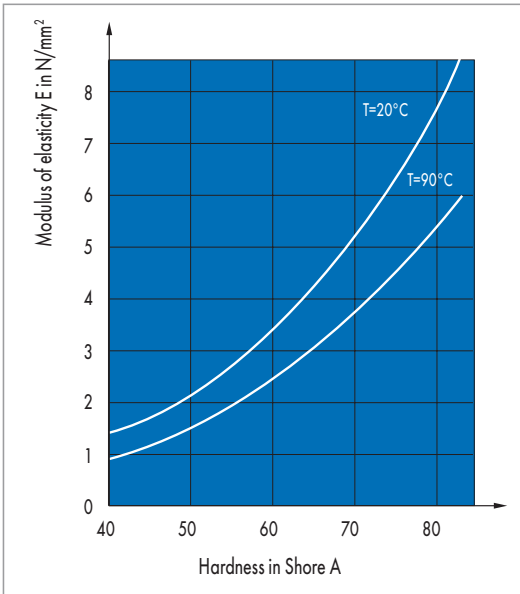


Fig. 7 Elasticity module

### Characteristic curves

If the linear shaft force  $F$  is applied throughout the stroke, then a characteristic curve is derived. As the linear shaft force depends upon the set pressure and effective area or, respectively, effective diameter, the characteristic curve is then essentially determined by the dependency of the effective diameter of the stroke. The choice of the basic diaphragm types plays a decisive role here. The principle correlation is depicted in → Fig. 8. As the change of the characteristic curve increases at the end of the stroke end position, the characteristic curve progression allows for optimisation by the choice of the operating area. By distending the diaphragm ( $H_g < H_{max}$ ) the peripheral areas can be "truncated", providing for a more favourable overall characteristic curve with reduced influence on the stroke.

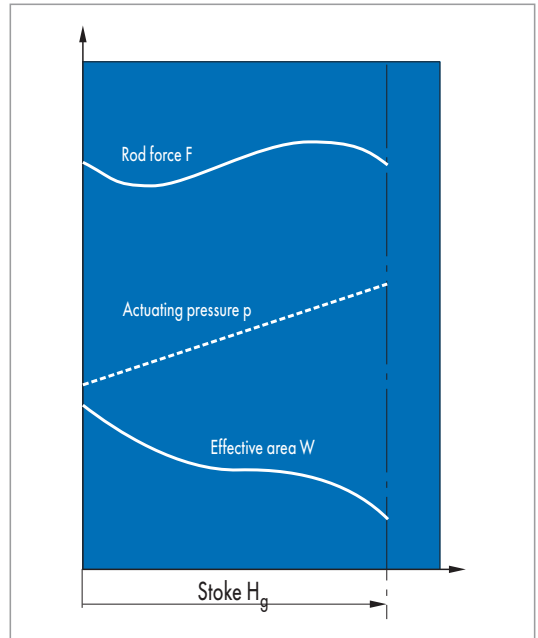


Fig. 8 Linear shaft force

### Inherent resistance

Inherent resistance is understood to be the resistance that a diaphragm induces, under the exclusion of all outside influences, into the movement from one position at the end of the stroke to the other. As a rule, this resistance is determined by measuring the pressure necessary to overcome the resistance.

It is caused by tensile stress in the diaphragm surface during stretching out in the course of the uncoiling movement and through bending stress during outward travel of the diaphragm from the manufactured position.

→ Fig. 9 shows diagrammatically the progression of the inherent resistance as a function of the diaphragm stroke.

The increase in resistance is particularly large near the at the end of the stroke positions of the diaphragm. As with the characteristic curve, the influence on the stroke can be reduced by superelevating the diaphragm ( $H_g < H_{max}$ ).



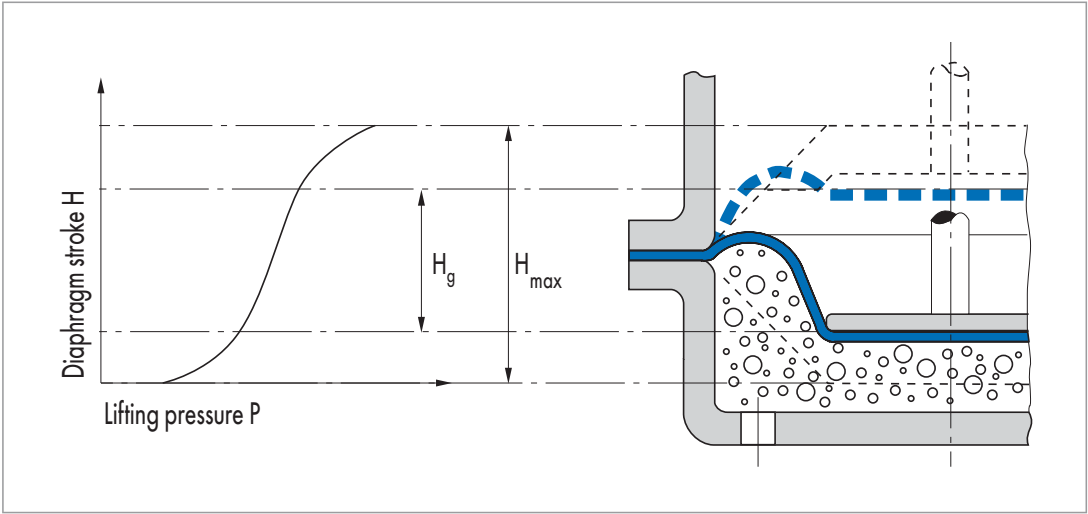


Fig. 9 Inherent resistance



## Design/Dimensioning

### Operating data and boundary conditions

The dimensioning of a diaphragm is essentially determined by the following operating data:

- The type of device (e.g. a cylinder operating under rough operating conditions or a measuring device with high demands regarding inherent resistance and hysteresis)
- Max. stroke with a subdivision in regard to the clamping plane
- Pressure (operating pressure and/or test pressure)
- Effective diameter (as a function of the stroke, if applicable)
- Ambient media
- Operating temperature range
- Actuation frequency
- Service life.

When dimensioning the diaphragm it is recommended to follow the procedure described below.

#### Step 1: Select the design type according to Tab. 1

Before selecting, the housing diameter  $D_g$  and diaphragm stroke  $H_{max}$  should be taken from the operating data. The ratios in the equations [7] through [10] are helpful in this regard:

For a pump diaphragm the volumetric displacement can be estimated with:

$$[7] \quad V = \pi/4 D_w^2 H_g$$

The reciprocating force can be derived with:

$$[8] \quad F_k = \pi/4 D_w^2 p$$

Optimum usage of the diaphragm stroke can be achieved with:

$$[9] \quad H_g = H_{max}$$

In the first approach the correlation between housing and effective diameter can be established (→ equation [6])

$$[10] \quad D_w = 0,85 D_g$$

As the stated relations only provide approximate values, it is recommended to assign a safety factor of

approx. 10% to the regulating power and volumetric displacement.

#### Step 2: Dimensioning of the diaphragm

With the dimensioning, the diaphragm and adjacent components – such as the housing and piston – are determined for the design engineering. When designing the diaphragm, along with the strictly functional aspect the manufacturing-compatible aspects must also be considered. An examination and optimisation of all dimensions by the diaphragm manufacturer is recommended in any case.

The aspects listed below should be given particular attention:

the values for  $H_{max}$  apply in any case in for a symmetrical distribution of the absolute stroke travel above and below the clamping plane, and they are:

$$[11] \quad H_{u\ max} = H_{o\ max} = H_{max}/2$$

With an asymmetric stroke distribution, the absolute stroke travel  $H_g$  is thus always smaller than the maximum possible stroke  $H_{max}$ . In order to minimise the bending stress and inherent resistance, the diaphragm thickness  $s$  is generally made to be as thin as possible. Here, however, in any case the specified limits of the material and manufacturing method must be observed. In general, it is recommended that fabric-free diaphragms are only utilised for pressures of less than approx. 2 bar. With higher pressures, thin-walled, fabric-reinforced diaphragms should be utilised instead.

As a result of the uncoiling movement, bending stress arises in the clamping area as well as in the flexed area. In order to limit this loading to non-critical levels, clamping ribs and rolling fold areas should be chosen for completely uncoiling diaphragms, dependent on the diaphragm thickness (→ Fig. 10).

$$[12] \quad \text{Clamping rib } p \geq 2 s$$

$$[13] \quad \text{Rolling fold span } b \geq 6 s$$

Attention should also be paid to the instructions on "Configuring the clamping and the contacting housing parts".

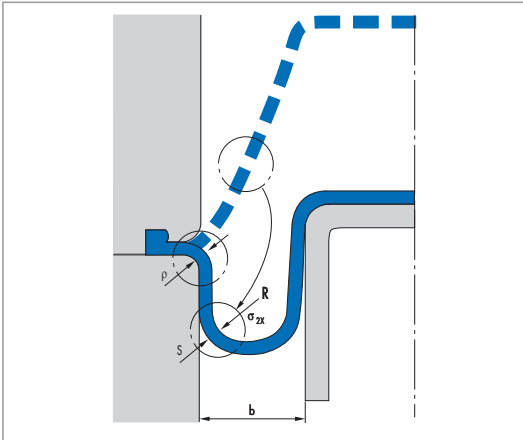


Fig. 10 Bending stress

### Step 3: Examination of the diaphragm stress

#### Component stress

Typical operating conditions for diaphragms are an unilateral pressure and an axial shifting between piston and housing. This results in essentially two different load stresses in the diaphragm wall:

- Elongation stress and tensile stress in the circumferential direction as a result of a change of the diameter during the uncoiling movement (→ elongation stress/tension in circumferential direction).
- Tensile stress in the radial or axial direction as a result of the pressure differential  $p$  (elongation stress/tension as a result of the pressure differential).

Under these conditions a multiaxis state of stresses is present. In practise, however, no reference stress load is calculated for the two components; instead they are regarded individually.

#### Elongation stress/tension in the circumferential direction

The distension in the circumferential direction as a result of the change of the diameter during the uncoiling movement (→ Fig. 11) is greatly dependent upon the forms of diaphragms, the installation space and stroke.

The max. circumferential elongation applicable to a rolling diaphragm is:

$$[14] \quad \epsilon_{u \max} = D_g / D_k - 1$$

The maximum circumferential elongation for flat diaphragms, convoluted form and dished diaphragms must be determined by suitable methods.

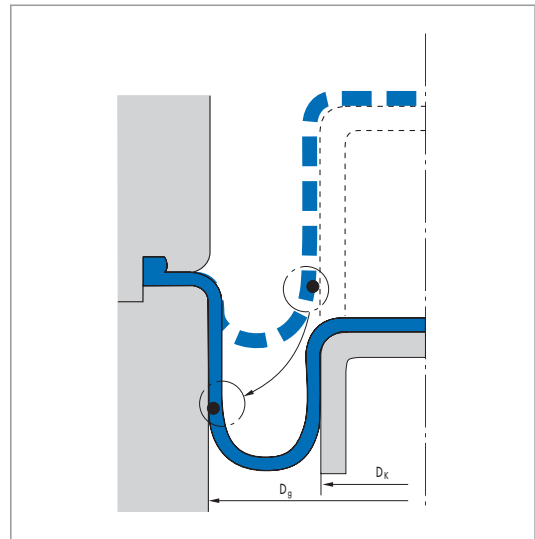


Fig. 11 Elongation as a result of uncoiling movement

#### Elongation stress/tension as a result of pressure differential

As diaphragms, contingent upon their geometry, have less inherent stiffness, an arced diaphragm cross-section forms (→ Fig. 12) under pressure. If the diaphragm is viewed, disregarding the curvature, upon first approximation as a straight pipe under internal pressure, then the tensile force in the diaphragm wall is derived from the "boiler formula" for thin-walled pipes:

$$[15] \quad \sigma_p = p R / s$$

By applying Hooke's Law for uniaxial state of stresses:

$$[16] \quad \sigma = E \varepsilon$$

... the elongation is derived for:

$$[17] \quad \varepsilon_p = p R / (s E)$$

Recommended values for the modulus of elasticity E are stated in Fig. 7 .

The force  $F_p$  per circumference length l is required as a parameter for fabric reinforced diaphragms.

From the equation [15] the result is:

$$[18] \quad F_p/l = \sigma' = p R$$

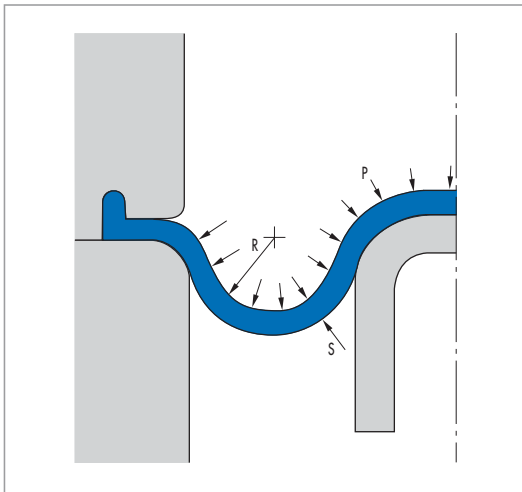


Fig. 12 Load stresses from a pressure differential

### Permissible load stress

When assessing the load stress determined according to the  $\rightarrow$  component stress, a distinction must be made between diaphragms with and without fabric reinforcement.

For fabric-free diaphragms under pressure load, in practical situations the specification of a maximum elongation has proven effective. This is founded upon the structure of the elastomers, which are composed of fibrous molecules that are interlaced with one another.

With fabric reinforced diaphragms the low percentage of contact area of the elastomers is disregarded and it is assumed that the tensile stress is carried solely by the fabric.

The tensile strength  $\sigma'_B$  of fabric is determined in tensile trials as the maximum tensile force in regard to the sample width and can be enquired from the manufacturer. By making use of a safety factor, consideration is given that the fibre direction around the periphery deviates in part from the direction (radial) of the stress. In addition, with fabric the dependency of the tensile strength upon the operating temperature must be considered.

Parameters		Permiss. load stress	
		Without fabric	With fabric
Circumf. elongation (mean value)	$\varepsilon_U$	$\rightarrow$ a)	$\leq 30\%$ / $\leq 15\%$
Elongation due to internal pressure	$\varepsilon_p$	$\rightarrow$ b)	$\leq 20\%$ /
Force per width	$F_p/l$	$\rightarrow$ b)	$\leq 0,2 \sigma'_B$

Tab. 2 Diaphragm parameters

- a) Elongation stress/tension in the circumferential direction
- b) Elongation stress/tension as a result of the pressure differential

### Design examples:

#### rolling diaphragms with fabric layer

In a control valve a rolling diaphragm is supposed to be used according to the following boundary conditions:

- Housing- $\varnothing$   $D_g = 100 \text{ mm}$
- Piston- $\varnothing$   $D_k = 90 \text{ mm}$
- Pressure differential  $p = 10 \text{ bar} \approx 1 \text{ N/mm}^2$

The circumferential elongation as a result of the uncoiling movement should be examined and the minimum strength of the fabric determined:

- From the geometry it can be deduced that:  
 $b = (D_g - D_k) / 2 = 5 \text{ mm}$   
 $R = b / 2 = 2,5 \text{ mm}$
- With equation [14]:  
 $\varepsilon_{U \max} = 0,11 = 11\% \leq 15\% \rightarrow \text{i.O.}$
- With equation [18]:  
 $F_p/l = 2,5 \text{ N/mm}$
- From Tab. 2:  
 $\sigma'_B \geq F_p/l / 0,2 = 12,5 \text{ N/mm}$

The maximum circumferential elongation lies within the permissible range, the minimum tearing resistance for the fabric is 12,5 N/mm.

### Convuluted diaphragms without fabric

For a fabric-free convuluted diaphragm with a wall thickness of 2 mm, the rolling convolution radius at a pressure differential of 1 bar ( $\approx 0,1 \text{ N/mm}^2$ ) can be graphically determined as 15 mm. What is sought is the minimum Shore hardness of the elastomeric material.

→ Equation [17] with → Tab. 2:  
 $E_{\min} = p R / (s \epsilon_p \text{ permiss.}) = 3,75 \text{ N/mm}^2$

From → Fig. 7 :  
 Hardness  $\geq 61$  Shore A at operating temperature RT  
 Hardness  $\geq 69$  Shore A at operating temperature 90 °C.

### Design of the clamping and contacting housing parts

As a matter of principle, sharp edges are not permissible in the contact area of the diaphragm, as these unavoidably lead to high bending stress or mechanical damage during uncoiling movements and thus to failure.

The transitions from the clamping plane or, respectively, piston surface to the cylinder wall are to be rounded in order to avoid tension peaks (→ Basic Diaphragm Types and → Guideline on Dimensioning).

Applicable to the surface quality of all housing parts that come into contact with the diaphragm, and where there is a possibility of relative movement, is:

$$Rz \leq 10 \mu\text{m}$$

Where a rolling convolution has been formed (e.g. with a rolling diaphragm or a substantially elevated dished diaphragm), the housing and piston are to be designed so that a faultless bracing is provided for. If an undercutting occurs, then buckled folds and premature wear and tear can be expected (→ Fig. 13).

In the attaching in the housing or, as the case may be, on the piston, the diaphragm is to be clamped and bolstered against the pressurising forces. This is often combined with the sealing of the parting plane. These tasks can be fulfilled with various clamping geometries. Frequently used are:

- Design in the form of a gasket:  
 To improve the sealing effect, both flanges can be provided with offset-positioned flat beads or grooves.
- Circular, thick bead (O-ring): In both flanges there are grooves for inserting the beads.
- Semicircular sealing bead (half O-ring): the groove is only made in one flange, the other flange is made flat. Design implementation examples → dished diaphragms (long-stroke rolling diaphragm)
- The bead and groove geometry must be designed so that a compression of 20% to 30% is attained. It should also be considered that elastomers are nearly incompressible. The clamping groove should be made large enough to accommodate the compressed volume, even allowing for a possible thermal expansion – or swelling as a reaction to media exposure – with sufficient safety.

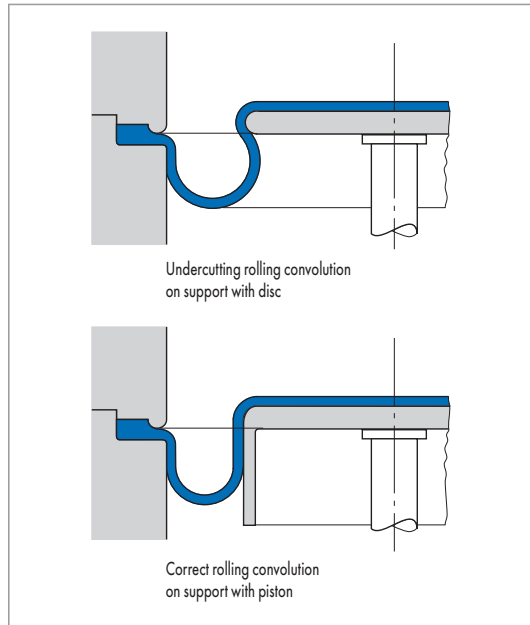


Fig. 13 Bracing of the rolling convolution by means of a piston



### Diaphragm dimensional tolerances

In general, DIN ISO 3302 Part 1 "Rubber – Tolerances for Products - Dimensional Tolerances" applies to the diameter tolerance of moulded diaphragms and form-pressed diaphragms made of rubberised fabric, whereby the tolerance class M 2 and for diaphragms with fabric and the tolerance class M 3 for diaphragms without fabric are acceptable.

Diameter [mm]	Tolerance	
	For fabric-free diaphragms [mm]	With fabric and/or a metal part [mm]
... 6,3	± 0,15	± 0,25
above 6,3 ... 10	± 0,20	± 0,30
above 10 ... 16	± 0,20	± 0,40
above 16 ... 25	± 0,25	± 0,50
above 25 ... 40	± 0,35	± 0,60
above 40 ... 63	± 0,40	± 0,80
above 63 ... 100	± 0,50	± 1,00
above 100 ... 160	± 0,70	± 1,30
above 160	± 0,5%	± 0,8%

Tab. 3 Diameter tolerance for moulded diaphragms

The tolerances listed in the following, already restricted with regard to DIN ISO 3302-1, apply to the wall and bead thicknesses of moulded diaphragms.

Wall and bead thickness S [mm]	Tolerance [mm]
... 0,5	± 0,05
above 0,5 ... 3,0	± 0,10
above 3,0 ... 6,0	± 0,15
above 6,0 ... 10,0	± 0,20

Tab. 4 Thickness tolerances for moulded diaphragms

Closer manufacturing tolerances can be adhered to with stamped diaphragms made of rubberised fabric. Thus, DIN ISO 2768 m applies to the diameter tolerances of stamped flat diaphragms.

It should be noted that, with greater wall thicknesses, a concave cut surface can possibly occur through deformation of the material during the cutting process.

Diameter D [mm]	Tolerance range as per DIN 2768 m [mm]
above 3 ... 6	± 0,1
above 6 ... 30	± 0,2
above 30 ... 120	± 0,3
above 120 ... 400	± 0,5
above 400 ... 1000	± 0,8

Tab. 5 Diameter tolerances for diaphragms made of rubberised fabric

Tolerances that are closer than those previously stated can be agreed upon, if necessary, depending on the form and material of the desired diaphragms and after corresponding production trials. Such agreements, which typically involve increased production effort, should remain limited to unavoidable special cases, however (also refer to the notes in DIN ISO 3302 in this regard).

# Materials for Diaphragms

Depending on the usage, various materials can be applied. Thus, the material configuration of the elastomer to be used is contingent upon, for example, the physical, thermal and chemical load stresses. Additional fabric reinforcement is also foreseen for higher loads. Depending on the type of pressure applied – unilateral or bilateral – and the form of the diaphragm to be produced, it is designed with a fabric insert or layer.

## Elastomers

When selecting suitable elastomer properties, the following characteristics stand in the foreground:

- For secure sealing of the clamping areas, the material should have a low pressure release values in long-term tests.
- The material should be sufficiently firm enough for the respective load stress, elastic, flexible, resilient, chemically resistant, gas proof and abrasion resistant.
- No material fatigue may occur under dynamic loading.
- With regard to the manufacturing quality, good viscoelasticity, favourable vulcanisation aspects and high adhesiveness to potential metal or fabric inserts are demanded of the material.
- The material must be capable of the chemical load stress with being destroyed or swelling up impermissibly.
- At the maximum operating temperature, the material should not soften or harden (thermal ageing) or crack due to weathering (ozone ageing), and should remain sufficiently flexible at the minimum temperature.
- Low gas permeation values and good media resistance in combination with good flexibility when cold are necessary as material characteristics for accumulator diaphragms.

(For general material information → General Technical Data and Materials, page 897.)

Determining the upper operating temperature of elastomeric material: A decisive value for the application of an elastomeric material is its pressure release behaviour (→ Fig. 14). With regard to this, a reduction of the tension in a compressed state is presented as a function of time and temperature. The upper temperature operating range limit is identified by this.

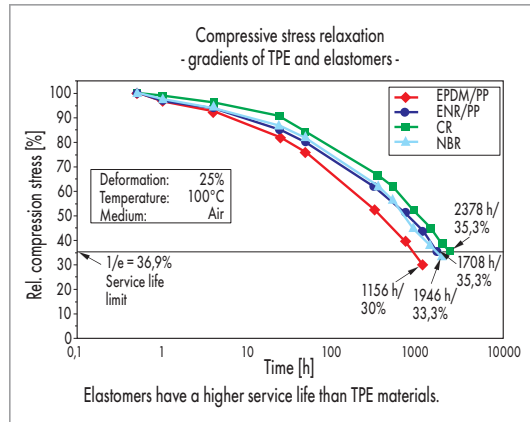


Fig. 14 Compressive stress relaxation

Under lower temperature operating conditions, crystallisation processes lead to a hardening of the materials. This causes a raising of the module (see the characteristic curve G, → Fig. 15). The material thereby transforms from an elastic state to a stiff, inelastic state. As  $T_{ij}$  value, the crystallisation transition point is stated here.

### AU – Polyurethane

Combines good physical values with high elasticity. AU is resistant against oils and greases and also against corrosion but is, however, only somewhat hydrolysis resistant. Thermal operation -25 °C to +80 °C.

### CR – Chloroprene rubber

Is very flexible at cold temperatures, ageing-resistant material for pressurised diaphragms without fabric.

### ECO – Epichlorhydrine rubber

Is used in pressure accumulator diaphragms for special demands with regard to gas proofness, resistance to oil and flexibility when cold.



**EPDM – Ethylene-propylene-diene rubber**

Is a common diaphragm material used with cold and warm water, hot water and steam up to 130/140 °C. KTW (potable water) certifications, WRC and FDA approval. Special qualities are available for use in the foodstuffs industry. EPDM is not resistant to oil.

**FFKM – Perfluoro rubber (Simriz)**

Through the use of special perfluorated (i.e. completely hydrogen-free) polymers and corresponding compounding and processing techniques, materials with rubber-elastic properties can be manufactured, which closely resemble PTFE in their media resistance and thermal resistance. This very expensive material is used anywhere where extreme safety standards apply and a high maintenance and repair effort justify the price for these diaphragms. Preferred areas are the chemical industry, the crude oil production and processing industry, equipment and power plant construction and in the aviation and aerospace technology. Thermal operating conditions from -15 °C to +230 °C.

**FKM – Fluoro elastomer rubber**

Is characterised by high thermal and chemical resistance as well as low values for gas emission and gas permeability at room temperature. FKM is the preferred material for diaphragms in vacuum technology as well as in usage with gases and fluids with a high aromatic level ("super fuels"). Special fluoro elastomers are necessary for use with water vapour (on enquiry).

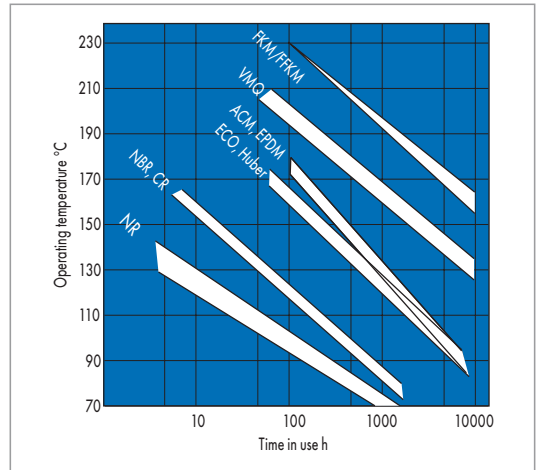


Fig. 16 Permissible temperature-time limit for some elastomers under the influence of warm air

**FVMQ – Fluoro silicone rubber**

Is used for special requirements with regard to fuel resistance under cold temperatures. Temperature range approx. -60 °C to +175 °C.

**HNBR – Hydrogenated acrylonitrile-butadiene rubber**

Has a higher resistance to heat and physical strength with less abrasion than NBR. The chemical resistance is in many cases identical to NBR.

It is better suited against mineral oils (e.g. pentosine CHF 11S, dexron III).

An application case would be, for example, an accumulator diaphragm for hydraulic oil. HNBR also has an even higher dynamic load resistance than NBR, this is used for applications as a pump diaphragm.

Operating conditions from 30 °C to +150 °C.

**IR – Butyl rubber**

Is used for especially gas proof pressure accumulator diaphragms. The preferred hydraulic medium is brake fluid (DOT 4).

**NBR – Acrylonitrile-butadiene rubber**

This is the standard material for all diaphragms pressurised with compressed air and mineral oils. Types with a higher acrylonitrile content are used if sealing against natural gas, propane and all oils based on mineral oil are desired. For better resistance against swelling and gas proofness, worse cold temperature characteristics must be accepted as a trade-off.

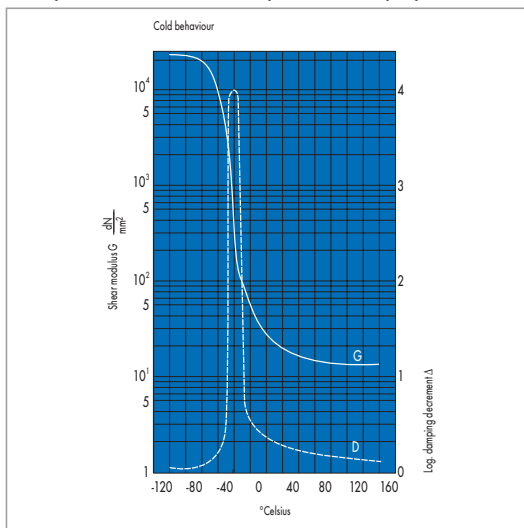


Fig. 15 Behaviour when cold



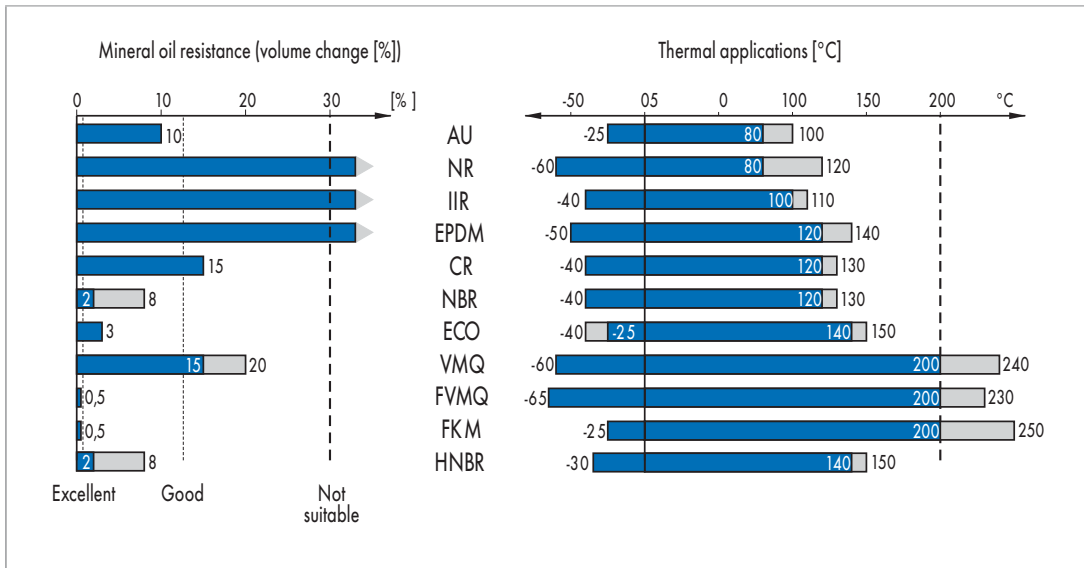


Fig. 17 Material characteristics

### NR – Natural rubber

Is characterised by high strength, elasticity and flexibility when cold. NR is not resistant to oil and must be protected by an additive when exposed to ozone effects.

### VMQ – Silicone rubber

Is used for high thermal load stresses of -40 °C to +200 °C. Certain compound mixes are physiologically neutral and can be sterilised with hot air, thus VMQ is suitable for the foodstuffs industry and life sciences.

### Diaphragm fabrics

In order to prevent the tearing of a pure rubber diaphragm in certain pressure ranges, strengthening elements are used for reinforcement (→ Diaphragms With Fabric Reinforcement). Two different types are used for applications in this regard:

Fabrics and knitted fabrics, which can lead to different characteristics of the end product simply due to their weave structure alone.

A distinction is still made between fabric layers and fabric inserts. The choice of the type of woven material and application depends on the application and the form of the diaphragms. Our product developers would be pleased to support you in designing the proper product concept for your diaphragms.

In principle, there are three different material groups available for diaphragm applications:

- Polyester
- Polyamide
- Aromatic polyamide.

### Aramid fabric

Aramid fabric (fabric made of aromatic polyamide – known by the trade name "Nomex Nylon" – only loses its strength slowly in hot water with increasing temperature. Nomex Nylon is therefore – in combination with EPDM rubber – the suitable material for fabric diaphragms in hot water areas.

### Polyester fabric

Polyester fabrics are already characterised by good strength values with thin fabric thicknesses. They can therefore be relatively broad woven. This benefits the deep drawing quality. Exposed to air and mineral oils, the strength only decreases slowly with increasing temperatures. In contrast, however, a complete material disintegration as a result of saponification must be expected in hot water above 100 °C.



### Polyamide fabric

Polyamide fabrics provide for a better – particularly if appropriately pre-treated – bonding of rubber and fabric than polyester fabrics. This is important particularly for diaphragms with high stress loads and special service life requirements. A progressive decline in strength must be anticipated with increasing operating temperatures. A certain disadvantage is presented by the relatively thick fabric thicknesses as well as the deep drawing quality, so that manufacturing-compatibility aspects can limit the applicability.

Code	Maximum tensile force at 20 °C [N/mm]	Fabric thickness [mm]	Deep drawing quality
<b>Polyester fabric</b>			
85	≥25,0	0,27	good
86	≥20,0	0,27	good
87	≥11,0	0,17	good
88	≥7,0	0,12	medium
<b>Polyamide fabric</b>			
22	≥22,0	0,36	limited
29	≥29,0	0,70	limited
31	≥110,0	0,60	limited
32	≥60,0	0,38	medium
57	≥33,0	0,32	good
143	≥56,0	0,40	limited
<b>Aramide fabric (Nomex)</b>			
34	≥27,0	0,40	limited
61	≥14,0	0,30	medium
72	≥9,0	0,30	good
<b>Polyester woven/knitted materials</b>			
2	≥12,0 <sup>1)</sup>	0,50	good
4	≥3,2 <sup>1)</sup>	0,40	good
<b>Aramide woven/knitted materials</b>			
1	≥2,8	0,40	good
11	≥4,9	0,60	good

Tab. 6 Materials for diaphragms

<sup>1)</sup> Values apply in the staff direction; not measurable in the machine direction due to the formation of snags

### Foils made of PTFE

A pure rubber diaphragm – with the exception of a diaphragm made of Simriz – has the disadvantage, as explained in (→ Diaphragms with supports made of PTFE), that they do not remain resistant against aggressive materials over a longer time period. As an aid, a protective foil can be used; most are made of PTFE.

Here we make use of various PTFE properties in order to give the composite diaphragm one of the specific characteristic requirements. A few special characteristics are to be noted:

- Electrically conductive foil
- Especially flex-fatigue resistant foil.

On enquiry, we use other foils in applications as well, providing that they endure the load stresses of the vulcanisation process.

### Insert parts

Insert parts are considered to be those of any type of material that is vulcanised into the diaphragm. The spectrum ranges from simple metals through to modern synthetics. These "inserts" handle various functions. For instance, they convey linear shaft force to the diaphragm or stiffen it at the desired location.

Adhesive agents are used in order that these parts adhere properly to the product. Our chemical engineering can offer the right solution to almost all conventional rubber-metal combinations.

## Symbols used

Designation	Code symbol	Unit
Rolling fold span	b	mm
Housing diameter	$D_g$	mm
Piston diameter	$D_k$	mm
Mean diameter	$D_m$	mm
Effective diameter	$D_w$	mm
Modulus of elasticity	E	N/mm <sup>2</sup>
Elongation	$\varepsilon$	-
Distension due to pressure differential	$\varepsilon_p$	-
Circumferential elongation due to uncoiling movement	$\varepsilon_u$	-
Linear shaft force, regulating power	F	N
Force in diaphragm wall as a result of pressure load	$F_p$	N
Mould release depth, upthrow	h	mm
Absolute stroke travel	$H_g$	mm
Stroke portion above the clamping	$H_o$	mm
Stroke portion below the clamping	$H_u$	mm
Max. stroke	$H_{max}$	mm
Max. stroke portion above the clamping	$H_{o max}$	mm
Max. stroke proportion below the clamping	$H_{u max}$	mm
Pressure differential	p	N/mm <sup>2</sup>
Radius of the curve of the rolling convolution	R	mm
Transitional radius in the clamping area	$\rho$	mm
Wall thickness in the flexed zone	s	mm
Elastomer hardness	SH	Shore A
Tension	$\sigma$	N/mm <sup>2</sup>
Tensile stress from pressure differential	$\sigma_p$	N/mm <sup>2</sup>
Force in diaphragm wall per circumference length	$\sigma'$	N/mm
Tensile strength of fabric	$\sigma'_B$	N/mm
Temperature	T	°C
Volumetric displacement	V	mm <sup>3</sup>
Effective area	$A_w$	mm <sup>2</sup>

Tab. 7 Overview table of the symbols



# Products

## Diaphragms

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# Diaphragms

In nearly all sectors of industry, in specific applications designers need to flexibly connect together components, to separate spaces between components and at the same time to create a leak-proof separation.

These tasks can almost always be addressed by using a diaphragm made from highly elastic materials. Very different requirements in relation to mechanical, thermal and chemical loads result in custom designs in the majority of cases. Our specialists with know-how from many years of experience are available to prepare these custom designs.

Along with custom diaphragm shapes, we also offer standard products that are presented in the following section.

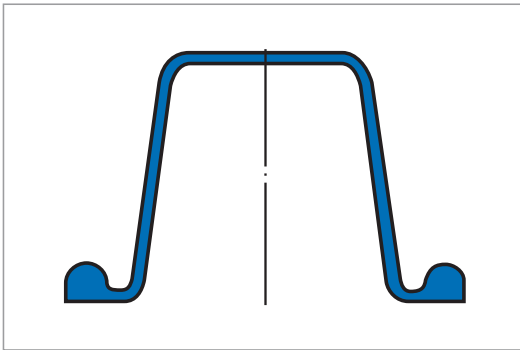
These are

- Long-stroke rolling diaphragms
- Rubberised fabrics (fabric rubberised on both sides)
- Sheet goods.

Rubberised fabrics and sheet goods are predominantly used for the economic manufacture of flat diaphragms or gaskets by punching.



# Long-Stroke Rolling Diaphragms BFA



Long-Stroke Rolling Diaphragms BFA

## Product description

Long-stroke rolling diaphragms are thin-walled, special sensitive diaphragms made from highly elastic materials with fabric reinforcement.

Along with this standard design type BFA, the long-stroke rolling diaphragms can also be supplied made in special tools without fabric, type BFAO.

## Product advantages

The small diaphragm thickness and large height of the diaphragm relative to the diameter provide the following advantages:

- Low, almost constant resistance to movement over the entire stroke
- Considerably greater stroke lengths in comparison to conventional diaphragms with the same diameter
- Effective area remains the same over entire stroke
- No additional resistance to movement on starting or on change in direction of movement; no notch point in operating range
- Low requirements on piston and cylinder in comparison to lip seals.

## Application

Long-stroke rolling diaphragms are used in hydraulically and pneumatically-activated control and regulation equipment, pressure switches and pressure transducers as well as measuring and display equipment. In the design without fabric, they are used at low pressures.

## Material

Standard material: 50 NBR 253 based on acrylonitrile-butadiene rubber (NBR) with or without polyester fabric.

Details on general structure of long-stroke rolling diaphragms and the properties of the elastomers.

Rolling diaphragms made from silicone rubber, fluoro rubber and EPDM with fabric are only produced to a height of  $H_{\max} = 0,6 D_g$  ( $D_g$  = cylinder diameter).

## Operating conditions

The standard range BFA made from nitrile rubber with fabric reinforcement for use in compressed air and mineral oils permits operating pressures up to 10 bar and test pressures up to 15 bar. Special qualities are available on enquiry for applications involving town gas and natural gas, petrol and brake fluids as well as for high thermal loads.

The type BFAO should only be used when the operating pressure does not exceed 1,5 bar. Low longitudinal elongation must be taken into account.

In operation, even with piston return, a low pressure difference of approx. 0,15 bar must be present for all designs, otherwise folds or kinks will form in the rolling convolution. This counter pressure can be achieved using a regulator valve. A ventilation hole must be provided to prevent a pressure build-up on the non-pressurised side.

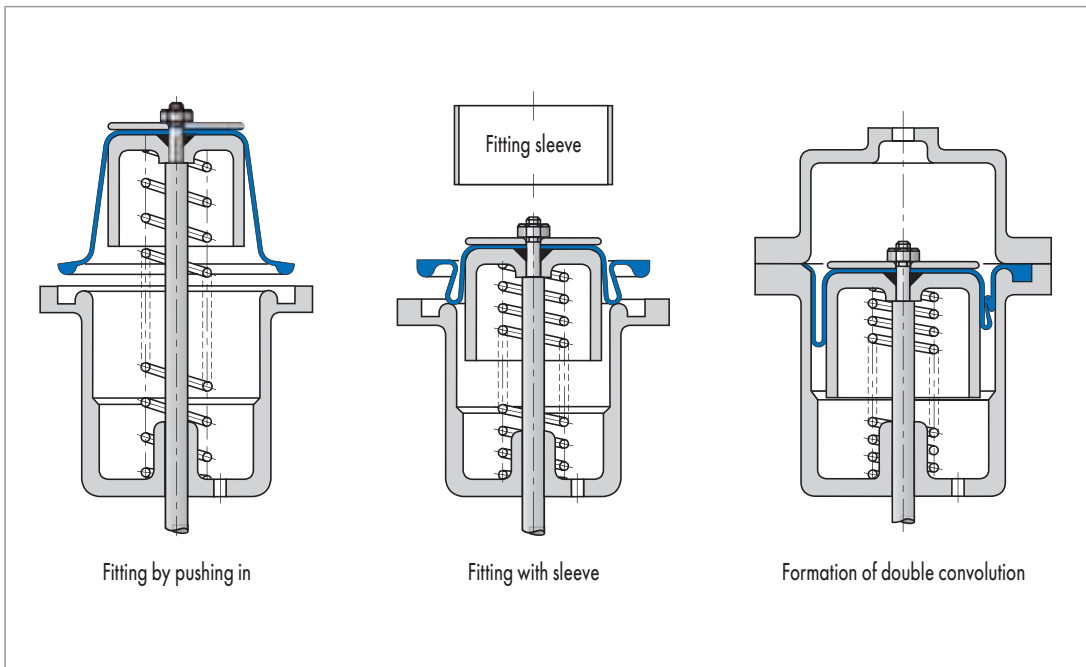
## Fitting & installation

Long-stroke rolling diaphragms with fabric layer, the fabric must be on the non-pressurised side. The diaphragm is inverted before fitting. Should the rolling convolution formed in this way arch upwards when performing this action, the use of a mounting sleeve is necessary.

Do not use a screwdriver!

Another possible fitting method: fit inverted rolling diaphragm to the piston, place bead in the groove

and push piston into the cylinder. In this way the rolling convolution is formed. The piston must be secured against twisting after fitting to avoid the formation of a skewed convolution. A plain washer is sufficient as the spring support. Stroke limiting is always to be provided. The rolling area for the diaphragm must be finely machined and polished. The transition radii on the clamping flange, piston base and cover plate are to be smooth and free from scoring.

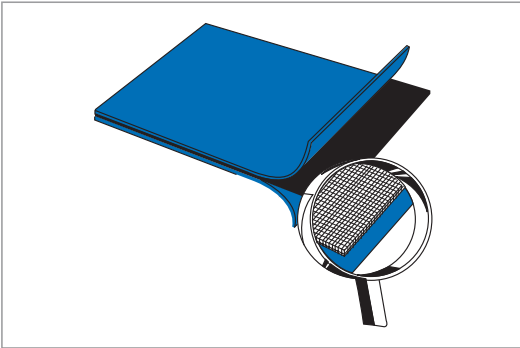


Cylinder-Ø	$D_g$	up to 60 mm	up to 100 mm	up to 150 mm	> 150 mm
<b>Installation dimensions</b>					
Piston Ø	$D_k$	$D_g - 5$	$D_g - 10$	$D_g - 10$	$D_g - 10$
Groove Ø	$D_n$	$D_g + 15$	$D_g + 21$	$D_g + 27,5$	$D_g + 27,5$
Piston radius	$R_k$	3,5	4,5	5,8	7,0
Cover radius	$R_c$	2,0	2,0	2,0	2,0
Groove depth	$H_g$	3,0	4,0	5,0	5,0
Groove width	$W_g$	4,0	5,5	7,2	7,2
Rim width	$W_i$	3,5	5,0	6,5	6,5
Rim height	$H_i$	2,3	3,1	3,5	3,5
Rim radius	$R_i$	1,75	2,5	3,25	3,25
<b>Diaphragm dimensions</b>					
Flange Ø	$D_f$	$D_g + 14$	$D_g + 20$	$D_g + 26$	$D_g + 26$
Wall thickness	$W$	0,45	0,55	0,8	1,0
Flange bead	$H_b$	3,6	5,0	6,3	6,3
Radius	$R_w$	1,75	2,50	3,25	3,25
<b>Minimum length of finely machined areas</b>					
on the piston	$L_k$	$0,5 (H+S_a)$	$0,5 (H+S_a)$	$0,5 (H+S_a)$	$0,5 (H+S_a)$
on the cylinder	$L_c$	$0,5 (H+S_b)$	$0,5 (H+S_b)$	$0,5 (H+S_b)$	$0,5 (H+S_b)$
<b>Diaphragm stroke</b>					
in one direction max.	$S_a$	H-8	H-14	H-20	H-20
in opposite direction max.	$S_b$	H-8	H-14	H-20	H-20
<b>Fastening plate</b>					
	A	$D_k + 2,9$	$D_k + 4,1$	$D_k + 5,6$	$D_k + 6$
	D	1,5	3,0	4,0	5,0





## Rubberised Fabric



Rubberised Fabric

### Product description

Rubberised fabrics are special, high-quality fabrics coated on both sides with suitable elastomer qualities. Special production processes make it possible for even thin layers of elastomer to be applied to the pre-treated fabrics with good adhesion and free of pores.

### Product advantages

Flat diaphragms can be punched from these rubberised fabrics without problems. The manufacture of moulded diaphragms is performed by embossing at raised temperatures, here certain restrictions in relation to the diaphragm height that can be attained must be taken into account depending on the fabric quality and material thickness.

### Application

Diaphragms made from rubberised fabric have the task of forming a leak-proof yet flexible separation. Rubberised fabrics are designed to suit the mechanical, thermal and chemical loads for the related application.

Main areas of use:

- Measuring, regulating or control diaphragms
- Pump diaphragms
- Separating diaphragms
- Flat diaphragms.

### Material

Acrylonitrile-butadiene rubber (NBR), chloro-butadiene rubber (CR), ethylene-propylene-terpolymer rubber (EPDM), epichlorohydrin rubber (ECO) and fluoro elastomer (FKM) are preferably used as elastomers. Polyester (PES), polyamide (PA) and spun rayon (ZW) are used for reinforcement. The coating comprises one of the stated elastomers depending on the application.

### Operating conditions

The media resistance is dependent on the coating material and the fabric. This can be found in the table of stock articles. The maximum tensile force defines the pressure resistance of the rubberised fabric.

### Fitting & installation

A prerequisite for clean sealing in the clamping area is adequate compression (10% of sheet thickness) as well as a score-free surface on the metal or plastic parts.



## Rubberised fabric designs

Code	Elastomer	Fabric	Nominal width [mm]	Max. tensile force [N/mm]	Thickness [mm]	Tolerance	Colour	Operating temperature min/max [°C]	Media	
MT 471/ 505412	NBR	PA	1,40	11	0,30	±0,03	Blue	-25 ... +90	Fuels, heating and fuel gases, mineral oils, greases, inorganic acids and bases, flame resistant hydraulic fluids (HFA, B, C), oil-bearing compressed air, water to 80 °C	●
MT 479/ 505414	NBR	PA	1,40	11	0,17	±0,03	Blue	-25 ... +90		●
MT 481/ 505415	NBR	PES	1,50	50	0,90	±0,07	Blue	-25 ... +90		●
MT 486/ 505416	NBR	ZW	1,50	15	0,38	±0,05	Red	-20 ... +90		●
MT 496/ 147030	NBR	PA	1,50	50	1,10	±0,15	Red	-30 ... +90		●
MT 488/ 49042567	NBR	PA	1,50	50	1,10	±0,15	Red/ Green <sup>c)</sup>	-20 ... +90	Diesel fuels, mineral oils, oil-bearing compressed air, heating oils, water up to 80 °C	●
MT 489/ 49042568	NBR	PA	1,50	40	0,68	±0,07	Red/ Green <sup>c)</sup>	-20 ... +90		●
MT 490/ 505417	NBR	PA	1,50	24	0,40	±0,05	Green	-20 ... +90		●
MT 475/ 505413	CR	PES	1,50	25	0,45	±0,05	Black	-30 ... +90	Oil-bearing air, water (ozone and UV resistant)	●
MT 510/ 49046470	CR	PA	1,50	50	1,10	±0,15	Black	-30 ... +90		●
MT 511	EPDM	PA	1,50	24	0,55	±0,06	Black	-45 ... +120	Hot water, steam, glycol based brake fluid	●
MT 491	ECO	PA	1,40	11	0,32	±0,05	Black	-35 ... +130	Fuels, oils, greases, air (max. 130 °C)	●
MT 504	ECO	PA	1,50	30	1,00	±0,10	Black	-35 ... +130		●
MT 503	FKM	PA	1,4	24	0,30	±0,03	Black	-10 ... +130	Fuels, heating and fuel gases, hydro-carbons, phenols, solvents, acids, bases	●

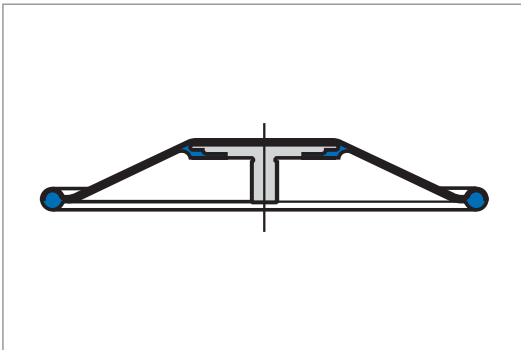
● Available from stock

<sup>a)</sup> PA = olyamide; PES = polyester; ZW = spun rayon

<sup>b)</sup> Recommended values as supplied – check for the related application necessary

<sup>c)</sup> Red = fuel inside; Green = oil side

# Diaphragms for Pumps and Compressors



Diaphragms for Pumps and Compressors

## Product description

In modern pumps both pure elastomer diaphragms and elastomer combinations are utilised, namely:

- Fabric for reinforcement
- PTFE layer against chemical attack
- Metal or plastic support components for force or path transmission.

## Product advantages

Diaphragms for pump applications feature:

- High media resistance through PTFE film layer
- Long-term stability through fabric reinforcement
- Simplified fitting through integrated insert
- Product-specific material customising for achieving the optimal service life.

## Application

Diaphragms are used in the most varied applications in diaphragm pumps and compressors for "metering" or "conveying" fluids or gaseous media: e.g. dosing or feed pumps in laboratory technology or large feed pumps that convey mud or other fluids and gases.

## Material

Elastomer	NBR, HNBR, CR, EPDM, FKM
Fabrics	PES, PA, NOMEX
Layer	PTFE and TFM
Insert	Metal (brass, steel) and plastic

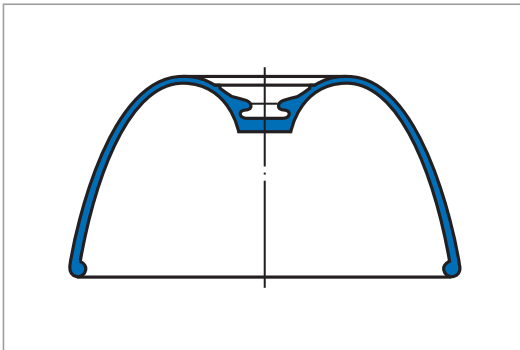
## Operating conditions

The media resistance is dependent on the elastomer or the PTFE film layer which has proven itself as a shield against aggressive media on the side in contact with the media.

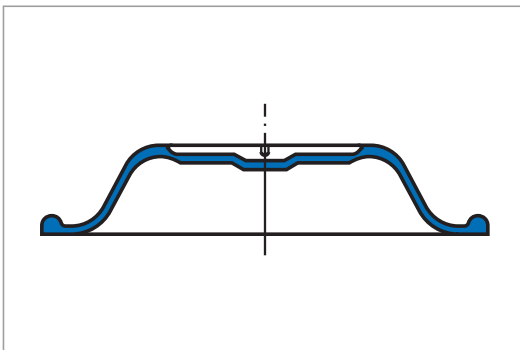
Diaphragms for ATEX-compliant units can be manufactured with layers made from electrically conductive material.



# Diaphragms for Accumulators and Bladders



Accumulator Diaphragms



Accumulator Bladders



## Product description

Diaphragms in accumulators consist of cold-flexible, especially gas-proof elastomers with low permeation rates. As a flexible partition in the gas chamber of the accumulator, they have the job of sealing the hydraulic fluid of the pressure circuit.

For example:

- Accumulator diaphragms
- Accumulator bladders.

## Product advantages

Diaphragms and bladders for accumulators feature:

- Highly gas-proof elastomers
- Specially-developed elastomer mixtures fulfil the highest requirements for general industry
- Product design to customer-specific requirements.

## Application

Accumulators in hydraulic circuits e.g.:

- General industry (high pressure cleaners, injection moulding machines)
- Medical technology (computer tomographs, X-ray machines)
- Aerospace industry.

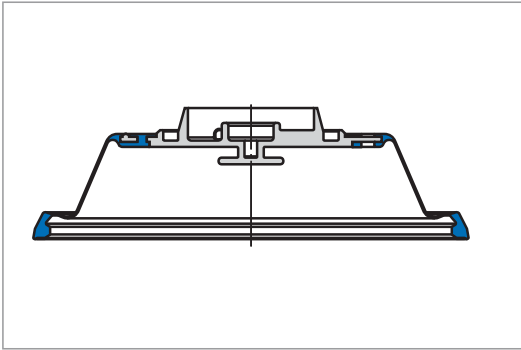
## Material

<b>Elastomer</b>	NBR, HNBR, ECO, EPDM, FKM, CIIR
<b>Insert</b>	Metal or plastics

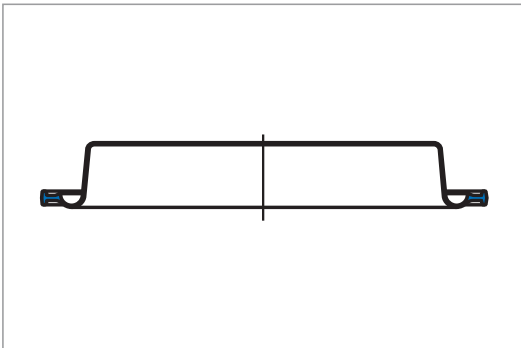
## Operating conditions

<b>Media</b>	All known hydraulic fluids and gases (nitrogen)
<b>Temperature</b>	-40 ... +150 °C
<b>Pressure</b>	up to 200 bar (pressure-balanced)

# Diaphragms for Industrial Valves



Thin-walled, sensitive diaphragms



Adjustment and control diaphragms

## Product description

Diaphragms for industrial valves are available in the most varied forms, materials and designs:

- As high quality moulded diaphragms (in dished diaphragms, convoluted diaphragms or as flat diaphragms) with and without fabric reinforcement and/or vulcanised valve disks
- Diaphragms from only a few millimetres in diameter in microvalves, to up to 1 m large moulded diaphragms in plants and pipeline construction
- Diaphragms made of rubberised fabric present an alternative to pressed moulded diaphragms.

## Product advantages

- Approved materials for use with foodstuffs and drinking water e.g. DVGW, FDA, KTW, WRAS etc.
- Product-specific material customisation to achieve an optimal function and service life.
- An assortment of elastomers and fabrics are available for the most diverse requirements with regards to pressure, temperature and medium with which practically all requirements can be fulfilled.

## Application

- Adjustment and control valves in plants and pipeline construction
- Metering systems in the foodstuffs industry e.g. drink bottling plant
- Diaphragms for shut-off valves
- Thin-walled, sensitive diaphragms for adjustment and control valves, e.g. for respirators and airpicks
- Gas pressure regulators
- Pressure-controlled diaphragm controllers or pressure reducing regulators
- Diaphragms for pressure switches for water level regulation in washing machines, dishwashers, coffee machines and water heaters as well as in pneumatic applications.



## Material

Elastomer	NBR, HNBR, EPDM, CR, ECO, AU, VMQ, FKM, FFKM, special silicon-based materials and TPU
Fabric reinforcement	PA, PES, Aramid (Nomex)
Coating	PTFE and TFM layer or Simriz®
Insert	Metal or plastic

## Operating conditions

Media	Media resistance is dependent of the particular application e.g. milk products, hydraulic oils, water, mud, chemicals etc.
Temperature	-100 ... +220 °C
Pressure	depends on the application

