FABRIC COMPENSATORS

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FABRIC COMPENSATORS

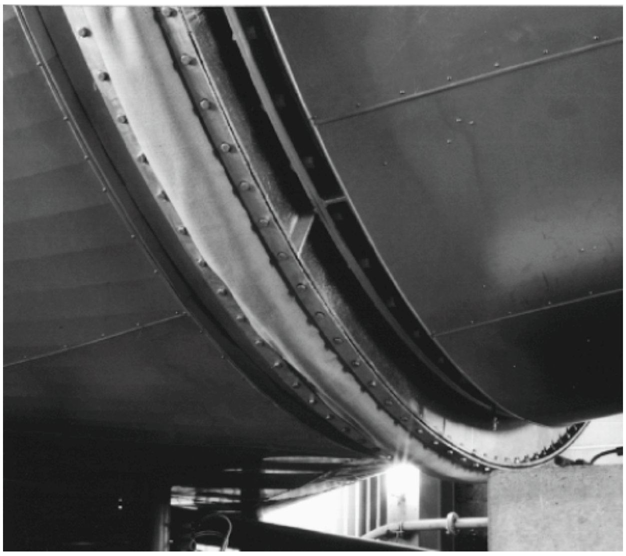
1.0 General Information

Several decades ago, when Kempchen first began producing soft-material compensators, metal compensators were still predominantly being used in the field of power plants and chemicals.

Today, KLINGER Kempchen soft-material compensators have found a solid range of applications. Without these versatile assembly parts, modern industrial plants would not be possible. Without the use of soft-material compensators, the costs of such plants would be considerably greater.

The main advantage of soft-material compensators is their multidimensional absorption of movement despite having very low reaction force. Their superior movement absorption allows for cost-effective piping, while their low reaction force perwiths cost-effective fix point construction.

KLINGER Kempchen has developed a patented method for sintering PTFE sheets onto all types of fabrics. This has brought significant improvements to the properties of soft-material compensators.



KKLINGER Kempchen compensators in flue gas distributing main

1.1 Range of application

Soft-material compensators have been proven to withstand:

» in pipes and ducts for gaseous media such as air, flue gas, exhaust gas

» temperatures of up to 700 °C and higher

» pressures of up to 500 mbar

» major axial movement and - often concurrently - lateral or angular loads

» all industry sectors such as thermal power plants, gas turbine plants, the chemicals industry, flue gas desulphurisation plants, chimney and flue construction, ship construction, stationary diesel generator sets, waste incineration plants, flue gas treatment plants, dedusting plants, metallurgical industry.

Only materials that pass our quality inspection are used for the production of soft-material compensators and other assembly parts. The requirements profiles for our material properties are based on decades of experience, and serve as the criteria for purchase and incoming goods inspection.

Quality brand for
fabric compensators

KLINGER Kempchen makes the distinction between the groups of components used in the assembly of soft-material compensators and/or the necessary steel constructions:

Soft-materials compensators:

Insulation layers, insulation packs,
sealing foils, sealing layers
supporting layers,
protective layers, reinforced edges

Compensator protection components:

Internal pass tube,
pre-insulation,
external protective grating or equiv,
outlet nozzle,
sash frame

Compensator connection:

Bolted counterflanges,
clamping flanges, band clamps

2.0 Materials

2.1 Kempchen soft-material compensators and their construction

Soft-material compensators are generally made up of several layers. In most cases, these layers are not glued or sewn together. In the clamping area, however, the individual layers of the soft-material compensator are always connected for transport reasons.

As is explained in greater detail in Section 6.0 'The sealing of soft-material compensators and impermeability testing", superstructures with multiple layers, such as those necessary for controlling high temperatures, are more difficult to assess with respect to impermeability than are soft-material compensators consisting of just one or two layers.

If impermeability is a particularly important concern, it can be achieved by using special heat-dispelling constructions of one- or two-layer Kempchen soft-material compensators.

2.1.1 Insulation layers, insulation packs

Insulation layers are necessary if the temperature of the media is higher than the maximum allowable sustained temperature of the sealing layers. The different types of insulation layers vary widely in their mechanical stability and their resistance to temperature and chemicals. They are therefore selected based on conditions in which they will be used.

Insulating felts are used as insulation packs. Due to their low resistance, these are wrapped in stabler, more heat-resistant fabrics or bound in high-grade steel wire mesh. In the case of larger movements, at least two such insulation packs are located so as to be moveable in front of the sealing layer.

2.1.2. Sealing foils, sealing layers

Depending on the temperature range, various types of synthetic rubber, metal foils, and plastics are used either on their own or as a fabric coating

The sealing layer is of major importance, as soft-material compensators are always part of leak-proof piping or duct systems. Three aspects are of particular significance:

2.1.2.1

The pressure differential acting at the sealing layers, causing strain. For this reason, supporting layers are placed in the direction of the decrease in pressure behind the sealing layers for support: they are located outside for internal pressure and inside in front of the sealing layers for low pressure.

2.1.2.2

Since condensation may collect in front of the sealing layers, the resistance of the insulation and any insulating fabric layers must be taken into consideration.

2.1.2.3

It is important to note that rubber and plastic foils and laminated fabrics are not entirely gas-tight. Only metal foils may be used as a gas barrier. One disadvantage of metal foils is their relatively high sensitivity, e.g. to flue gas condensation; another is their low expandability.

2.1.1.1 Temperature and media resistance

Conditions for use	Sustained temperature resistance		Short-term peak temperature		Acid-proof	Base-proof	Solvent-proof
Fabric and mats	°C	°F	°C	°F			
Aramid	**180**	356	**250**	482	0	0	+
Glass fibre weave	**400**	752	**450**	842	+	0	+
Glas felt mats	**500**	932	**650**	1202	+	0	+
Rock wool mats	**700**	1292	**750**	1382	0	0	+
Silicate felt mats	**1200**	2192	**1350**	2462	+	0	+
Silicate fibre weave	**1200**	2192	**1350**	2462	+	0	+

+ = yes | 0 = conditional | - = no

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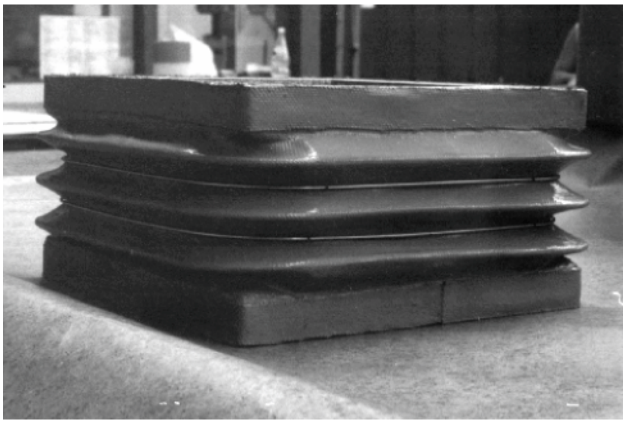

Rectangular pleat compensator

2.1.2.4 Temperature and media resistance

The table shows the resistance to sustained and temporary temperatures of various foils and coated fabrics used in soft-material compensators. Resistance to acids, bases and solvents can only be given in this catalogue in terms of tendencies.

In the event of a thermal load greater than the sustained temperature resistance indicated in Table 2.1.2.4., both constructive and insulation-related measures must be taken (see 2.2.).

2.1.2.5

The sealing layers in the compensator's clamping area must be tightly screwed to the clamping flanges. To achieve this, we recommend that a surface pressure of 5 N/mm² always be present between the fabric and steel flange.

This can be easily attained at temperatures up to and including the sustained temperature resistance of the sealing layers.

However, if the flange temperature is higher than the sustained temperature resistance in the sealing layer area, the porosity of the insulation layers will make sealed closure more difficult.

There are three ways to solve this problem:

a) Impregnate the insulation layers in the flange area with the appropriate impregnation agents to create internal impermeability. The resulting slight reduction in the insulation effect is compensated by the corresponding thickness. At higher temperatures, a certain acceptable amount of permeability is inevitable both after assembly and after a long period of operation.

2.1.2.4 Temperature and media resistance

		for FGD, FGC, WI plants*	Sustained temperature resistance		Short-term peak temperature		Acid-proof	Base-proof	Solvent-proof
Foils			**°C**	°F	**°C**	°F			
PTFE			**260**	500	**280**	536	+	+	+
Aluminium			**500**	932	**550**	1022	-	-	+
High-gradesteel				**600**	1112	**850**	1562	+	++
Coating Fabric									
PVC	Polyester		**60**	140	**65**	149	+	+	-
EPDM	Fibre glass	*	**100**	212	**120**	248	+	+	0
Silicon	Fibre glass		**220**	428	**230**	446	-	-	0
FKM	Fibre glass	*	**205**	401	**250**	482	+	+	0
PTFE[1)]	Fibre glass	*	**260**	500	**290**	554	+	+	+
Single-later composite material									
EPDM	with 1.45393[3)]	*	**100**	212	**130**	266	+	+	-
FKM	with 1.45393[3)]	*	**180**	401	**>250**[2)]	>572[2)]	+	+	0

1) sintered

2) temporary peak temperature; please contact KLINGER-Kempchen concerning insulation

3) also available with fibre glass

® registered trademark, DuPont

\+ = yes | 0 = conditional | - = no

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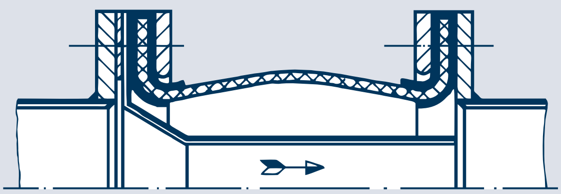
b) Another option is to fold in the outer protective layer and seal it at the flange; or wrap an additional fabric casing, for instance one which is coated with silicon rubber, all the way around the compensator flange as shown in Figure 2.1.2.5.1. This measure yields a suitably air-tight construction. After a long period of operation, however, greater permeability results with this measure than with solution a) above.

c) Another solution is construction according to 3.4.6.

2.1.2.5.1



2.1.2.6 Pulsation

High-frequency pulsating pressures such as exist in exhaust systems must be viewed extremely critically. Gaps in the compensator area must be kept as small as possible, and there must be sufficient amounts of firmly stuffed pre-insulation so as to prevent the fabric from fluttering.

2.1.2.7 Vibration

Vibrations are harmful to glass weave and quartz fabric (and to all other fabric as well). For this reason, compensators for shaking trough, for instance, should use sealing layers made of rubber foils or plastic foils, preferably without fabric if possible, or with polyester, nomex or Kevlar fabrics, which are more resilient.

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2.1.3 Supporting layers

Chacteristic properties of supporting layers are their lesser expandability and greater stability in comparison to the sealing layers. The following reductions can be made if several supporting layers of equal expandability are arranged consecutively:

2 layers at k = 0.8

3 layers at k = 0.7

4 layers at k = 0.6

As a rule, the operating temperature must be below the sustained temperature resistance. If temporary peaks in temperature may be anticipated, please confer with our engineering consultants about the duration of these peaks and their potential reduction of stability and temperature resistance.

The supporting layers are always arranged behind the sealing layers in the direction of the decreasing pressure. The choice of the appropriate supporting layer in terms of temperature resistance and stability greatly depends on the proper pre-insulation, the reduction in pressure and the allowable sustained temperature resistance of the sealing foils.

Variations in expandability of the supporting layers are to be avoided, as the expandability of the least expandable layer will count.

KLINGER Kempchen uses the following supporting layers for the various temperature and operating conditions:

Supporting layer, e.g.	Sustained temperature resistance °C	°F	Short-term peak temperature °C	°F
Polyester fabric	**150**	302	**160**	320
Aramid fabric	**180**	356	**250**	482
Fibre glass	**400**	752	**450**	842
High-grade steel wire mesh	**600**	1112	**850**	1562
Silicate fabric	**1200**	2192	**1350**	2462

2.1.4 Protective layers, reinforced edge

2.1.4.1 Protective layers

The outer layer of the soft-material compensator serves to protect against environmental impact factors such as sun, rain, dust, industrial climate, sandstorms, etc. In order to provide adequate protection, the outer layer must also be mechanically resistant.

Protective layers made of fabrics laminated with materials such as neoprene/hypalon, viton, silicon, and PTFE have proven to be satisfactory in this regard.

It is important that heat-resistant protective layers made from glass weave sintered with PTFE foil allow surface temperatures up to 260 °C. The sealing layer, which might for instance also be made of PTFE, can then reach temperatures greater than the dewpoint and the formation of condensation can be reduced or prevented.

2.1.4.2 Internal flange sealing

Proper training in flange sealing is of major significance for the total concept of soft-material compensators.

Flange sealing on the heated inner surface serves the following purposes:

a) secures the insulation required of the other layers, particularly the sealing layer, and

b) ensures the functioning of the sealing in the flange area

This gives rise to somewhat of a conflict of interests; on the one hand, the flange sealing should be porous in order to retain heat in the flange; on the other hand, however, the sealing should be impermeable. KLINGER Kempchen uses the following materials for flange sealing depending on the temperature range and permeability requirement:

Materials for edge reinforcement	Sustained temp. resistance approx. °C	approx. °F
Fabric strips from Aramid thread	180	350
Fluorelastomer	200	400
PTFE strips	260	500
Fibre glass strips, non-impregnated	450	850
Fibre glass strips, impregnated	450	850
Quarz fabric strips, non-impregnated	1000	1800
Quarz fabric strips, impregnated	1000	1800

As an additional means of sealing the flange area, KLINGER Kempchen has developed a sintered PTFE flange barrier (DBP).

2.1.4.3 Reinforced outer edqe

The same materials are used here as described above. It is important that the outer edge reinforcement of bellied form

compensators be wide enough to prevent contact between outer protective layer and the counterflange, which is often at a high temperature, and the screw.

2.1.5 Materials for FGD* plants

Depending on the intended use, we recommend our ReaFlex and ReaTex compensators for FGD plants, see page 213.

* flue gas desulphurisation (German: REA)

2.2 Compensator protection components

2.2.1 Internal pass tube

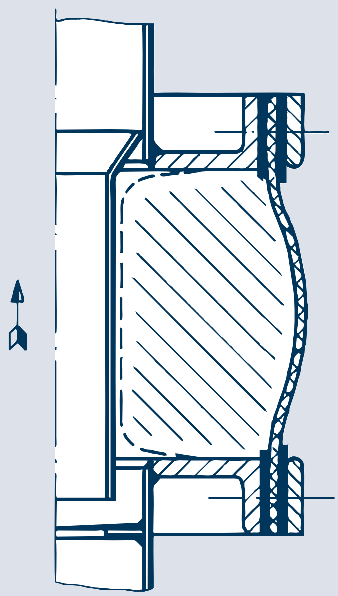
Pass tubes should always be used to protect fabric compensators.

Pass tubes prevent abrasion in dust-laden gas flows, protecting the fabric compensator from becoming damaged.

In clean gas flows, the use of a pass tube reduces the loss of pressure by allowing for more favourable operation in terms of flow technology. The temperature at the compensator is also reduced by using a pass tube. The space between the pass tube and the compensator can be used for insulation when filled with a heat-absorbing material, see 2.2.3.

In horizontal ducts, the pass tube should always be placed in the direction of the flow. In vertical or inclined ducts, it may be beneficial to arrange the pass tube against the direction of the flow in order to prevent the area between the compensator and the pass tube from filling with dust or condensation, etc. When the pass tube is placed against the direction for the flow, a pass tube plate should be placed at a short distance from the open end of the pass tube, see below. 2.2.1.3.1

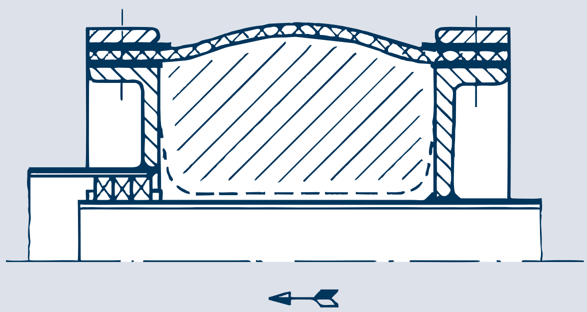
2.2.1.3.1



2.2.2 Protective devices and constructive measures for high dust incidence

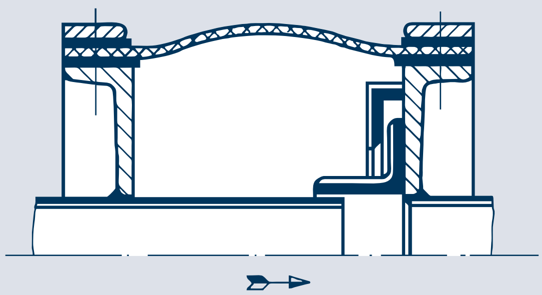
KLINGER Kempchen recommends the use of pass tubes as a general rule. However, in some cases it may be advantageous to refrain from using a pass tube. One such situation is a high incidence of dust that may accumulate as a result of humidity and/or temperature. Given the movement to be executed by the compensator in an axial or lateral direction, the compensator would be destroyed by the presence of a pass tube and the accumulation of dust. It is better to omit the inclusion of a pass tube so that the accumulated dust or mud formed can be released by the movement of the compensator unit itself. For dry dust, for instance that which can be found in cement factories, metallurgical plants or lime industry, a packing box with coarse packing cord is used for predominantly axial movement, as in Figure 2.2.2.2.1.

2.2.2.2.1



A design with a sash frame as shown in Fig. 2.2.2.3.1 has proven suitable for the absorption of both axial and lateral movements. The sash frame should sit with as little slackness as possible between the ducting flange and the pass tube so that the it can be moved both in the axial and lateral movement direction

2.2.2.3.1



Although sealing using sash frames does not yield a dust-tight seal, it will serve as a major barrier to the rapid penetration of dust into the space between the pass tube and the compensator.

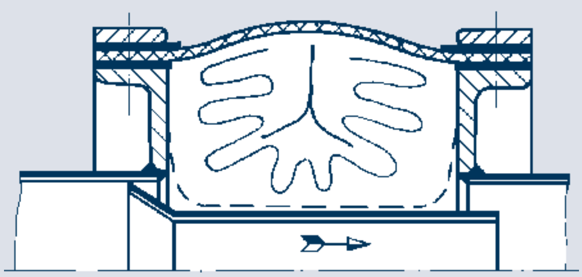
It may occasionally be necessary to remove part of the compensator to remove any dust that has penetrated.

2.2.3 Pre-insulation

High temperatures may necessitate that the space between the compensator and pass tube be used for housing pre-insulation, provided that there is sufficient room. In the event of high movement absorption, mineral fibre mats or quartz fabric mats may be wrapped in high-grade steel wire fabric for pre-insulation. Several such pre-insulation packs can be relocatably positioned so as to inhibit radiation exchange and partially prevent convective heat transfer.

A U-shaped folded insulation mat suffices for lesser movement absorption.

2.2.3.1



Proper design of the pre-insulation (including the parallel case design, see 3.4.6) is particularly essential in high temperatures. Another advantage of the aforementioned parallel case design is that the actual gap between the end of the ducts is only slightly larger than is necessitated by axial movement. In the operating state, this gap is closed save for a small safety distance. The pre-insulation housed in the space resulting from the staggered compensator connector flanges can be properly led and can absorb relatively large movements. Gas flows that are highly dust-laden require pre-insulation less for thermotechnical reasons than for preventing or at least reducing the penetration of dust by padding the space between the compensator and the pass tube. In the event of a very high incidence of dust, a proper pre-compensator may be necessary.

2.2.4 Outer protective grating, outer insulation

The customer may wish to use a protective grating or plate to protect the soft-material compensator against mechanical damages from falling parts - especially during installation - or from rain, snow- or sandstorms or other detrimental effects. When adding such protective mechanisms, a measure which is often taken retroactively, the potential effects on the insulation must be taken into consideration alongside the intended protective effects. Protective shields made from aluminium, for example, may alter the radiation exchange between the compensator's surface and the environment, an effect which must be taken into account. Even if spacers are used to ensure adequate convection, a non-allowableheating of the compensator's surface may occur.

The same applies to protective grating or rain hoods, particularly if they are affixed too tightly, thus preventing the necessary corrective cooling of the compensator's surfaces.

Soft-material compensators may only be insulated from the outside if the media temperature roughly corresponds to the hightest allowable temperature of the sealing layers. For compensators equipped with sealing layers made from silicon rubber or silicon-coated fabric, this means a temperature limit of 150 °C or 200 °C (see 2.1.2.4). For those equipped with sealing layers made from PTFE or glass weave, for instance, the temperature limit is 260 °C (see 2.1.2.4).

In the event of media temperatures in excess of these limits, the soft-material compensators may not be insulated from the outside, coated with paint, etc.

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2.2.5 Protective devices and constructive measures for high condensation incidence, for FGD plants

At flue gas desulphurisation plants - and at other types of plants in all sectors of industry - condensation may occur in sufficiently large amounts as to require special measures. In horizontal ducting systems, the fluid may collect inside the compensator on the lower side of the duct and be released in the flange area. In order to prevent this undesirable occurrence, KLINGER Kempchen has developed special outlet nozzles made of PTFE as shown in Figure 2.2.5.1.1.

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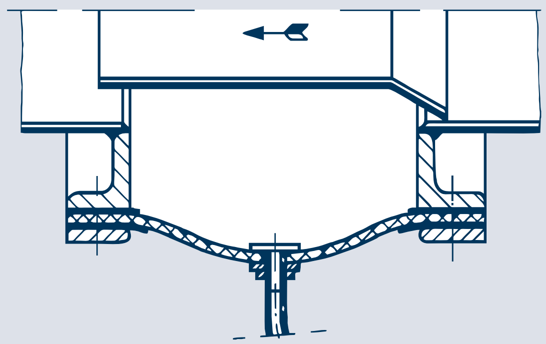
Using plastic piping strainlessly affixed at all direction levels, the fluid can be led away without any problem.

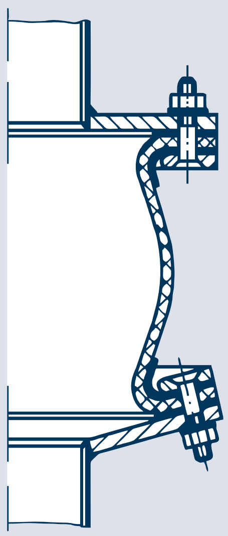
In the event of low pressure, please confer with us regarding the appropriate constructive measures.

2.2.5.1.1



In order to avoid fluid accumulation in vertical ducts, KLINGER Kempchen recommends setting the lower duct reinforcement, which generally also serves as a compensator flange, at an incline, as shown in Figure 2.2.5.2.1. The fluid can thus be led away from the clamping area.

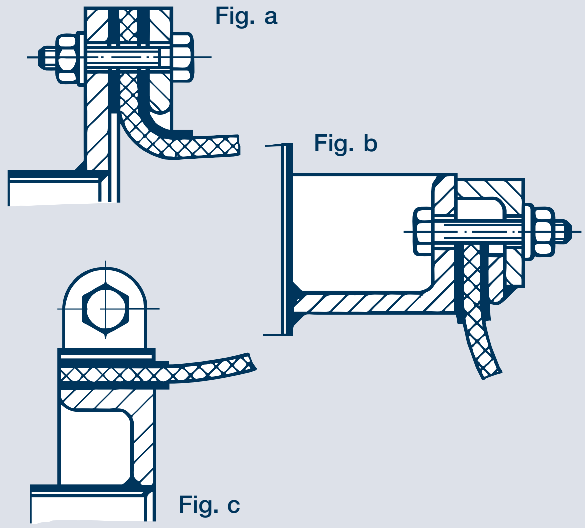
2.2.5.2.1



2.3 Compensator connection design

Fastening of the compensator can be achieved in the following ways:

1) using a through bolt and a screwed counterflange, Fig. a
2) without a through bolt, using a strap clamp, Fig. b
3) with band clamps, Fig. c

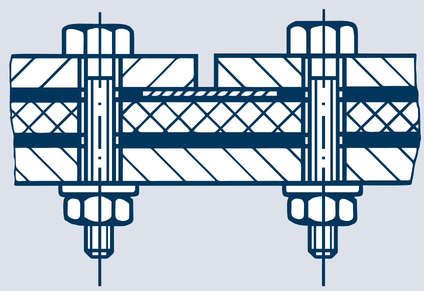


2.3.1 Screwed counterflanges

Through bolts are typically used for screwed flanges. The duct flange and compensator flange are equipped with through bolt holes for this purpose. In the event of greater pressure and installation lengths, which may be necessitated by greater movement absorption, screwed flanges are advantageous. One disadvantage of screwed flanges is the possibility that they may complicate the sealing process in the flange area. Further details on this topic can be found in Chapter 6.0.

As shown in Fig. 2.3.1.2.1, a partitioned execution is often chosen for counterflange frames. The gaps are bridged by placing thin sheets (0.5 mm thick) underneath. Particularly for smaller dimensions, however, non-partitioned frames are also common.

2.3.1.2.1



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It is important to note that the radii will decrease by approx. 25 % due to the compressability of the soft-material compensator flange, when the screws are tightened into place. Given a thickness of 16 mm for the soft-material compensator flange, and a compressability of 25 %, the circumference of a quarter circle changes corresponding to the change in radius of

$$\Delta U = \Delta r \cdot \frac{\pi}{2} = 6{,}28mm$$

In terms of the flanging radii, long slots in the steel clamping flange are therefore necessary for band compensators due to the change in thickness. The constructing engineer must take this into account when constructing the flanges. Therefore it is necessary to determine the design of the soft-material compensator, and with it, the compressibility of the soft-material compensator flanges. If the cross-section of the pipes is round, sufficient slackness for the screw can be achieved in the screw hole by partitioning the entire flange into a sufficient number of sections.

The thickness of the screwed counterflange is calculated according to the following table, which assumes a required surface pressure of 5 N/mm². The second criterion is the allowable deflexion of the counterflange, which is assumed to be a through beam with a distributed load. For flanges or counterflanges with an angle profile instead of the basic square profile, a narrower flange thickness may be chosen that corresponds to the greater moment of inertia.

Information on the required torque and determination of thickness for the counterflanges

1) Compensator and edge reinforcement made from elastomers (FKM, EPDM)
2) Fabric compensator with edge reinforcement made from FKM, EPDM
3) Fabric compensator with edge reinforcement made from fabric

Sometimes prescribed in construction, sometimes may be chosen. Please avoid dimensions in brackets!		This torque is necessary to produce adjacent bolt force.		The chosen bolt creates the required sealing pressure in the range from l [mm]· b [mm]	The distance between the bolts may not be too large for two reasons: 1.) So that the surface pressure of 5 N/mm² for fabrics and 2 N/mm² for rubber can be attained	2.) So that the deflexion and thereby the reduction in surface pressure are not too large.	Typical measurements that have tested and proven suitable may serve as indicators.		
Bolt quality 5,6	Design	Torque [Nm]* from	to	Bolt force [kN]**	Bolt distance l [mm]	Bolt distance l [mm]	Flange width b [mm]	Bolt distance l [mm]	Flange thickness h [mm]
M 10	1	7	9	4,8	$l \leq \frac{2370}{b}$	$l \leq 3{,}7 \cdot h \cdot \sqrt[3]{b}$	30	80	8
	2	11	13	7,2					
	3	18	21	12,0					
M 12	1	12	14	7,2	$l \leq \frac{3460}{b}$	$l \leq 3{,}3 \cdot h \cdot \sqrt[3]{b}$	40	90	10
	2	18	21	10,8					
	3	30	35	17,6					
(M 14)	1	19	22	9,6	$l \leq \frac{4760}{b}$	$l \leq 3{,}0 \cdot h \cdot \sqrt[3]{b}$	40	120	12
	2	29	34	14,4					
	3	48	56	24,0					
M 16	1	29	34	13,0	$l \leq \frac{6540}{b}$	$l \leq 2{,}7 \cdot h \cdot \sqrt[3]{b}$	50	130	15
	2	44	51	19,5					
	3	73	85	32,5					
(M 18)	1	40	48	16,0	$l \leq \frac{7940}{b}$	$l \leq 2{,}5 \cdot h \cdot \sqrt[3]{b}$	50	160	18
	2	60	72	24,0					
	3	100	120	40,0					
M 20	1	56	66	21,0	$l \leq \frac{10220}{b}$	$l \leq 2{,}3 \cdot h \cdot \sqrt[3]{b}$	60	175	20
	2	84	99	31,5					
	3	140	165	51,5					
(M 22)	1	74	88	25,2	$l \leq \frac{12760}{b}$	$l \leq 2{,}2 \cdot h \cdot \sqrt[3]{b}$	60	210	25
	2	111	132	37,8					
	3	185	220	63,0					
M 24	1	96	114	28,8	$l \leq \frac{14720}{b}$	$l \leq 2{,}1 \cdot h \cdot \sqrt[3]{b}$	60	240	30
	2	144	172	43,2					
	3	240	285	72,0					

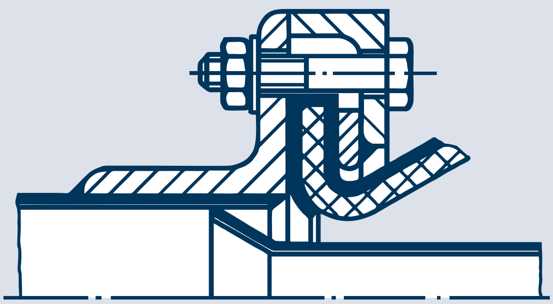
* The lower torque is to be used with well-lubricated screws, the higher with screws with poor lubrication. The indicated torques may be exceeded by a maximum of 50 %.

** The bolt forces indicated are based on the adjacent flange width and screw distance as well as the surface pressure required for the material.

2.3.2 Clamping flanges

For certain areas of application - for instance, in the presence of poisonous or combustible gases - the use of flanges with strap clamps are recommended instead of screwed flanges with through holes, as the former provide for a more air-tight seal. See also the typical design illustrated in Fig. 2.3.2.1.1. However, this special design is only advantageous for ducts with square cross-sections. In the case of round cross-sections, the strap clamps would need to be partitioned into numerous individual pieces to produce an evenly distributed clamping effect.

2.3.2.1.1

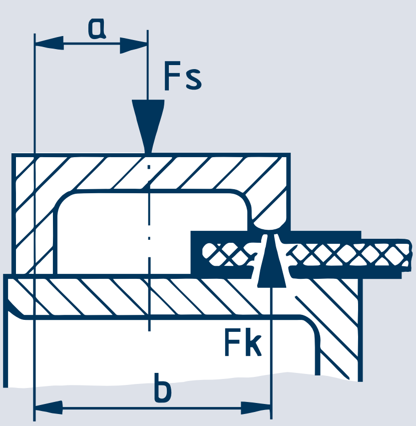


Although this type of connection has many advantages, including improved sealing possibilities, it cannot be used universally: due to its one-armed lever design, it requires more than twice as much bolt force than an ordinary through bolt to achieve the required surface pressure of 5 N/mm² in the soft-material compensator region.

As is shown in Fig. 2.3.2.2.1, the required bolt force $a \cdot F_S = b \cdot F_K$ is calculated based on the relationship as follows:

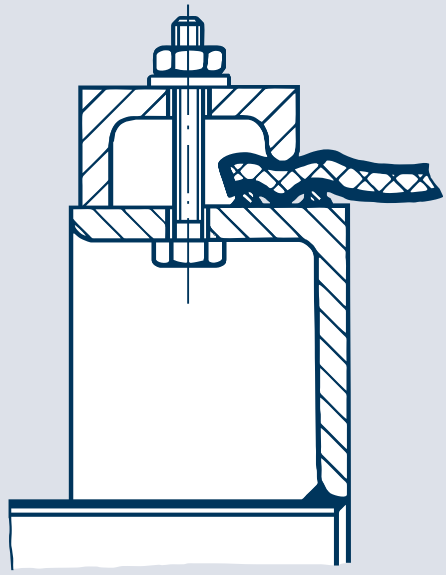
$$F_S = \frac{b}{a} \cdot F_K$$

2.3.2.2.1



An additional disadvantage of this design is its low retention force, even when measures are taken to increase the clamping force, for instance by soldering round wires onto the flange surfaces, as is shown in Figure 2.3.2.3.1.

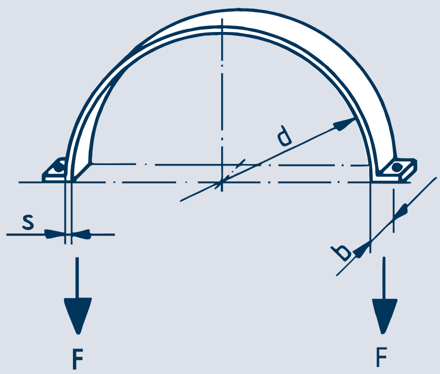
2.3.2.3.1



2.3.3 The band clamps

In certain limited situations, it may be advantageous to use band clamps to affix round compensators having a Type 120 hose connection or Type 110 elbow connection. Two factors determine the limitations for use: first, the fact that any band clamps used must be thin in order to function properly, as they are predominantly meant to transmit tensile stress rather than shear stress. Second, the clamping force is limited by the stability of the band clamps' material. A diameter of 800 mm yields a surface pressure of under 5 N/mm², or the amount of pressure required for screwed flanges (see Fig. 2.3.3.1.1).

2.3.3.1.1



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An ordinary band clamp gauge of s = 1,5 mm and a allowable band stress of σ_{zul} = 400 N/mm² result in a maximum diameter of only d = 400 mm if a surface pressure of σ_D = 3 N/m² is to be achieved. Greater diameters and band clamps with less resistance - or clamping screws not adequately tightened in relation to the resistance of the band clamp - therefore yield surface pressures significantly less 5 N/mm² and the proper impermeability is thus not achieved.

For safety reasons, it may be necessary to place two narrow band clamps (see Fig. 2.3.3.4.1) next to each other on the angle flange, so that in the event of failure of one band clamp - e.g. due to corrosion - the compensator is at least held in place by an additional band.

$$d \cdot b \cdot \sigma_D = 2F$$

$$b \cdot s \cdot \sigma_{zul} \geq F$$

Example:

$$d \leq \frac{2 \cdot b \cdot s \cdot \sigma_{zul}}{b \cdot \sigma_D} = 2 \cdot s \frac{\sigma_{zul}}{\sigma_D}$$

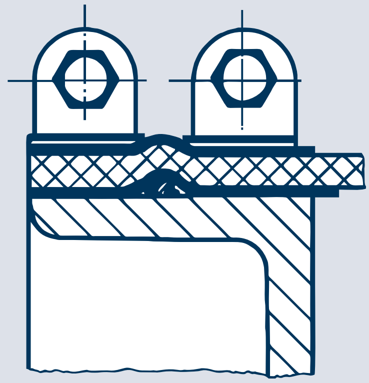
σ_{zul} = 400 N/mm²

s = 1,5 mm

d = 800 mm

$$\sigma_D \leq \frac{2 \cdot 1{,}5 \cdot 400}{800} = 1{,}5 N/mm^2$$

2.3.3.4.1



Another disadvantage of band clamps are the problems that arise from their use on flanges at higher temperatures. Because the flange of the soft-material compensator is a poor conductor of heat, a considerable temperature differential may arise between the band clamp and the duct flange. This will lead to either an overextension of the band clamp or an unallowable compression of the compensator flange, leading to a loss of impermeability after one or more instances of temperature change.

If in such cases there are particular reasons that require the use of band clamps rather than more advisable types of connections using screwed counterflanges, the use of clamp screws with disk spring sets of corresponding strength is strongly recommended.

When using band clamps, one must also take into account the fact that the clamping force of the tumbuckle will only yield the required surface pressure when in the immediate vicinity of the latter depending on the embrace friction. For this reason, band clamps have a maximum length of 1000 to 1500 mm. In the event of a greater diameter, two or more band clamps must be affixed consecutively. In such cases, the turnbuckles are to be moved accordingly, depending on the number of bands.

It can be said in summary that band clamps can be used only in relatively cool pipes (media temperature t < 200 °C) with a relatively small diameter (d ≤ 1000 mm) at relatively low pressure, (medium pressure p ≤ 0,1 bar)

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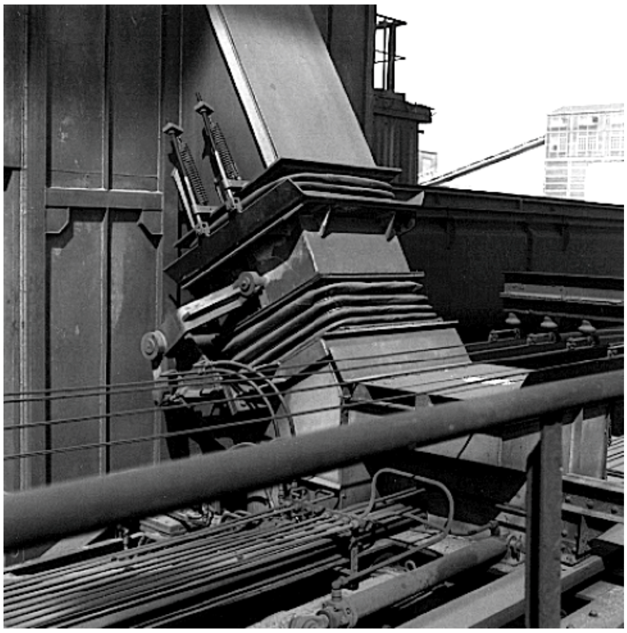
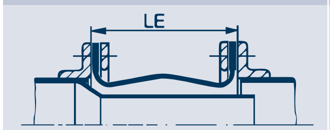
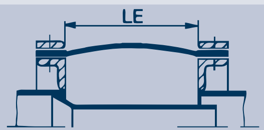
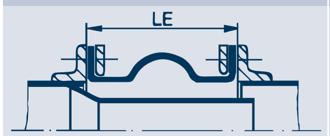
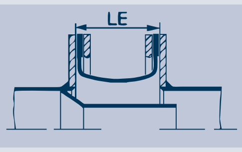
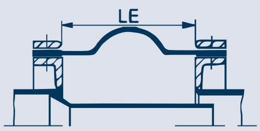
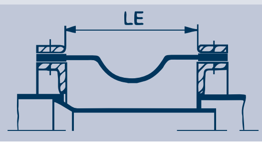
3.0 Compensator Models

Because of their universal utilisability and multi-dimensional movement absorption, soft-material compensators are not differentiated according to axial, lateral and angular capacities, as is the case with metal or rubber compensators. Rather, they are defined according to their degree of movement absorption and their type of connection, as is shown in the table below.



Compensator at hood truck of a coking plant

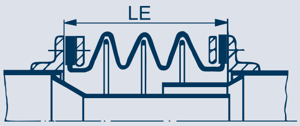
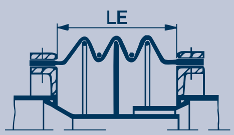
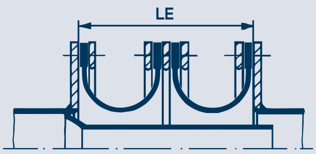
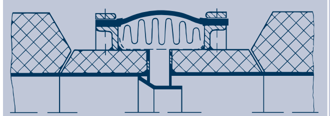
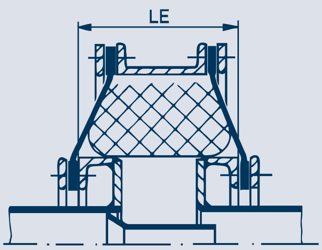
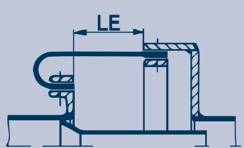
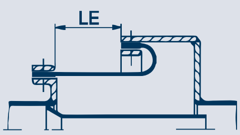
3.1 Overview table

	Type	Description	Bewegungs-aufnahme 1)	Comments Recommended LE dimensions
	110	U-shaped compensator	Δl axial (0,1 to 0,3) LE Δl lateral (0,05 to 0,2) LE	U-shaped and band compensators are the best value standard units for the majority of applications in circular and rectangular ducting. Type 110: LE = 150 to 400 mm Type 120: LE = 100 to 400 mm
	120	Band compensator		
	211	U-shaped compensator for overpressure	Δl axial (0,2 to 0,5) LE Δl lateral (0,1 to 0,2) LE	Particularly suitable for ducting with square or rectangular cross-section as a special corner construction if possible Type 211: LE = 200 to 400 mm Type 212: LE = 150 to 400 mm
	212	U-shaped compensator for low vacuum	Δl axial (0,2 to 0,5) LE Δl lateral (0,15 to 0,2) LE	
	221	Band compensator for overpressure	Δl axial (0,2 to 0,5) LE Δl lateral (0,1 to 0,2) LE	With rectangular compensators, the corners should be shaped by the height of the angular profile. LE = 150 to 400 mm
	222	Band compensator for low vacuum		

1) The movement values indicated are temperature-dependent. Our technical consultants can provide further information.

FABRIC COMPENSATORS

3.1 Overview table

	Type	Description	Movement-absorption [1)]	Comments Recommended LE dimensions
	310	Pleat compensator with flange connection	Δl axial (0,4 to 0,7) LE Δl lateral (0,1 to 0,2) LE	Pleat compensators are particularly suitable for circular duct cross-section in the smaller sizes (up to about 2,000 mm diameter). With larger diameters only low pressures possible. LE = 200 to 800 mm
	320	Pleat compensator with band ends		
	412	Multipleshaped compensator with intermediate flanges and hinged trellis support. Also in single u-shaped design possible.	Δl axial (0,4 to 0,7) LE Δl lateral (0,1 to 0,3) LE	Multiple shaped compensators can be applied to large rectangular or circular duct cross-sections and are particularly suitable for large axial movement. The intermediate flanges can be supported by hinged trellis guides or special suspension systems. LE = 200 to 450 mm per u-turn
	120 GT	Parallel case design	Δl axial (0,1 to 0,3) LE Δl lateral (0,05 to 0,2) LE	The parallel case design was developed for rapidly increasing high temperatures, as among others common in gas turbines. See also 3.4.6.
	510	Membrane compensator	Δl axial (0,4 to 0,7) LE Δl lateral (0,1 to 0,2) LE	Membrane compensators are particularly suitable for large diameters, large axial movements and high temperatures. Compensators of this type require supporting or suspension systems. LE-dimension by agreement
	621	Tuck up band compensator for overpressure	Δl axial (0,6 to 0,8) LE Δl lateral (0,1 to 0,2) LE	Tuck up band compensators have proved particularly useful in conjunction with steel chimney liners, as they can absorb very large axial and lateral movements. LE-dimension by agreement
	622	Tuck up band compensator for low vacuum		

[1)] The movement values indicated are temperature-dependent. Our technical consultants can provide further information.

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3.2 Explanation of overview table

3.2.1

Types 110 and 120 are suitable for the absorption of small changes in length, as they are designed without bulges and thus without a special corner construction. They are therefore inexpensive to produce and can perform in a large range of applications.

3.2.2

Types 211, 212, 221 and 222 have a built-in bulge which doubles their capacity for axial and lateral movement absorption. The corner can be constructed as a mitre with a joint in the supporting layer or as a segment corner with two joints, see Fig. 3.2.2.1.

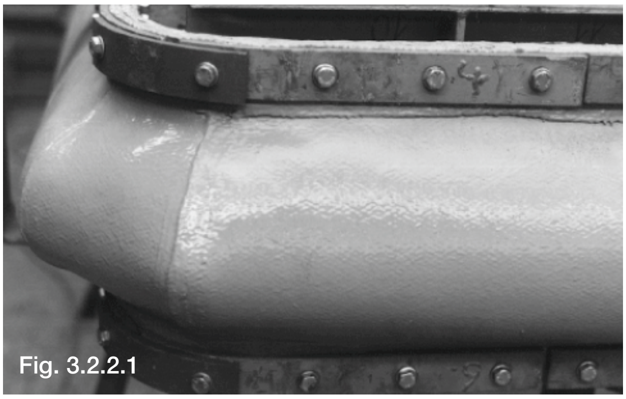


Fig. 3.2.2.1

3.2.3

The pleat compensator (type 310 and 320) or the multiple shaped compensator with intermediate flanges (type 412) absorb larger movements, particularly axial movements. Pleat compensators are specially designed for ducting with a round cross-section and smaller dimensions under approx. 2000 mm in diameter. Larger diameters are only allowable at low pressures.

Instead of the support wires ordinarily found in round pleat compensators, rectangular designs require flat iron support frames.

3.2.4

The type 412 multiple compensator in particular provides interesting possibilities for application, as long as the intermediate flanges required for types 412 and 510 can be suspended or supported. KLINGER Kempchen's hinged trellis supports for vertical and horizontal pipelines were developed for this purpose. See Figs. 4.3.1.1 and 4.3.1.2.

3.2.5

Tuck up band compensators can be designed for over pressure (type 621) or low vacuum (type 622). They are particularly suited for steel chimney liners. Tuck up band compensators are the preferred choice for use with large diameters. They absorb large axial and radial movements as may arise in conjunction with thermal striping in collector chimneys. They are connected via angle flange or hose connections.

3.2.6

The LE-dimension must be met during assembly, with the following tolerance: + 0 / -10 mm.

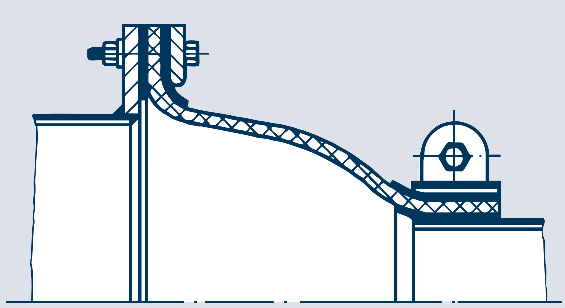
The lateral of the connector ends alignment must not exceed 10 mm during assembly.

3.3 Special models

Because of the diversity of demands placed on soft-material compensators, KLINGER Kempchen has developed a series of special models in addition to the standard models depicted in overview table 3.1. These special models include:

3.3.1 Compensators with different types of connections on each side - Fig. 3.3.1.1

3.3.1.1



3.3.2 Conical and truncated conical compensators

3.3.3 Compensators for wall ducts

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3.3.4 Special compensators for rotary air pre-heaters

3.3.5 Special compensators for diesel engines, exhaust systems, Fig. 3.3.5.1

Fig. 3.3.5.1

3.3.6

These special models of our vulcanised rubber fabric compensators for flue gas purification plants (FGD) can be found in our special brochure on REA (meaning: FGD flue gas desulphurisation plant) compensators. Please see pages 211/ 212 for a thorough description of our solutions for sealing of lining joints in chimneys.

3.4 Notes on selecting and dimensioning a soft-material compensator.

3.4.1

We recommend selecting a compensator from the overview table if possible because of the price advantage of these standard models.

The maximum allowable movement absorption can be found in overview table 3.1. Please note that the smaller number applies in higher temperatures due to the thicker construction, while the larger number characterises the movement absorption of a thinner construction.

The dimensions for movement absorption presuppose that axial compression and lateral movement take place simultaneously. If this is not the case, it is important that you make mention of this when enquiring.

Reference values for the temperature-based elongation of attached duct cross-sections

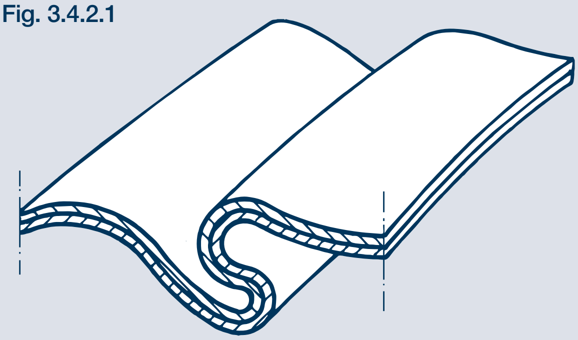
Extension dimensions in mm/m at temperatures from 20° C to

Temperature °C	50	100	150	200	250	300	350	400	500	600
Ferritic Steel	0,32	0,89	1,51	2,18	2,87	3,61	4,35	5,12	6,66	-
Austenitic Steel	-	1,34	2,08	2,97	3,76	4,75	5,69	6,64	8,62	11,2

3.4.2

It is important that the soft-material compensator's parallel construction of its insulating layer, sealing layer, wire layer and protective layer remain intact during the anticipated movement, no matter what kind of compensator is chosen. Puckering and buckling are to be avoided, particularly in the outer skin, as this may lead to overheating due to an obstruction of heat output. See Fig. 3.4.2.1.

Fig. 3.4.2.1



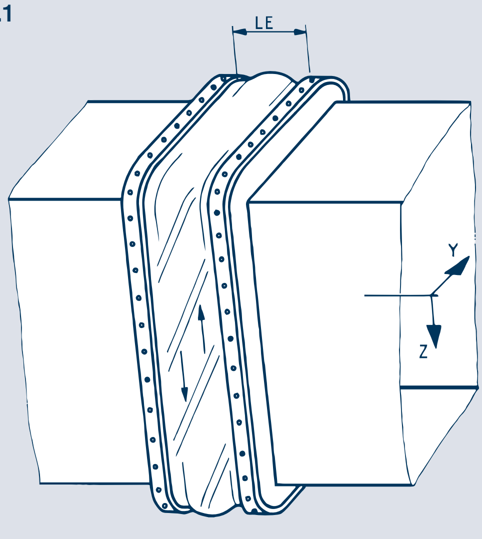
3.4.3

Lateral movement absorption is determined not only by the installation length LE of the flange distance, but also by the length of the side in which the lateral movement takes place. As shown in Fig. 3.4.3.1, a smaller lateral movement is possible in direction Z as in direction Y.

long side ≙ smaller lateral movement absorption

short side ≙ larger lateral movement absorption

3.4.3.1



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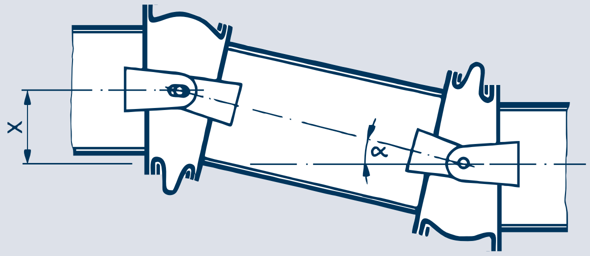
3.4.4

Constructive measures can be taken for particularly large lateral movements. A flexibly suspended section of ducting is one possible solution. The compensators are then loaded as shown in Fig. 3.4.4.1 and function as angular compensators.

3.4.4.1



3.4.5

Soft-material compensators intended for use as angular compensators must be equipped with a built-in bulge. They should be somewhat pre-loaded so that absorption of not only compression movement but also expansion can take place without the compensator becoming overloaded.

3.4.6 Parallel case design for reduction of compensator flange temperatures

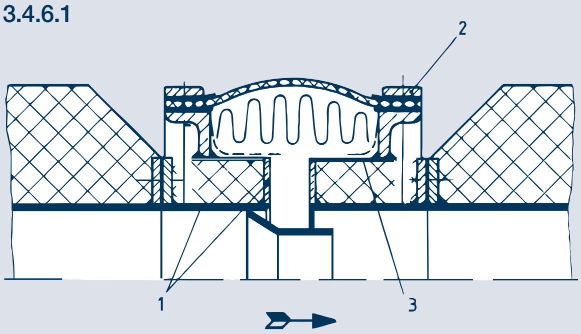
The flange construction in Fig. 3.4.6.1 demonstrates that the hot ducting sections (1) and the cold ducting sections (2) are separated by ducting sections (3), which are made from thin ferritic / austenitic steel with a thickness of only 1.5 to 3 mm.

Gas turbine plants have been designed with a daily start-stop cycle and thermal strain of approx. 600 °C, rising and falling in 6 minutes.

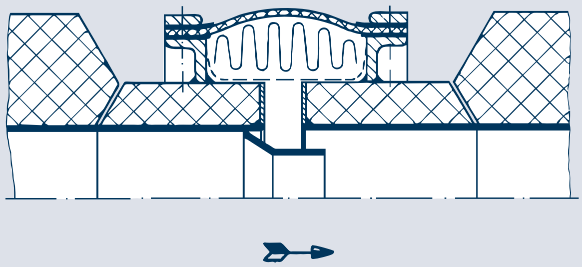
Other parallel case constructions have been designed in accordance with Fig. 3.4.6.2. The parallel case design is available as a screw-in unit or weld-in unit.

The advantage of these designs is the considerably lower temperature of the connection and compensator flange as well as the near closure of the gap between the ducting ends in operating condition.

3.4.6.1



3.4.6.2



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4.0 Connection options

The following descriptions of types of connections are intended to demonstrate the options available and their limits.

The temperature restrictions given depend to a large extent on the construction of the compensator. As an example, please keep in mind that these limits are approximately 100 °C lower for use on silicon or viton-coated fabrics than on fabrics coated with PTFE. PTFE-coated fabric can be used for sustained temperature ranges up to 260 °C, while silicon- and viton-coated fabrics can only be exposed to sustained temperatures of up 150 °C to 180 °C.

The options for attaching soft-material compensators are given in point 2.3.

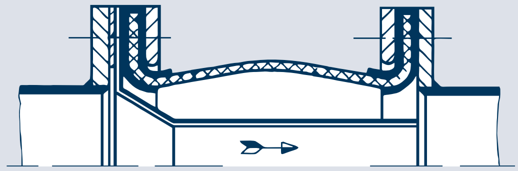
Only flanges with a flat face should be used as welding flanges or welding neck flanges, such as DIN 2526 Form B or DIN 28032 DIN 28034 Form D.

4.1 Flange connection design

Pipelines and ducting are often have angle steel or flat steelframe reinforcement, so that a flange connection already exists for the compensator. This very simple type of connection is possible at media temperatures between 350 °C and 400 °C, see Fig. 4.1.1. This connection also produces an optimal seal.

compensator in a pipe in of a blast-furnace

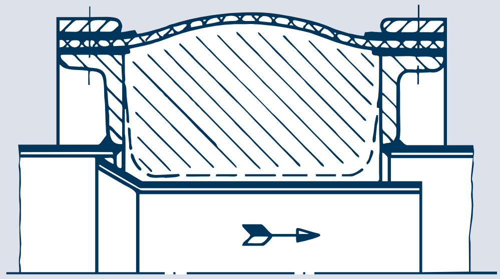
4.1.1



4.2 Designs for hose compensator connections

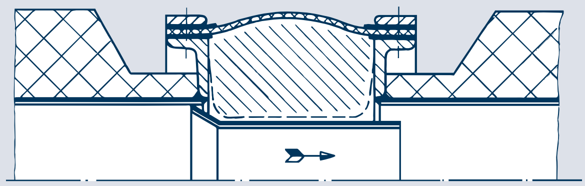
For media temperatures of approx. 400 °C and above, a reinforcement of the ducting ends using an angle or U-profile is recommended, so that compensators can be mounted with a hose connection (see Fig. 4.2.1).

4.2.1

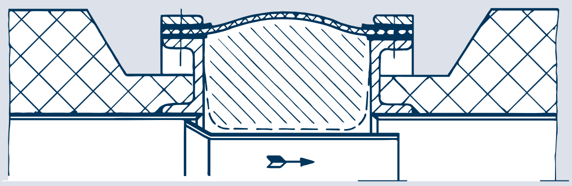


By selecting one of the designs shown in Figs. 4.2.2 and 4.2.3, and setting back the insulation somewhat in the flange connection area, flange temperatures can be reached that are approximately 100 °C than would otherwise be attained.

4.2.2



4.2.3



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Using band clamps for attachment (see 2.3.3) at diameters up to 1000 mm offers the advantage of avoiding screw holes. An additional advantage is the excellence of the seal attained. At diameters over 1000, screwed counterflanges are the preferred option. These offer a satisfactory sealing capacity.

4.3 Hingend trellis support / bar guides

Fig. 4.3.1.1

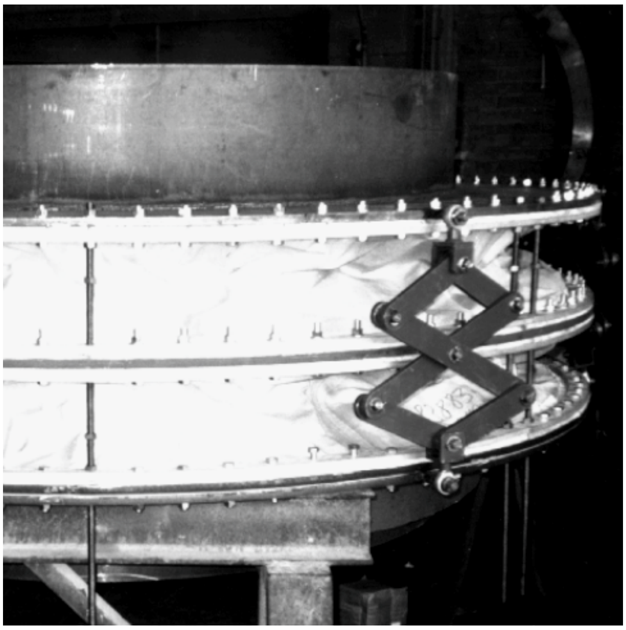
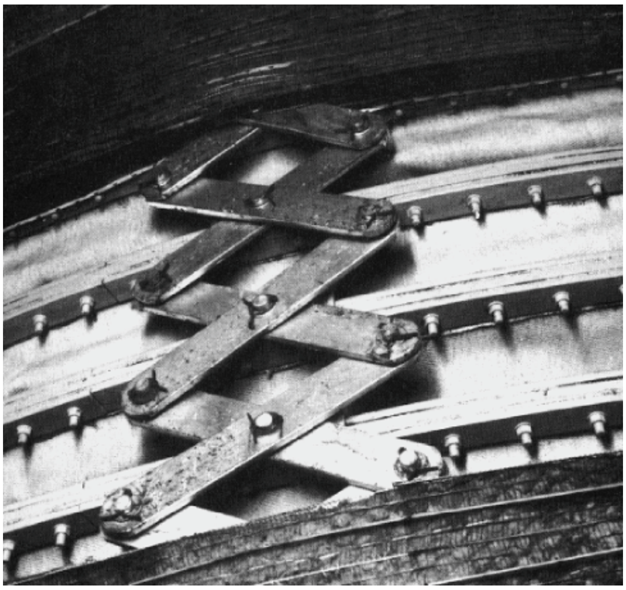


Fig. 4.3.1.2

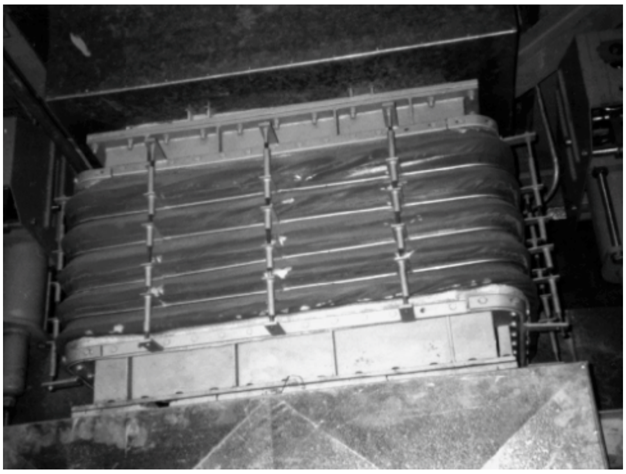


Compensator in the chimney of a coal power plant

As indicated in 3.2.4., the multiple shaped compensator can be used with an intermediate flange and hinged trellis support on large ducting cross sections and large axial movements in vertical and horizontal conductings.

The number of compensators and intermediate flanges necessary is determined by the size of the large axial movements to be absorbed. In order to avoid sagging or drooping in a horizontal or vertical direction, Kempchen has developed a hinged trellis support for this purpose (Figs. 4.3.1.1 and 4.3.1.2). The intermediate flanges are supported by hinged trellis and an even distribution of axial movement is carried over the entire multiple shaped compensator, without lateral step aside Bar guides have proven suitable for use in pleat compensators without intermediate flanges (Fig.4.3.1.3).

Fig. 4.3.1.3



Compensators at the entrance to a heat recirculation pipe at a sintering plant

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5.0 Thermal calculation of compensator construction

The foils shown in Table 2.1.2.4 are used as sealing layers.

The highest allowable sustained temperature in the foil(s) or outer coating installed as a sealing layer represents the critical point in the temperature-dependent construction of the compensator. For this reason, these sealing layers serve as the thermal calculation criteria for the compensator's construction.

There are two main areas which must be distinguished: the free area between the two flanges and the loaded area of the compensator between the flange and the counter flange.

5.1

Constructive design of the soft-material compensator for ducting with round, square or other types of cross sections results in different behaviours for heat conduction and heat transfer.

In practice, there may be parallel layers in the free clamping area, to which the theoretical approach and simplifying assumptions (Point 5.3) may apply very well. However, in the pleat area there may be complicated ratios which are not easy to detect by calculation.

Heat transfer takes place through convection or radiation. However, heat transfer is to a large degree dependent on the temperature level and the temperature differential of the ambient air for convection, and on the surfaces standing in the radiation exchange.

Flow ratios also play a major role in heat transfer both inside the compensator and on its external protective layer.

Thus there is considerable variation among the outer surface temperatures of the protective layers of compensators in horizontal ducting. The highest outer surface temperatures occur as a result of thermally determined flow ratios in the middle of the underside and topside of the compensator. These areas are thus particularly vulnerable.

5.2

As is it nearly impossible to detect all of these operating conditions and limiting terms, the following simplifying assumptions are made:

1. We assume the soft-material compensator to be constructed from plane parallel heat insulation layers which allow heat to flow vertically to the two adjacent surfaces.
2. We consider the stationary condition to be that which is reached after a certain amount of time.
3. We assume that the temperature differential that causes the heat output from the surface into the ambient air via convection to be same as the temperature differential that causes heat transfer via radiation.

The following assumptions are made:

1. That the capacity for heat conduction depends on the temperature.
2. That the plane-parallel layer is thinner in the clamping area than in the free area.
3. That when stationary, the heat flow of the compensator through the individual layers may be assumed to be constant, allowing for computation of the temperatures on the parts of the soft-material compensator's individual layers in question.

5.3

The following are two typical temperature diagrams of standard superstructural parts.

In example 5.3.1., the critical point, which serves as the basis for thermal computation, is the external silicon layer 6.

In example 5.3.2., the critical point, which serves as the basis for thermal computation, is the PTFE foil 4.

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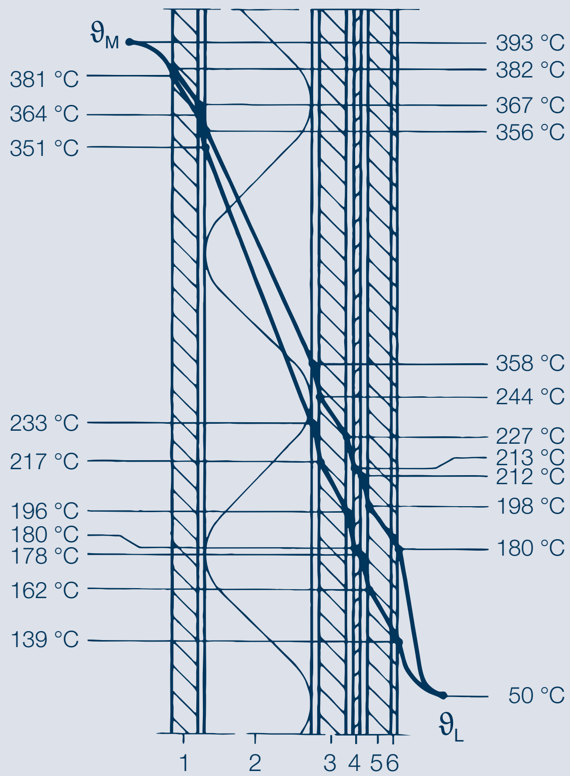
Temperature Curves

Example of Design



5.3.1 Temperature curve of a fabric Compensator with external silicon-coated layer.

1 Glass weave

2 Glass fibre mat

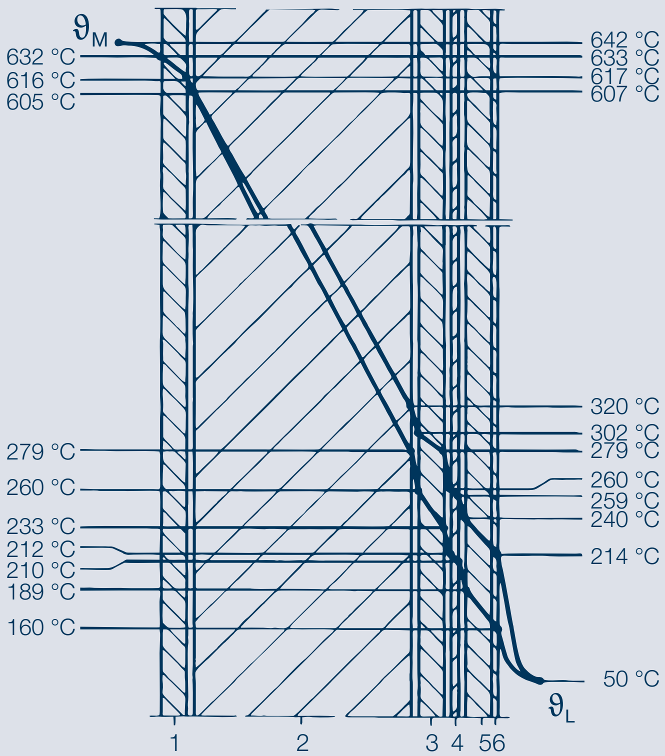
3 Glass weave

4 PTFE foil

5 Glass weave

6 External silicon coating

The upper/lower curve shows the temperature for restricted/free convection and radiation.



5.3.2 Temperature curve of a fabric Compensator with external PTFE layer.

1 Silicatex

2 Kerlane

3 Glass weave

4 PTFE foil

5 Glass weave

6 Outside PTFE coating

The upper/lower curve shows the temperature for restricted/free convection and radiation.

FABRIC COMPENSATORS

6.0 On Impermeability in soft-material compensators and testing.

The impermeability required of a soft-material compensator varies widely by

- temperature range
- type of compensator
- medium.

Single-layer, compact rubber compensators, fabric compensators with flange sealings made of rubber, and fabric compensators with textile flange sealings can be used in increasingly greater temperatures. The demands for gas-tightness are to be reduced with increasing temperature stress.

6.1 Single-layer rubber compensators

The greatest level of impermeability can be attained with compact rubber compensators made from e.g. EPDM, butyl rubber or fluorelastomer. These compensators have a flange area and compensator bellows made of vulcanised rubber. The compensator bellows is equipped with a vulcanised metallic or non-metallic textile reinforcement. This type of compensator passes the Nekal test at surface pressure of approx. 2 N/mm².

In conformance with the quality and test specifications RAL-GZ 719 Section 2.2.6 "Impermeability", no bubbles may appear in the bellows area or clamping area, as a qualitative demonstration of the Nekal test. Depending on the type of rubber used, rubber compensators can be used at temperatures up to 205 °C. Below the dewpoint, these types of compensators are also impermeable when condensation is present.

6.2 Multi-layer fabric compensators with flange sealings made from rubber

For temperatures up to 260 °C we prefer to use fabric compensators with an internally sintered PTFE foil up to 0.5 mm thick. These compensators have been tested and shown to last for many years at both higher temperatures and incidences of greater condensation. They also pass the Nekal test due to the flange sealing, made of fluor rubber or PTFE, which is tightly attached to the PTFE coating

6.3 Multi-layer fabric compensators with textile flange sealings

This type of compensator is used at temperatures over 260 °C. The bellows area can be sealed using gas-tight rubber, plastic or metal foils. In the flange area, however, no gas-tight materials may be used at temperatures over 260 °C. The glass-oder ceramic weave stripes do not pass the Nekal test at high temperatures, but are flue gas tight.

Flue gas tightness refers to impermeability that meets technical standards. In the Nekal test, individual bubbles that appear via diffusion across the heat-insulating flange sealings are allowed in the flange area.

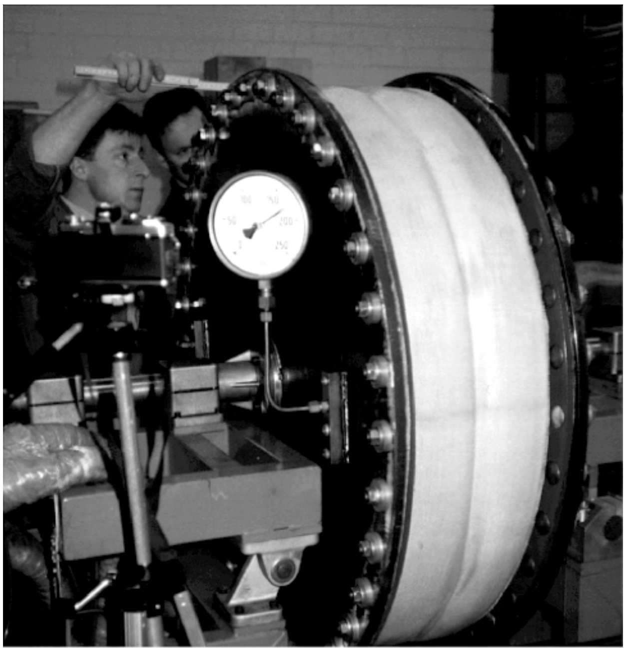
6.4 Conditions for impermeable soft-material compensators

The flange area is the weakest spot of the soft-material compensator. For this reason, the surface pressure and the attainable surface pressure and the actual surface pressure are of great importance during assembly.

Instructions for the proper thickness of the counterflanges depending on the width of the counter flange and the distance between the holes are given in 2.3.1.4. One precondition is that the ducting or piping flange is designed to be rigid, e.g. owing to the choice of an adequate thickness or due to elbowing.

The flange screws are to be tightened in accordance with the capacity and the relaxation properties of the compensator's various superstructural parts. Table 2.3.1.5 also provides instructions for this.

The screws should be re-tightened to the target moment one hour after completion of assembly.



Employees pressure testing a compensator
at the Kempchen compensator testing station

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