The expansion-joint is accepted, if there is no leakage and no significant distorsion or instability.

8.2. Demonstration tests

For each type of expansion-joint, three supplementary joints are fabricated. These joints correspond exactly to those to be installed on the reactor.
One of the assemblies shall be used for destructive examination of geometry and mechanical values of the material.

The two other assemblies are submitted to fatigue tests at nominal pressure and temperature under conditions of displacements equal or greater than the operating displacements. The number of cycles to rupture has to be higher than the corresponding number of the designer's fatigue-curve, taking into account the usual safety coefficients.

9. REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section III
United Engg. Center, 345 East 47th Street, New York, N.Y. 10017.

[2] Standards of the Expansion Joint Manufacturers Ass., Imm, 331 Madison Avenue, New York, N.Y. 10017.

EXPANSION JOINTS FOR LMFBR

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SUMMARY

This discourse recounts efforts put into the SNR-2 project; specifically the development of compensation devices. The various prototypes of these compensation devices are described and the state of development reviewed.

Large Na (sodium)-heat transfer systems require a lot of valuable space if the component lay-out does not include compensation devices. So, in order to condense the spatial requirement as much as possible, expansion joints must be integrated into the pipe system. There are two basic types to suit the purpose: axial expansion joints and angular expansion joints.

The expansion joints were developed on the basis of specific design criteria whereby differentiation is made between expansion joints of small and large nominal diameter. Expansion joints for installation in the sodium-filled primary piping are equipped with safety bellows in addition to the actual working bellows.
Expansion joints must be designed and mounted in a manner to completely withstand seismic forces.
The design must exclude any damage to the bellows during intermittent operations, that is, when sodium is drained the bellows' folds must be completely empty; otherwise residual solidified sodium could destroy the bellows when restarting.

The expansion joints must be engineered on the basis of the following design data for the secondary system of the SNR project:

- working pressure:	16 bar
- failure mode pressure:	5 events
- failure mode:	5 sec., 28.5 bar, 520°C
- working temperature:	520°C
- temperature transients:	30°C/sec.
- service life:	200,000 h
- number of load cycles:	10^4
- material:	1.4948 or 1.4919
- layer thickness of folds:	0.5 mm
- angular deflection (DN 800):	+ 3° or
- axial expansion absorption (DN 600):	± 80 mm
- calculation:	ASME class

The bellows' development work is not handled within this scope. The bellows are supplied by leading manufacturers, and warrant highest quality.
Multi ply bellows were selected on the basis of maximum elasticity - a property that has a substantial effect on the reliability of the entire system.
Later on, a number of experimental programs will be presented and results of previous trials discussed.

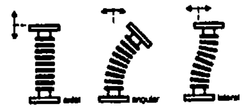
1. General

1.1 Typical SNR Application of Expansion Joints

1.1.1 Large Na- (sodium) heat transfer systems require a lot of valuable space if the component lay-out does not include compensation devices. So, in order to reduce the space requirements as much as possible expansion joints must be integrated into the pipe system.

1.1.2 There are four basic types of expansion joints:

a) axial
b) lateral
c) angular
d) cardanic-type angular expansion joints.



Although lateral expansion joints require as little servicing as axial expansion joints, certain structural features restrict their use to a limited range of pressures and temperatures, but this should not be discussed now.

Due to the "physical" definition of cardanic-type angular expansion joints (or universal expansion joints) all attempts to make them more space-saving and less maintenance-dependent, have failed.
For the above reasons, only axial and angular expansion joints are employed in the field under consideration.

1.1.1 But first, let's have a look at the main component of an expansion joint - the bellows. There are three different kinds of bellows:

a) single ply
b) laminated (≤ 3 layers)
c) multi ply (> 3 layers)

a. b. c.

The multi ply bellows have some very substantial advantages; so much so, that selecting that type was an easy decision to make.

The stratified structure of the multi ply bellows makes it very elastic in spite of its low flexural stiffness. This type of bellows, then, may be compared to a multi-leaf spring.

The cardinal variant of such bellows has its source in certain elastostatic interrelations (fig. 1).

When multi ply bellows are flexed, bending stresses occur in the folds, presenting themselves both as compressive stress and as tensile stress. The stress level is much lower than in the case of solid-walled bellows, because the elastic profile is broken down into myriad neutral fibres.

Today, there are no exact analytical calculation methods, related to the friction behaviour between the different layers of multi ply bellows. At present, the manufacturers of bellows work with calculations on empirical basis.

A leak, which always originates from a void or incipient crack, will at first allow the egress of only small amounts of medium. The laminated core support acts as a labyrinth seal. By the time the medium works its way to the surface, it is already in an expanded state. The multi-layered bellows expansion joints can therefore be regarded as one of the safest kinds of all.

1.2 Specific Requirements for Sodium-Filled Expansion Joints (fig. 2)

1.2.1 A good pipework lay-out must take into account all forces due to thermal expansion, contraction, dislocation, rotation, and other local stresses.
Being that expansion joints make up a substantial portion of the pipe network, the following criteria must be heeded:

1.2.1.1 Guides and supports for expansion joints must fulfil the requirements for pipe mounts as put forth in ASME code section III subsection NF.

1.2.1.2 Expansion joints must be installed in a manner to ensure accessibility for routine inspections and servicing. Easy removal or exchange must also be provided.

1.2.1.3 Expansion joints should only be installed in areas where corrosion of the bellows' material is unlikely.

1.2.1.4 If the piping is subject to cold flexure, the resultant stress must be kept away from the flexible elements.

1.2.1.5 The expansion joints should be arranged and anchored in a manner to minimize vibrations.

2. Engineering Design

The expansion joints of SNR secondary system must be engineered on the basis of the following design data:

- working pressure:	16 bar
- failure mode pressure:	5 events
- failure mode:	5 sec., 28.5 bar, 520 $^{\circ}$C
- working temperature:	520 $^{\circ}$C
- temperature transients:	30 $^{\circ}$C/sec.
- service life:	200,000 h
- number of load cycles:	10^4
- material:	1.4948 or 1.4919

- layer thickness of folds: $\geqq$ 0.5 mm
- angular deflection (DN 800): + 3^{o} or
- axial expansion absorption (DN 600): $\pm$ 80 mm
- calculation: ASME class

2.1 <u>General</u>

2.1.1 It may be assumed that the bellows supplied by major manufacturers (fig. 3) are in full compliance with stringent safety requirements and the latest state of the art, not only in the quality of materials, but in the production process as well.

The bellows' design in Ω-form was optimized for years by special development programs of the industry.
In practice, this gives an expansion joint a very pronounced soft resiliency in each fold and at the same time plenty of space to move in any direction, even though the profile of the folds is relatively small.
In comparison to other types of bellows this results in a modest face-to-face dimension and a small bellows cross section, which is advantageous in respect to anchor points. The multi ply bellows have another distinct advantage not to be overlooked; if for some unforeseen reasons, the device should develop a leak, the bellows body will not burst - this has been proven in a large number of experiments.

2.1.2 Each primary bellows with a pressure-regulating function should be enclosed by another bellows (the safety bellows). Once a leak is detected in the first bellows, the other may no longer be subjected to the limit stress under emergency conditions.

2.1.3 The transitions between pipe and bellows, bellows and bellows, inner and outer pipes must be designed to eliminate or transfer stresses as advantageously as possible. Therefore, the linkage to the parallel components must be elastic, that is, they must be designed as so-called Y-, Z-, or U-shaped parts.

2.2 <u>Design Features</u>

2.2.1 The fluids forces of interia resulting from changes in flow velocity (fig. 5), must be accounted for in the calculations and engineering design.

2.2.2 Expansion joints must be built and mounted in a manner to fully eliminate seismic forces.

2.2.3 The bellows must be constructed in a manner to preclude damage due to or during intermittent operation.
In other words, when sodium is drained off, the folds of the bellows must be completely empty; otherwise residual solidified sodium could destroy the bellows upon restarting.

2.2.4 Pipe restrictors and steel connectors on expansion joints must be constructed in a manner to ensure that the maximum bellows motion or stroke does not exceed the permissible standard values.

2.2.5 With respect to in-service inspection and the outside pressure, no thrust rings may be used, although they could protect the bellows against unacceptable deformation.

2.2.6 Some form of separating device, such as flow bushings or the like, should be installed in all expansion joints in order to prevent undue stress in the bellows as a result of vibrations, thermal shock and erosion which may accompany the flowing medium.

3. Fabrication

3.1 Materials

3.1.1 Materials for piping and turned parts

3.1.2 The entire pipework must be made of a material ensuring sufficient long-term strength in the face of high temperature flowing sodium. The structural material 1.4919 (comparable to the steel AISI 316 EL) is suitable, as evidenced by general and specific INTERATOM experiments. So it is only natural that all parts of the expansion joint be made of the same material with a view to strength properties and homogeneity. Also, there are no problems with additional filler materials during welding.

3.2 Assembly

3.2.1 As already discussed in section 1.1.3, the expansion compensating members (fig. 6) selected for use are multi ply bellows-type expansion joints, which have a number of important advantages. There is, however, one disadvantage: the ends of the bellows have to be welded on. This necessitates careful testing of all weld seams (X-ray and ultrasonic examination) prior to installation of the bellows in order to minimize the danger of leakage, with resultant escape of sodium or ingress of cover gas.

With respect to the quality control, an agreement between the industry and the supervising authority has to be made. Because the quality criteria of welds are only possible with X-ray examination connected with statistical destructive tests (in particular, micrographs).

3.2.2 Each successive weld seam must be subjected to either X-ray or ultrasonic testing during assembly of the complete compensation device. Inspection of all seams at once subsequent to completion of assembly is impossible.

3.2.3 All external welds, whether on the sodium-filled or gas-filled compartment, can be subjected to routine inspection methods as described in section 3.2.2, after completion of assembly. All interior welds are situated such that they can be visually inspected by the use of photoconductive internal inspection elements.

4. In-Service Monitoring and Maintenance

4.1 Degasification

4.1.1 The expansion joint's sodium-filled compartment must be degassed during system start-up on restarting after downtime in order to effectively prevent presence of a gas bubble in the sodium circuit. Therefore, the expansion joint must be located in a manner to ensure that a vent outlet at the uppermost point of the sodium-filled compartment is located.

4.1.2 Subsequent to a system shut-down, the entire piping system must be fully discharged. Therefore, a drain nozzle must be provided at the lowest point of the sodium-filled compartment, that is opposite to the vent outlet. Complete emptying of the bellows is practicable, because the bellows are subject to outside pressure.

4.2 Visual Inspection

4.2.1 The compartment formed by the safety bellows is provided with several inspection ports in the form of nozzles which are also used for charging with protective gas and inserting an endoscope.

In a shut-down condition, the internal inspection elements can be inserted through these ports in order to monitor all the weld seams which can not be seen from the outside (refer in this respect to section 3.2.3) and to inspect the inside of the bellows not in contact with sodium, so as to detect any detrimental changes which may have taken place.
This method also facilitates preparation of photographic documentation.

4.3 In-Service Monitoring (fig. 7)

4.3.1 Leak Detection via Differential Pressure

Expansion joints employing second bellows, the safety bellows which surround the working bellows, can be monitored via the enclosed safety compartment. Both, the working bellows and the safety bellows are accessible through the inspection parts. The pressure in the inert gas compartment between the working bellows and the safety bellows increases by approximately 2 bar as the medium, originally at about 20°C takes on its normal operating temperature of 520°C, in other words as it passes through a Δt of 500°C. This pressure is monitored by means of transmitters like BARTON cells.
If the working bellows, that is the one exposed to liquefied sodium on the outside, develop a leak, the pressure in the gas compartment will either increase or decrease. As soon as the BARTON cells detect a $\pm$ 0.5 bar deviation from the nominal value of 2 bars, an alarm is initiated in the form of a combined audio-visual signal.

4.3.2 Leak Detection via Sniffing Device

An electric conductor (beaded conductor with insulators) is inserted in the folds of the bellows, on the sodium-free side. If a leak causes the conductor to come in contact with even small amounts of liquefied sodium, the event can be detected by monitoring the resistance change of the conductor. The location of the leak can also be pin-pointed by the same information.

5. Experiments

5.1 Objects of Experiment

It was decided that expansion joints of small piping systems should be designed without safety bellows.
The following expansion joints were included in the experiment:

5.1.1 Axial expansion joints DN 80
DN 150

5.1.2 Angular expansion joints DN 80.

5.2 Pretrial Experiments (fig. 12)

5.2.1 Degasification of the upper space of compensation device in a loop system

In planning compensation devices, it is necessary to place great emphasis on fully dischargable bellows folds, which require the employment of bellows subject to outside pressure. Normally, vent lines will have to be attached to such expansion joints for the purpose of degassing the upper clearance space.

The question of whether or not degasification can be problematic in small size expansion joints was looked into by way of fluid experimentation.
The object of experimentation was to determine the fully degassed state of the upper clearance space. To this effect, the compensation device was mounted in the water circuit of an experimental facility. The water velocity amounted to 1.5 ... 3 m/s. The trial run was recorded on film.

5.2.2 Degasification Experiment

Three different plexiglass expansion joint models DN 80 were tested in a water cycle. Maximum flow was 2.5 m s^{-1}.

In variant 1 (fig. 8) the outlet was formed as a disk with an eccentric bore fitted to the pipe. Degassing was nearly complete. The extreme flow diversion produced turbulences with erosion effects in the outlet environments.

In the second variant (fig. 9) the outlet was formed as an eccentric cone. This design gave a disadvantageous result of degassing. The flow conditions were better than before.

An internal vent line (a cemented in-tube running from the outer jacket to the reduction) (fig. 10) was provided in order to permit evacuation of gas bubbles as a result of increased pressure in the outer jacket. This did result in total degasification of the expansion joint.

5.2.3 Testing of internally pressurized, horizontally mounted small-sized bellows

When using internally pressurized bellows in horizontal sodium piping, the problem is, that the bellows are unable to discharge completely after drainage, because a residual amount of sodium remains in the folds.
In order to understand the effects of residual sodium on the bellows, the following aspects had to be examined.

5.2.3.1 Will the residual sodium cause damage to the bellows so that there is danger of a leak?

5.2.3.2 Can the bellows be subjected to such stress due to the adhesive strength of the sodium that the folds of the bellows can become deformed?

5.2.3.3 Can the bellows be subject to deformation during warm-up due to the presence of still cold, solidified sodium in the folds?

5.2.3.4 The piping was provided with thicker insulation in the vicinity of the bellows.

5.2.3.5 The heating capacity in the vicinity of the bellows was increased in order to be sure that the sodium in the folds would melt first when the system was restarted.

5.2.3.6 No special heating circuit was installed.

5.2.3.7 Bellows with detachable insulation were installed to facilitate intermediate inspection, and a leak detection chain was installed underneath the bellows for the purpose of detecting a leak on a continuous basis as a measure of protection for the experimental set-up.
The purpose of the experiments was to prove that even internally pressurized bellows of a relatively small size are suitable for use in sodium circuits without need of any special electrical modifications such as secondary heating or suppressive elements.

5.2.4 Heat-up Trial

The analysis of results demonstrates quite clearly, that good results are obtainable through the installation of a heating capacity in the rear vicinity of the bellows, that is 5 to 6 times more intense than in the rest of the system. For approximately equal final temperature in the vicinity of 280^{o}C, the sodium in the folds of the bellows was heated up more quickly than the remainder of the pipework.

There were no problems during cool-down, because the piping reached the ambient temperature before the sodium solidified (fig. 13), due to such factors as thickness of insulation and sodium's congealing period.

5.3 Experimental Set-Up (Axial Expansion Joint DN 600)

5.3.1 Installation of expansion joints

The test objects will be set up and installed in a manner (fig. 3) to reflect actual operating conditions; as a result, no subsequent model calculations are necessary. The test set-up is designed to accept actual forces and stresses in any position, even under the highest anticipated temperatures and pressures.

5.3.2 Instrumentation

5.3.2.1 Temperature

The entire test section, with the component under examination - the expansion joint - is fitted with temperature sensors at all important locations. All measured values are transmitted for recording.

5.3.2.2 Stress

All points of force vectoring and stress transition determined by the construction are equipped with appropriate instruments such as load cells or wire strain gauges for high temperature zones. These measured values are also transmitted for recording, as in the case of temperatures.

5.4 Analysis

5.4.1 Plotting

All values mentioned in section 5.3.2 individually sensed will be transmitted and plotted.

5.4.2 Evaluation

The measured values, temperature and stress curves, will be evaluated with the aid of specially prepared computer programs.
The results allow quantitative and qualitative assertions. However, such assertions cannot yet be formulated because the experiments have not yet been concluded.

6. Prospects

6.1 Further Experimentation

6.1.1 In order to permit an analysis to define the behaviour of sodium in case of damaged bellows, it should be necessary to induce cracking at one or several places on the sodium side of the bellows. Such crack penetrating at least one, if not several layers.

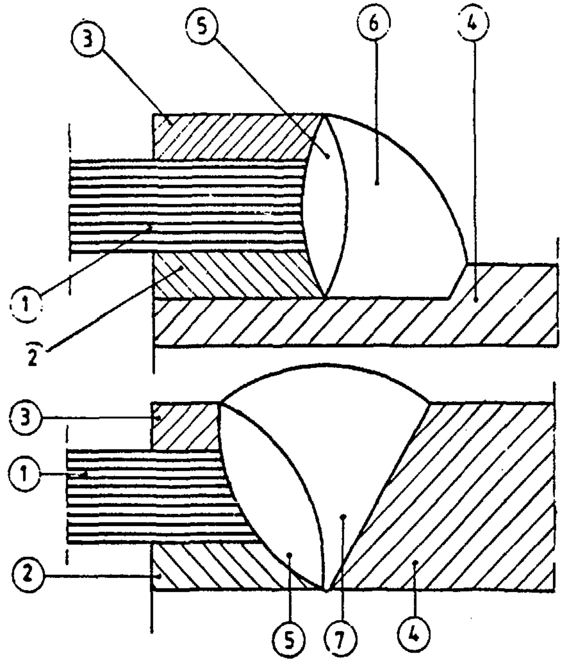
After a certain previously determined, relatively short period on operation, the bellows could be cut up and examined to find out whether or not the following assumptions can be termed as applicable:

a) Does the sodium penetrate through the crack and emerge drop by drop?

b) Does the sodium oxidize in the direct vicinity of the crack, because of the rest of oxigen on the surface of the bellows' layer?

6.1.2 At the same time, this short-term experiment could be used to determine whether or not the pressurized medium leads to a widening or elongation of the crack(s).

6.1.3 Another test along the same lines would be to provide for detection of bellows damage through an oscillatory system. To this effect, a detector would be attached directly to the bellows, making it possible to calculate and produce a certain frequency for superpositioning on the pipe system's natural frequency. A matching receiver could then detect any damage to the bellows by registrating the resultant change in frequency.

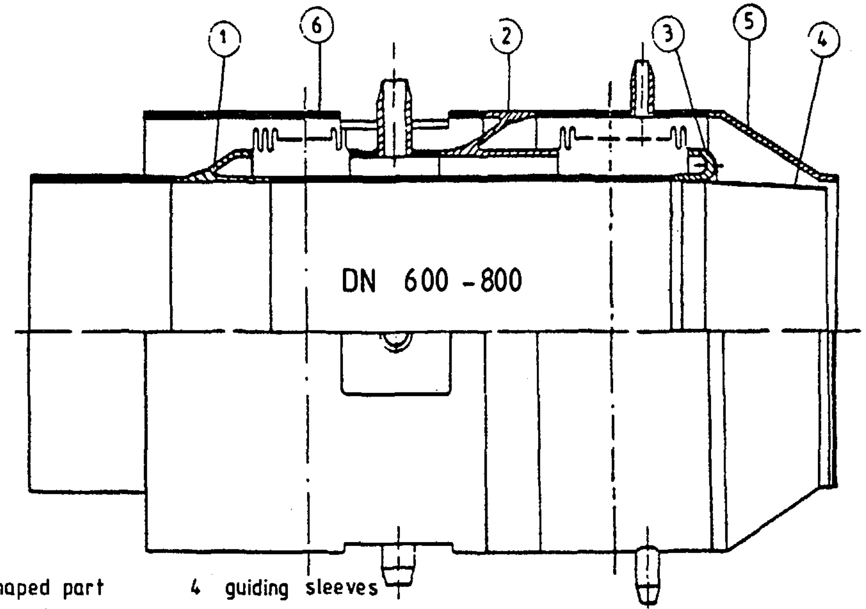


1 manifold bellows
2 inner ring
3 outer ring
4 joining part
5 packing weld
6 welding ◺
7 welding V

Bellows

Packing and Joining

Fig. 1

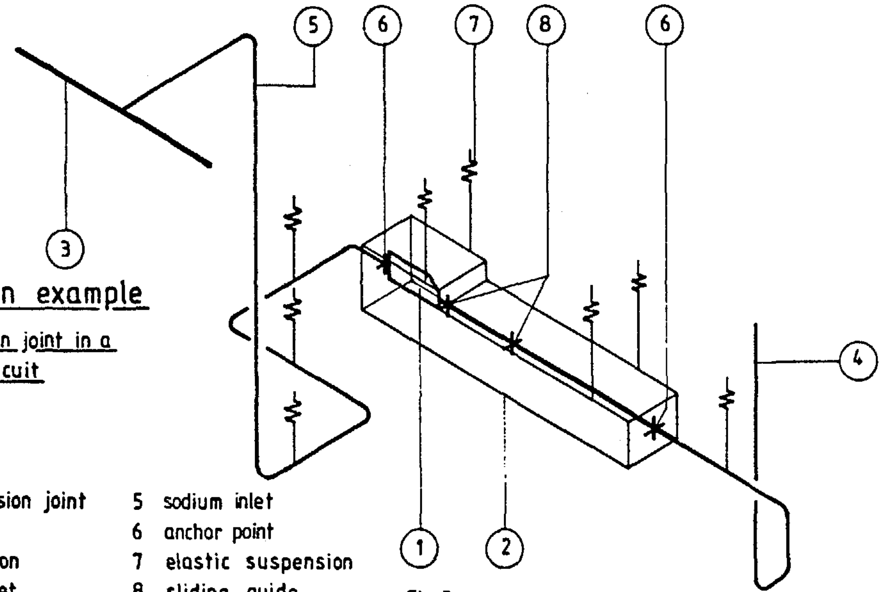


1 Y-shaped part
2 Z-shaped part
3 U-shaped part
4 guiding sleeves
5 reduction
6 protection pipe

Fig. 2

Axial Expansion Joint

Turning- and Leading parts

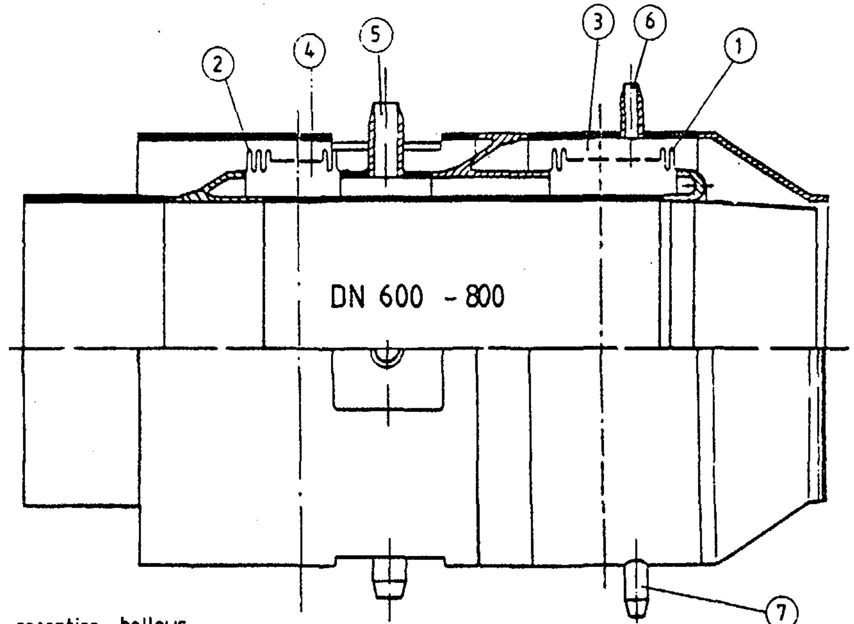


Installation example

Axial expansion joint in a sodium circuit

1 axial expansion joint
2 frame
3 line connection
4 sodium outlet
5 sodium inlet
6 anchor point
7 elastic suspension
8 sliding guide

Fig. 3

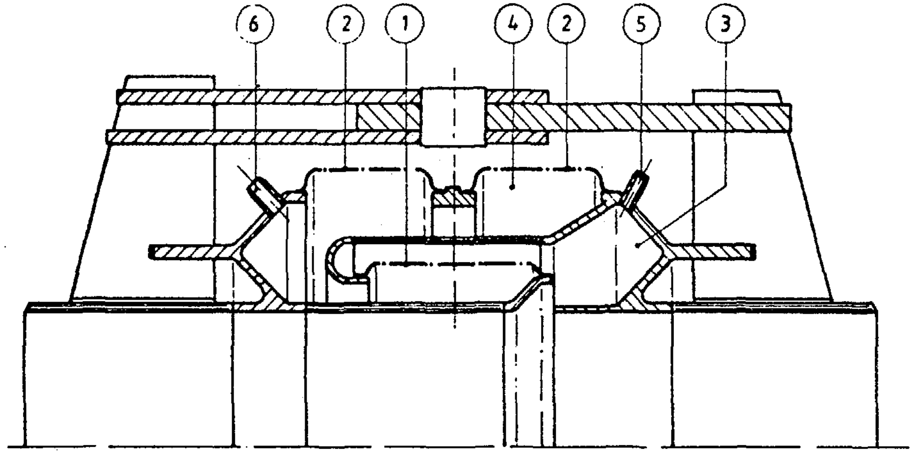


1 operation bellows
2 security bellows
3 sodium
4 cover gas
5 inspection nozzle
6 degassing nozzle
7 drain nozzle

Axial Expansion Joint

Construction

Fig. 4



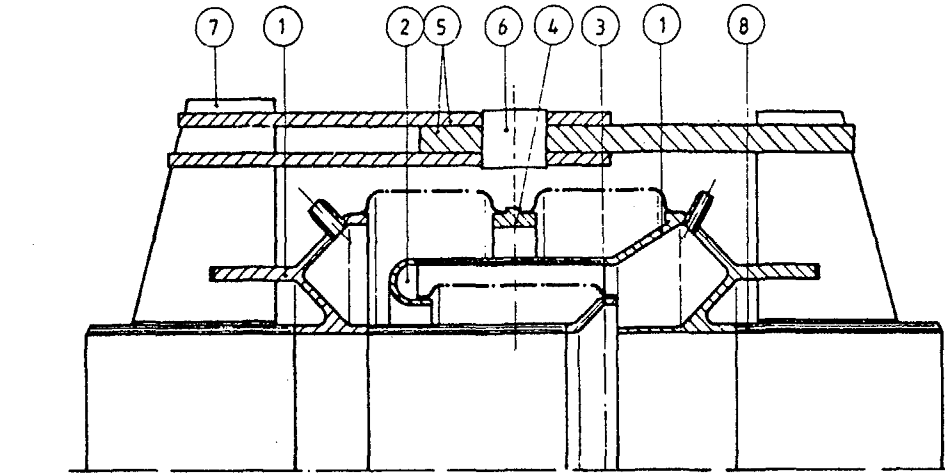
DN 800

1 operation bellows
2 security bellows
3 sodium
4 cover gas
5 degassing nozzle
6 inspection nozzle

Angular Expansion Joint

Construction

Fig. 5



1 Y-shaped part
2 U-shaped part
3 S-shaped part
4 T-shaped part
5 drawing anchor
6 bolt
7 anchor plates
8 pipe

DN 800

Angular Expansion Joint

Turning- and Leading parts

Fig. 6

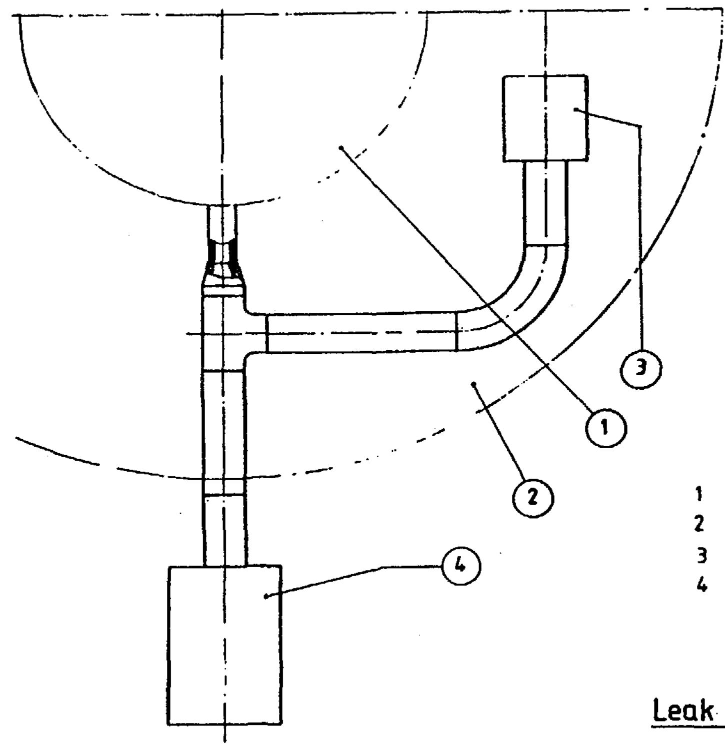
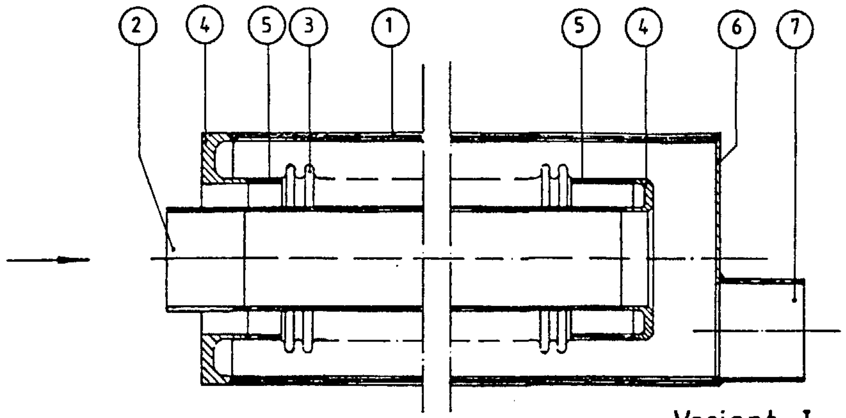


Fig. 7

1 expansion joint
2 insulation
3 BARTON cell
4 leak detection (inductive)

Leak detection equipment.

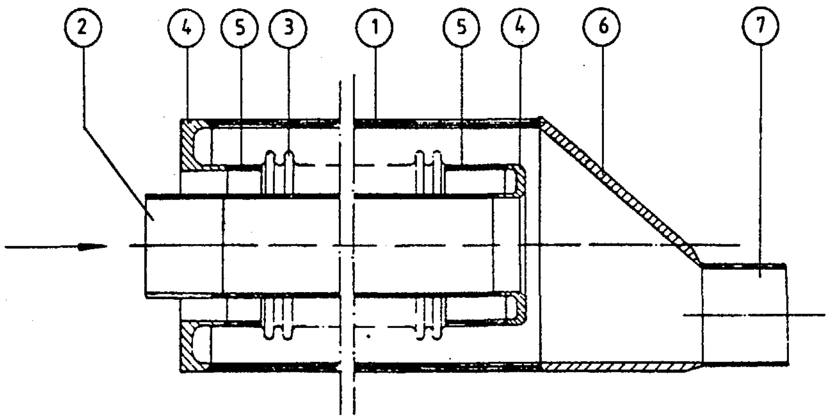


Variant I

1 plexiglass
2 water inlet
3 bellows
4 U-shaped turning part
5 transition part
6 eccentric bored disk
7 water outlet

Water model
gas reduction test

Fig. 8

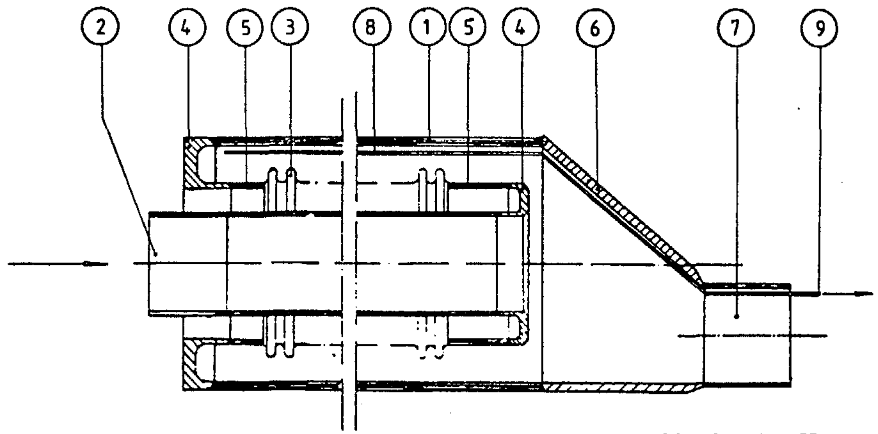


Variant II

1 plexiglass
2 water inlet
3 bellows
4 U-shaped part
5 transition part
6 cone
7 water outlet

Water model
gas reduction test

Fig. 9

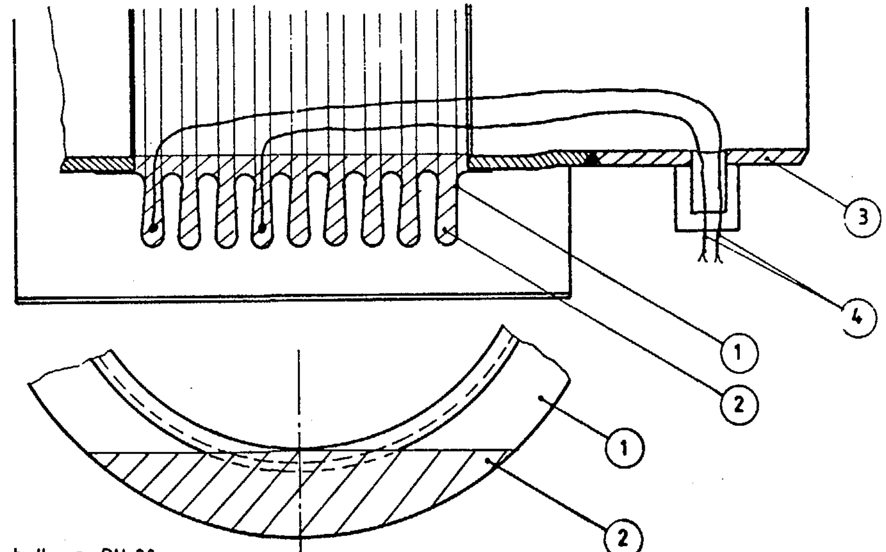


Variant III

1 plexiglass
2 water inlet
3 bellows
4 U-shaped turning part
5 transition part
6 cone
7 water outlet
8 gas bubble escape pipe
9 gas bubble outlet

Water model
gas reduction test

Fig. 10



1 bellows DN 80
2 sodium remainder
3 connecting piece
4 temperature measuring equipment

Fig. 11

Bellows DN 80

Sodium remainder for horizontally mounted pipes

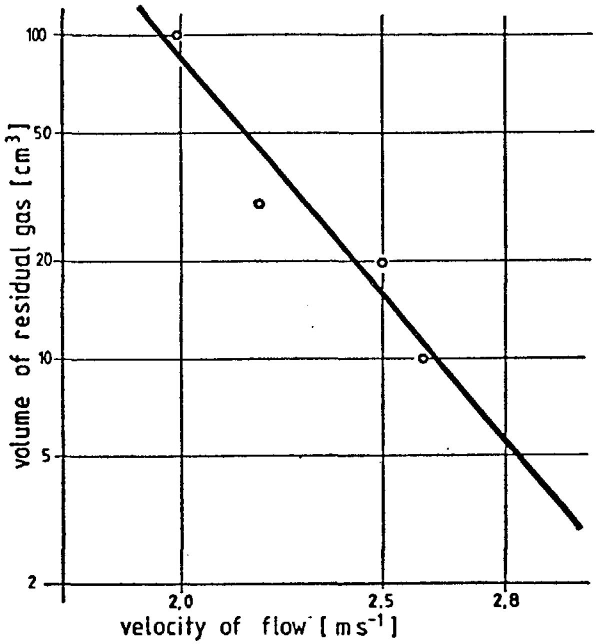


Fig.12

Gas reduction test

Water model

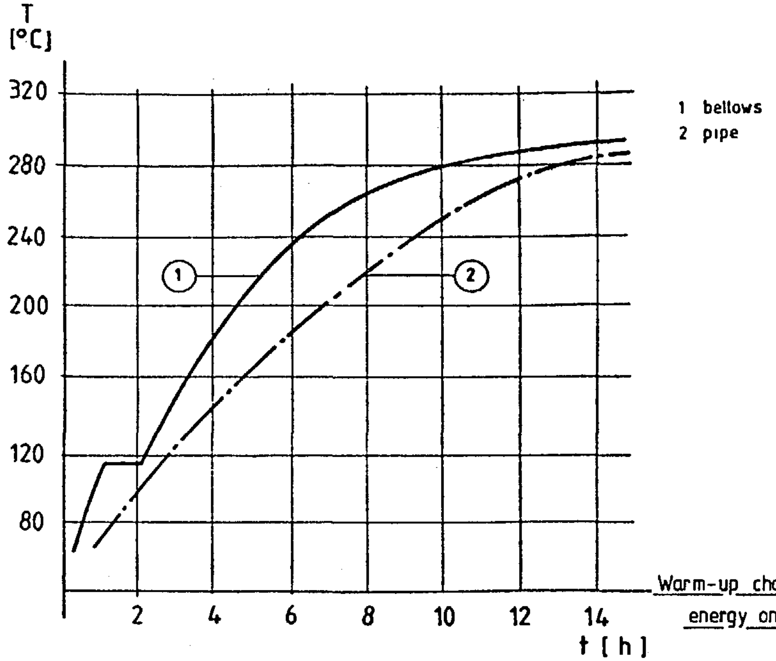


Fig.13

Warm-up chart for 5 to 6-fold heat-up energy on a DN 80 bellows

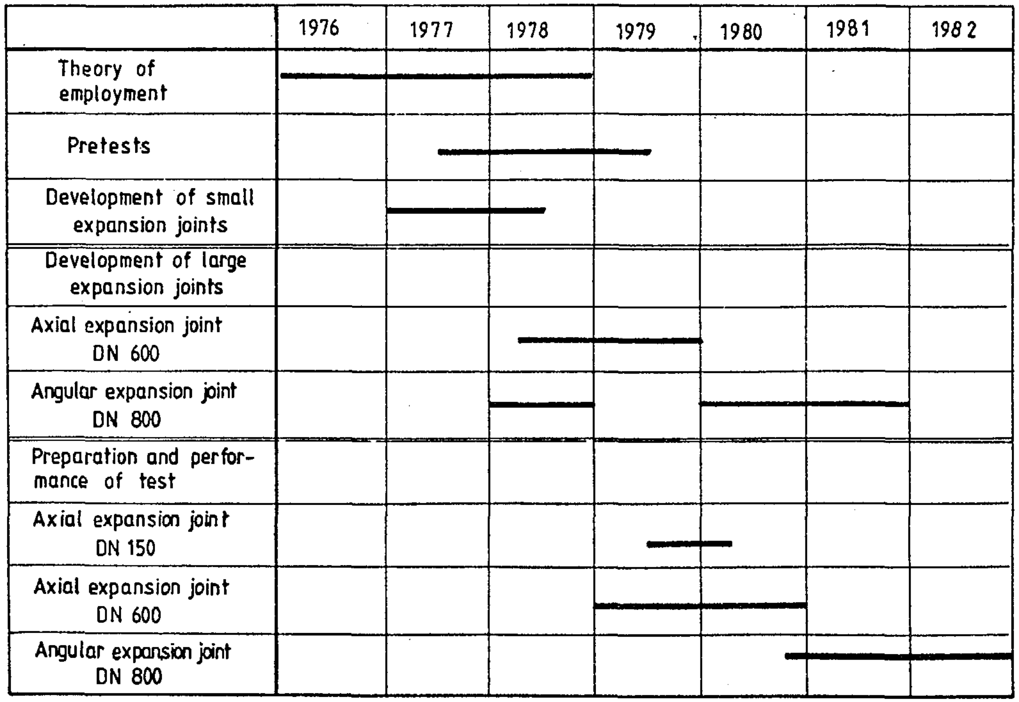


Fig. 14