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Design considerations for the foam structure in the barrel TRT

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The polypropylen foam from BASF is one of the options for the TRT radiator in the barrel region. Some of its properties are listed below.

We also indicate the status of development of the drilling procedure and present a few design considerations.

Due to the success with drilling in foam we do not pursue at present the idea of fabricating the foam in an appropriate mould (RD6 note 44). It may take a long learning procedure before foam of comparable homogenuity can be produced in that way.

Foam properties

The figures in Tab.1 represent our own measurements on samples taken from standard blocks of dimensions 90 x 50 x 15 cm^3. The errors take into account measurement errors and deviations between samples. Very long term effects in the material have not been studied. Deformations of up to 1 % were found to be elastic; the recovery time however was large (up to a few days).

In addition to the features in Tab.1 we tested the sensitivity to humidity. The length of a 10 cm block at room temperature changed by less than 5 μm when it was completely wettened and kept under conditions of 100 % humidity in a plastic bag for an hour. A second test concerned the water absorption. The weight of a block changed by less than 1 % when it was completely immersed in water and subsequently dried by ventilation with air under laboratory conditions for a day. When this test was repeated on a block with appropriate holes for the straws , it took almost two days to dry it out, but the remaining change in weight was within the measurement error of 1 %.

The foam is believed to be radiation hard up to 10^7 rad. Actual measurements with gammas from a Co^{60} source and neutrons from a reactor are in progress (in collaboration with the CERN Health Physics department).

Precision of drilling

The distance of the exits of drilled holes was compared to their distance at the entrance (7mm) in foam blocks of various thicknesses. For 10 cm thick blocks the differences of these distances were less than 60 μm, for 20cm thick blocks less than 150 μm. A prototype module, described below, with about 1200 holes will be measured optically to evaluate the same quantities on a larger sample. From our experience we trust that the drilling procedure can be perfectioned, if necessary, to give deviation from the design value of less than 150 μm in 20 cm long blocks. Larger block thicknesses are unpracticle because the drill motion becomes unstable.

Joints between foam blocks

The foam can be machined on a milling machine with great accuracy. Two pieces with machined plane surfaces can be joined at these surfaces and assembled in a frame for drilling. With the direction of the drill in the plane of the joint, the holes touching or intersecting the joint are nevertheless as precise as the others. The drill acts as if the block was uniform. This property can be used to envisage a design without gaps in azimuth. Individual foam pieces would extend over the full radial space from inner to outer radius, a 10 ^{0} interval in azimuth, say, and over 20 cm in beam direction. Two blocks adjacent in azimuth would be drilled in the same frame, each on half of its azimuthal coverage (see Fig.1). The second half of a block is then drilled in the next step together with its neighbour on the other side. Drilling of one hole takes on average less than half a minute for 20 cm thick blocks. The full barrel foam can thus be drilled in 2000 hours of machine time.

Positioning of foam blocks

The blocks are best positioned with the help of holes perforated at drilling time. One could for example sacrifice 4 straws in a 10^0 sector and replace them by C-fiber rods positioned with precision on the end plates.

Cooling of straws

The straws can be cooled by an air stream from the outside or by the gas inside. A gap between straw and foam of about $450\mu m$ will be necessary for mechanical reasons ($200\mu m$ for the reinforcement fibers, $150\mu m$ for the tolerance on the holes in the foam and $100\mu m$ for the tolerance in the straw position). While only a gentle air stream is necessary to avoid contamination of the foam with Xe gas from an eventual leak in a straw, this gap can also be used for cooling. An air flow of 5 cm^3/sec is necessary to absorb a heat of 13mW, if the temperature rise is to be less than 2K. The volume in a gap of $500\mu m$ between a 80 cm long straw and the foam is 5 cm^3. An air stream with a velicity of 0.8m/s or 3 km/h in such a gap can be maintained with an overpressure of 7 mb (see Fig.2). The total cooling requirement is 150 l/s of air on a 80 cm long detector.

A prototype (Figs. 3 -5) with blocks of 40 cm total length and about 1200 holes was built in order to see any difficulties in practice. In this design a 4 mm gap is left between the foam and the plate on which the straws end; this space is supposed to be sufficient to distribute the air pressure. The foam is covered on these ends by a thin C- fiber sheet (replaced by epoxy in the prototype). The 4mm gap between these cover plates and the straw end plates is maintained by a few spacers.

In the full detector one could envisage that the air is sucked in from the centre of the detector, leaving atmospheric pressure on the straw end plates. In this way no forces act on these plates. The price to pay is $\pm$ 4 mm space in the centre without radiator. This space is needed at a place in which the straws are anyhow insensitive due to a spacer which separates the two anode wires.

The prototype was operated with 100 straws in their positions; the other empty holes were covered with tape for the cooling test. During this work we found out that the foam is not completely gas tight; some of the air sneaked through the foam to the adjacent straw holes. An air flow of 1/2 l/sec, the design value, through the 100 straw gaps was maintained with an overpressure of between 3.5 and 7 mb. A more precise figure can be given when the air leakage to neighbouring channels is under better control. So far it was twice the gas flow through the gaps around the straws . We think that within a month this measurement can be finished. Twice this pressure will be needed for 80 cm straws. Also, the innermost and outermost layers of straws will have to be protected against air leakage in some way. More quantitative studies and also temperature measurements are in progress.

If it will be necessary to have an intermediate support at 40 cm from the straw ends, there are ideas of how to guide the air through this support (Fig.6). It may however be easier to further stiffen the straw , if needed, to avoid such a support .

Support of straws

While the mechanics of the straw end plates is not finalized ,it is useful to see the implications of a straw which sags under its own weight and is also squeezed by the anode wire. For sake of definiteness let us assume that the straw ends are rigidly fixed in their holes with the walls on a cylinder whose direction is parallel to the axis of the straw. Let l be the free length between supports (80 cm in our case), q the weight per unit length, T the tension on the anode wire, E $\cdot J_y$ the product of Young's modulus and the moment of inertia ($J_y = \int x^2 dA$, where x is the vertical distance from the straw axis).
The sag in the middle of the straw is then

$$s = \frac{2qEJ_y}{T^2}\left[\frac{1}{\cos\frac{\lambda l}{4}} - 1 - \frac{1}{2}\left(\frac{\lambda l}{4}\right)^2\right] \quad (1)$$

$$\lambda^2 = \frac{T}{EJ_y} \quad (2)$$

$$\lim_{T\to 0} s = \frac{ql}{EJ_y}\frac{5}{3}\frac{l^3}{2^{10}}. \quad (3)$$

From measurements on one individual reinforced straw we obtained

$$q = 1.2p/m \quad (4)$$

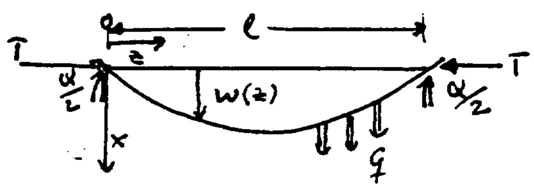
$$EJ_y = 80kp\cdot cm^2. \quad (5)$$

From the elongation quoted in the NIM paper we obtain $EJ_y = 66$ kp cm^2 for 3 fibers, suggesting 90 kpcm^2 for 4 fibers, in agreement with (5). The sagging without wire tension for a free length of 80 cm is then $80\mu m$, and $100\mu m$, if the wire tension is 50 g. This is acceptable. It means that an intermediate support for a 80 cm long straw is not necessary.

Appendix

Derivation of formula (1)

1. Consider first the case of a beam with uniform load (q per unit length) and an axial force T on the two ends, which are fixed in lateral position but free in their direction (i.e. the torque on the ends is zero). With vertical elongation w(z) the momentum of the external forces to the left of a section at z is



$$M_y = Tw(z) + \frac{ql}{2}z - \frac{q}{2}z^2. \tag{6}$$

It equals the momentum from the strain in the beam

$$M_y = -EJ_y w''(z). \tag{7}$$

The differential equation for w(z) is therefore

$$w(z) + \frac{1}{\lambda^2}w''(z) + \frac{1}{T}\left(\frac{ql}{2}z - \frac{q}{2}z^2\right) = 0 \tag{8}$$

$$\lambda^2 = \frac{T}{EJ_y}. \tag{9}$$

This equation is solved by considering

$$W(z) = \frac{q}{T\lambda^2} + \frac{q}{T}\left(\frac{l}{2}z - \frac{z^2}{2}\right) + w(z), \tag{10}$$

which satisfies

$$W''(z) + \lambda^2 W(z) = 0 \tag{11}$$

and has the general solution

$$W(z) = A\cos(\lambda z - \phi) \tag{12}$$

such that

$$w(z) = A\cos(\lambda z - \phi) - \frac{q}{T}\left(\frac{1}{\lambda^2} - \frac{l}{2}z - \frac{1}{2}z^2\right). \tag{13}$$

The boundary conditions w(0) =w(l)=0 give

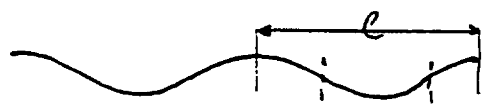
$$\phi = \frac{\lambda l}{2} \tag{14}$$

$$A = \frac{q}{T}\frac{1}{\lambda^2 \cos\left(\frac{\lambda l}{2}\right)}. \tag{15}$$

The sagging is

$$s = w(\frac{l}{2}) = \frac{qEJ_y}{T^2}\left[\frac{1}{\cos(\frac{\lambda l}{2})} - 1 - \frac{1}{2}\left(\frac{\lambda l}{2}\right)^2\right]. \tag{16}$$

2. The case with two supported ends is obtained from the previous case by a symmetry argument:
The solution of case 1) is the central piece of case 2). The end pieces are



reflections of the central piece. The sagging is therefore obtained by the replacement $w(l/2) \rightarrow 2w(l/4)$.

Figure captions

Fig.1. Drilling procedure for a detector without gaps in azimuth.
Fig.2. Measurement of air flow on a 1m long straw in foam.
Fig.3. Setup for cooling tests. Total height is 45 cm.
Fig.4. Detail of gas inlets.
Fig.5. Ensemble of test setup.
Fig.6. Intermediate support of straws with extensions for gas flow.
This support may be not necessary.

Table 1 : Measured features of NEOPOLEN-P9230 foams

	symbol/ units	RG70	RG80	RG90
density	$\rho/\frac{g}{l}$	65 ± 5	73 ± 4	79 ± 4
thermal linear expansion coefficient ($20°C \leq T \leq 100°C$)	$\alpha/\frac{10^{-6}}{K}$	120 ± 10	130 ± 10	130 ± 10
thermal volume expansion coefficient ($20°C \leq T \leq 100°C$)	$\gamma/\frac{10^{-5}}{K}$	36 ± 2	40 ± 2	40 ± 2
Young's modulus, modulus of elasticity ($0.5 \cdot 10^5 Pa \leq p \leq 1.5 \cdot 10^5 Pa$)	$E/\frac{kp}{cm^2}$ $E/10^5 Pa$	100 ± 10	130 ± 10	150 ± 10
modulus of shear, modulus of torsion (*drilled foam*)	$G/\frac{kp}{cm^2}$ $G/10^5 Pa$			37 ± 4
absorbtion length ($E_\gamma = 5.9 keV$)	X_o/cm	1.5 ± 0.2	1.5 ± 0.2	1.4 ± 0.1

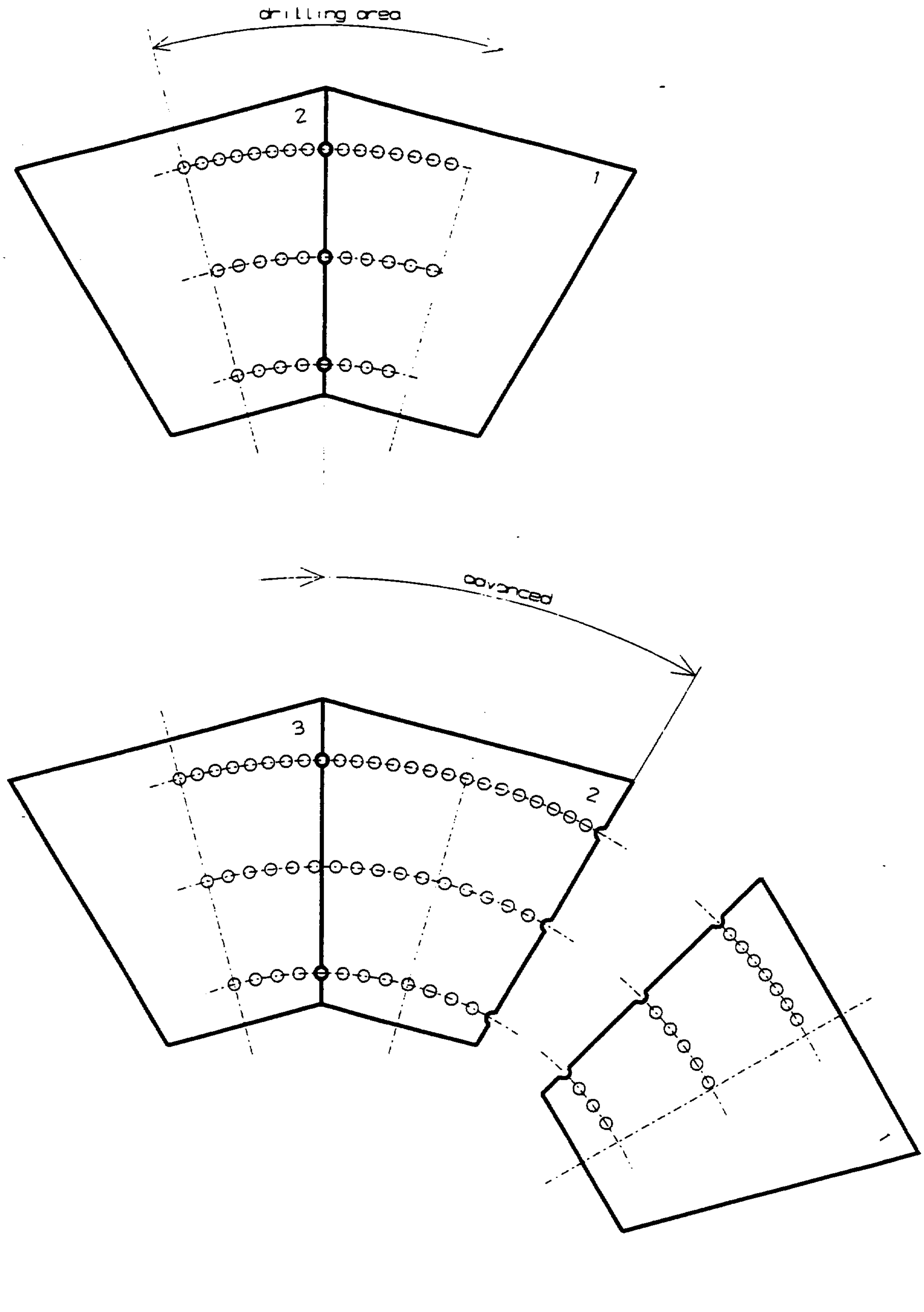
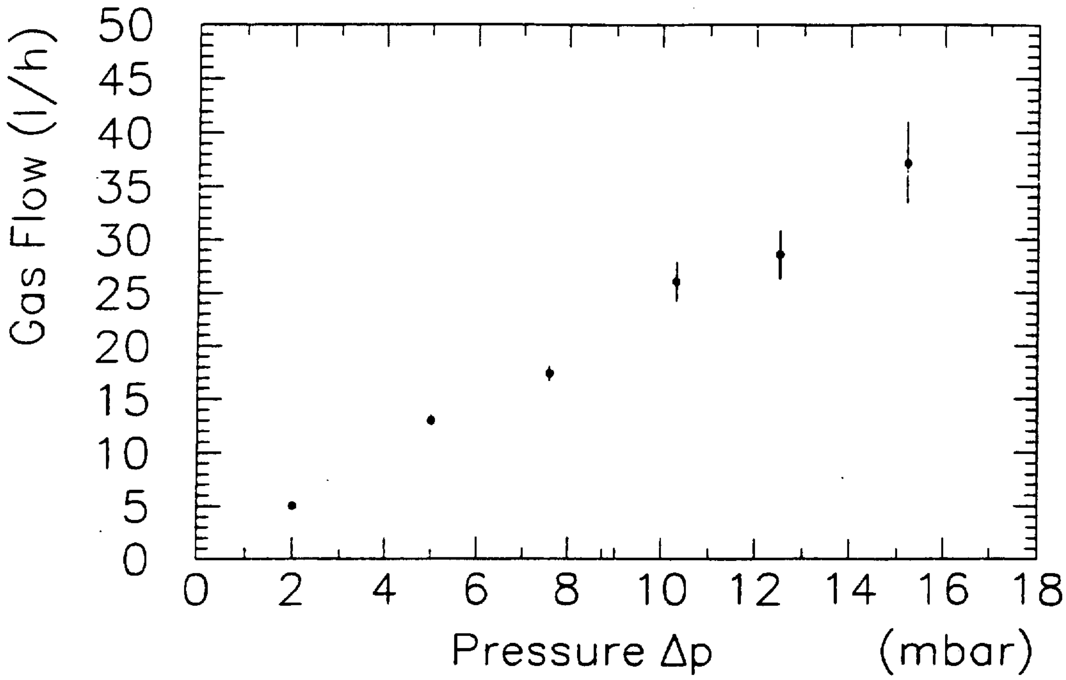
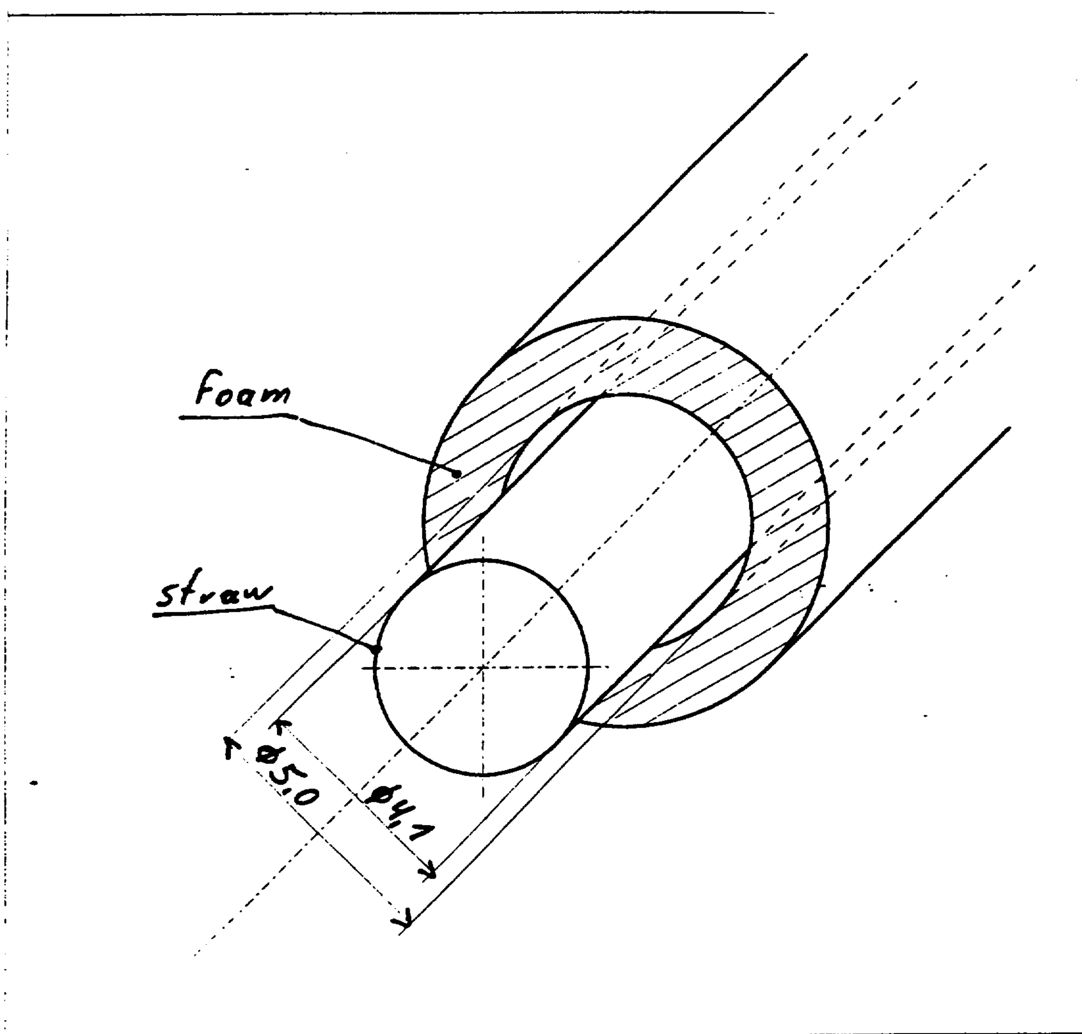


Fig. 1



Gas Flow (l/h)
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
Pressure Δp
(mbar)



Foam
straw
ø5,0
ø4,1

Fig. 2

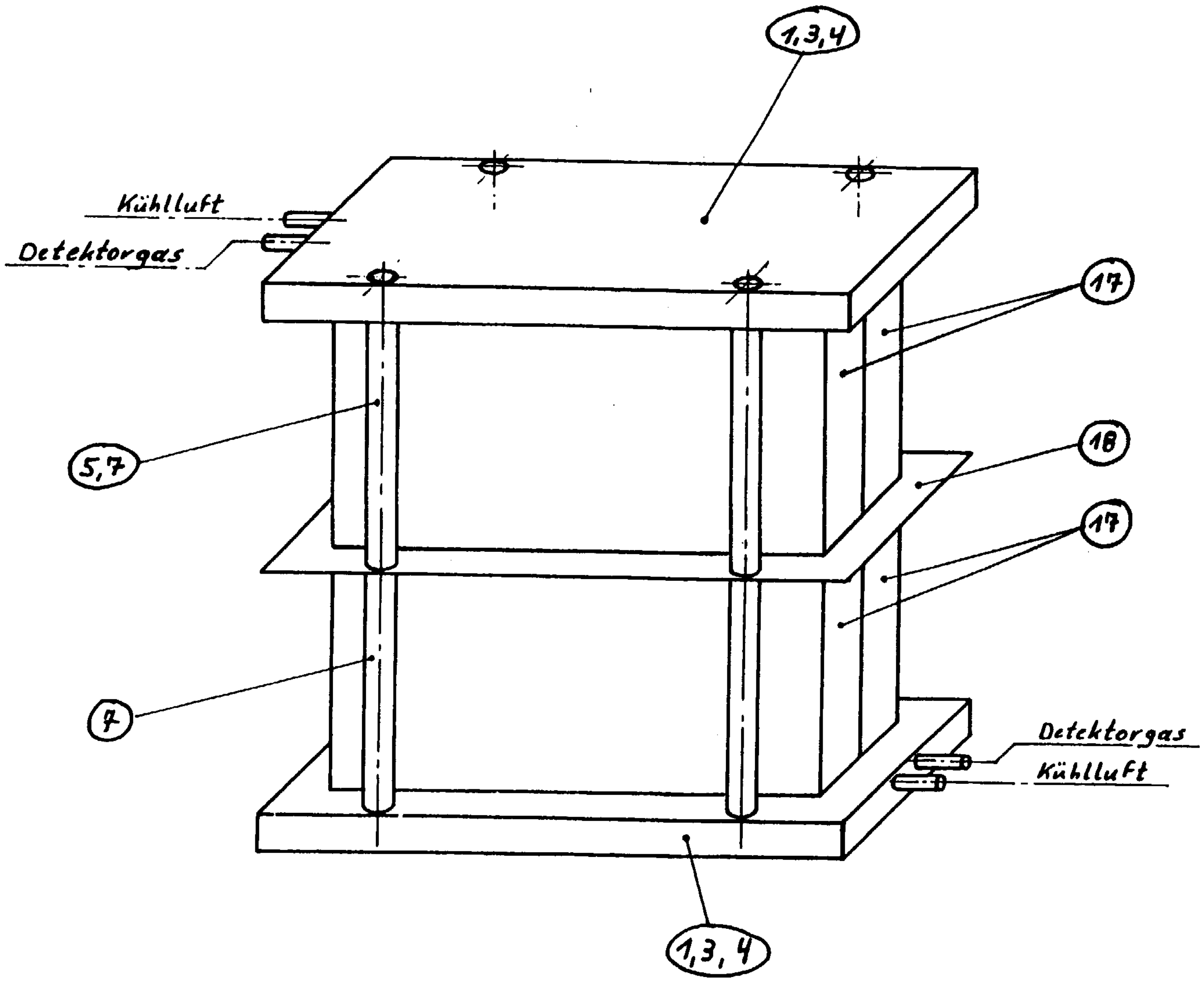


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Fig. 3

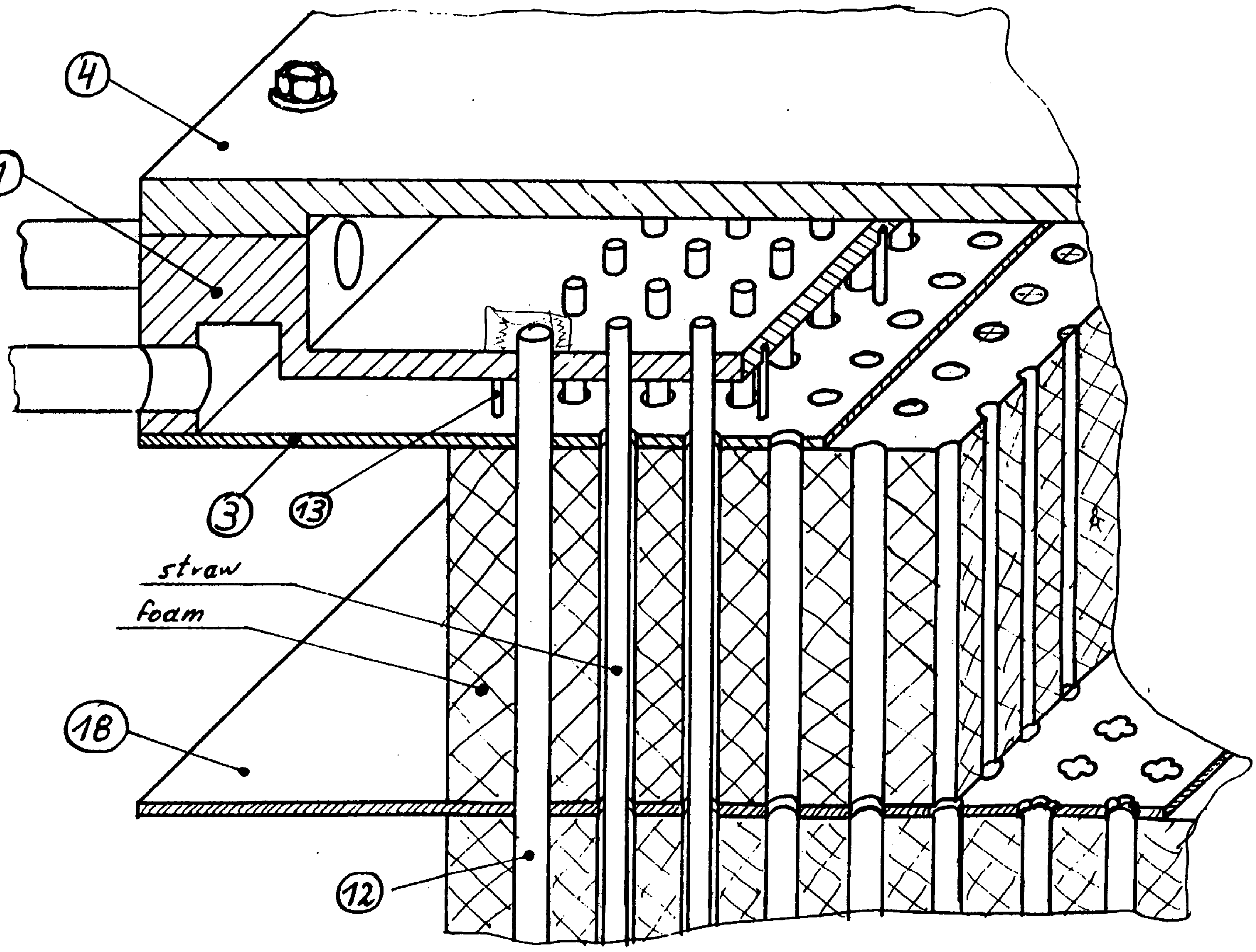
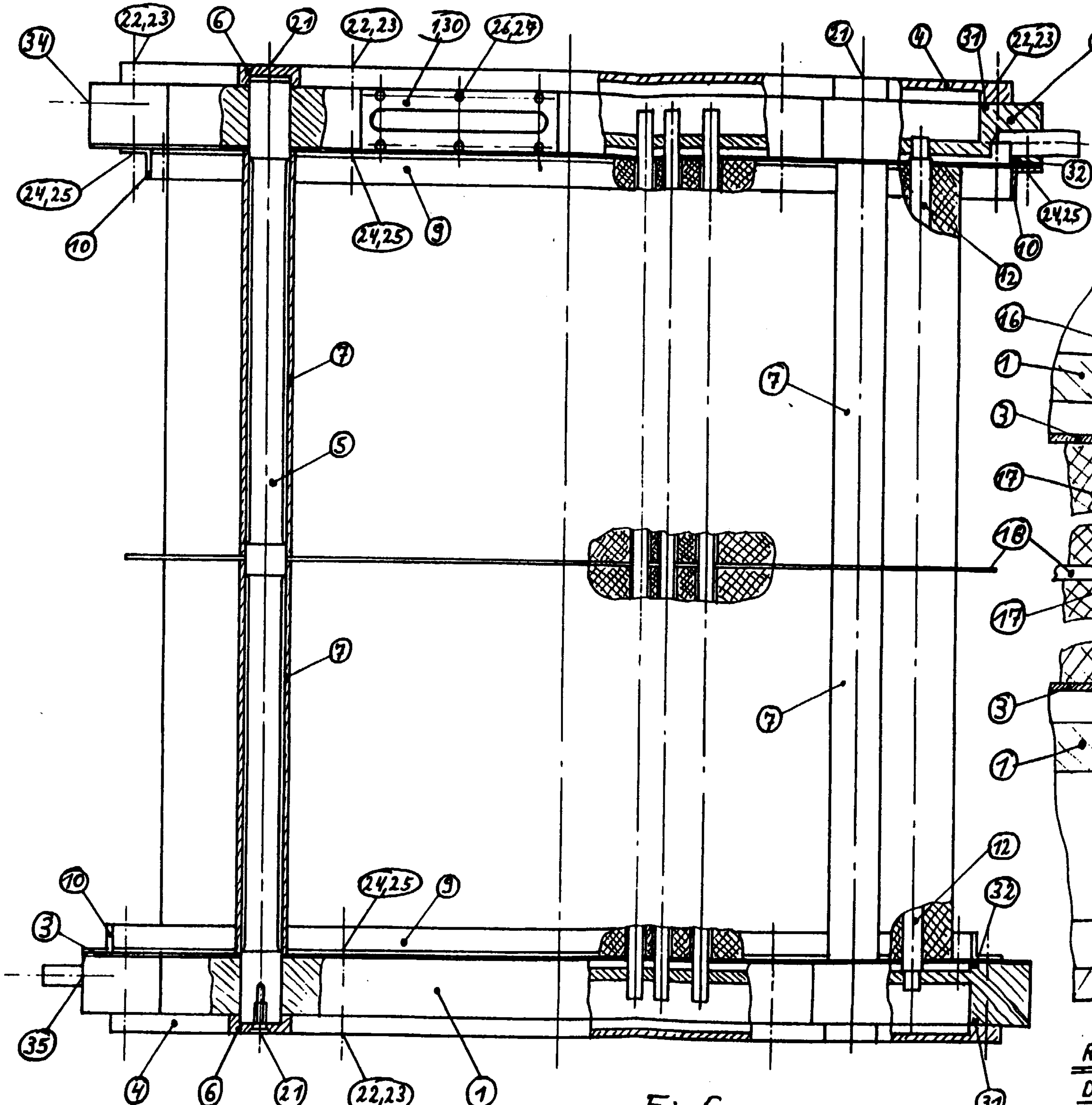


Fig. 4



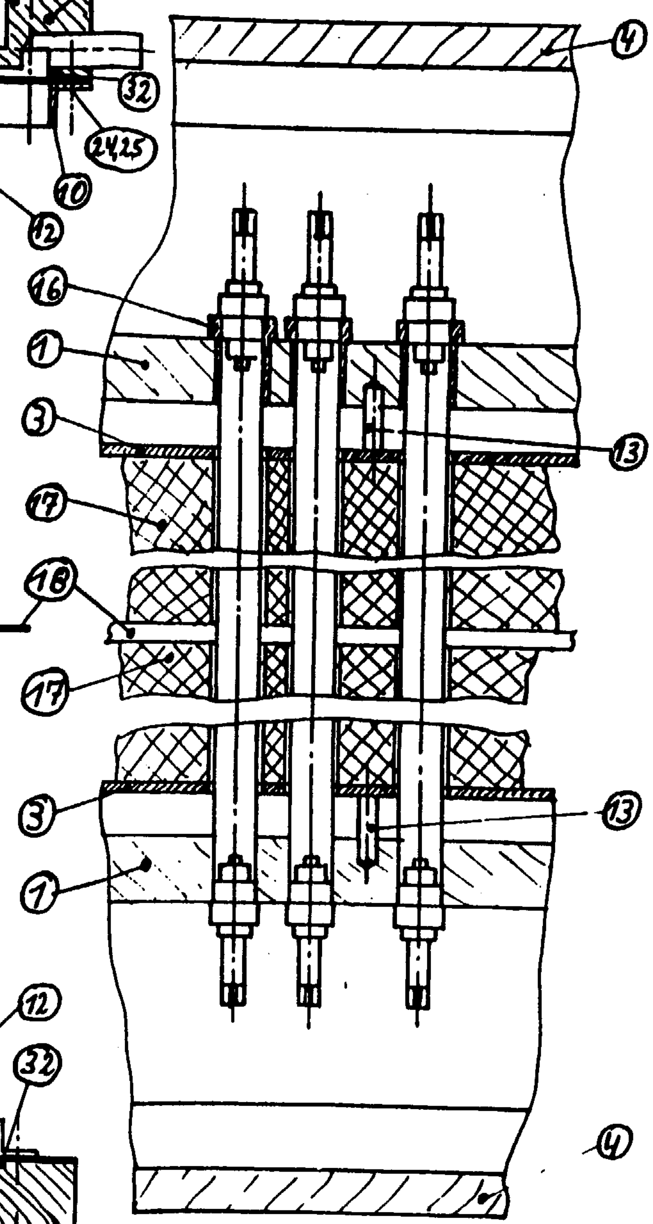


Fig. 5

RD6 Testaufbau
Disposition M 1:2
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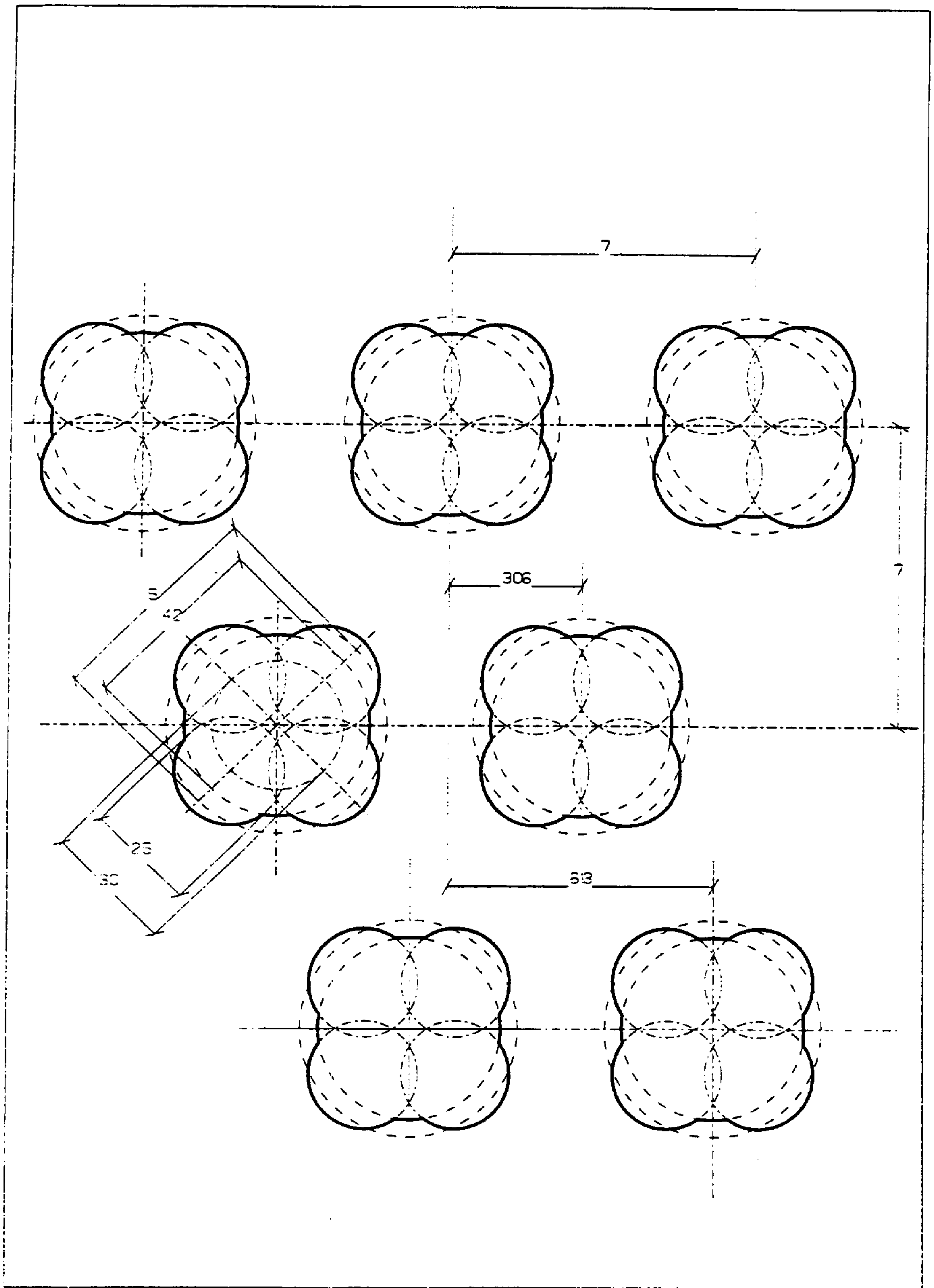

Fig. 6