Construction details of a closed and oil-filled tapping lines system for pressure drop fluctuation measurement

CONSTRUCTION DETAILS OF A CLOSED AND OIL-FILLED TAPPING LINES SYSTEM FOR PRESSURE DROP FLUCTUATION MEASUREMENT

C.W.M. van der Geld
R.B.M. v.d. Berg
P.G.M.T. Boot
P. Brinkgreve
J. Groot
T.A.M. Jansen

Eindhoven University of Technology
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NOMENCLATURE

P_3	spectral power in interval (0,25; 3) Hz
P_6	spectral power in interval (0,25; 6) Hz
P_{max}	maximum of P_6 for all flow regimes at certain system pressure
P_{noi}	value of P_6 for single phase water flow at well-defined superficial velocity (about 1,2 m/s for example)

Acronyms

OFTAL	Oil Filled TApping Lines system
RVS	Stainless steel
TUE	Technical University of Eindhoven

LEGEND TO FIGURES

General Legend :

Scale 1 : 1 unless stated as 2 : 1. Only the figures of the restriction and the membranes on scale 0,7 : 1 approximately. The appendix is decreased in size from A1 to A3 format.

Roughness according to NEN 630.

I.S.O. tolerances were used except for the O-ring chamber.

Piece number	Description	Material	#needed for construction of 8 OFTAL's		Comment
1	Welding piece	RVS 304	32		Browning
2	Mounting piece (nut)	RVS 304	32		Browning
3	Nipple	RVS 316	32		SEL
4	Pressure transducer	RVS	8		
5	Mounting piece (bolt)	RVS	16		
6	Fixing piece (coach)	RVS	8		round 0,5
7	Support piece (block)	RVS	8		
8	Bullet	RVS	8		round 4
9	Holder	RVS 316	8		
10	Nose	RVS 316	8		
11	Special bolt ('inbus')	RVS	64	Nen 1241	M6 x 60
12	Viton O-ring	rubber	8	R 3106	Eriks
13	Mounting piece	RVS	8	thickness	0,02
14	Restriction	Copper	16		
15	Mounting piece	RVS			
16	Ring of Stenan	Stenan	16		
17	Lava sealant	Lava	16		2 parts
18	Pressing piece	Al_2O_3	16		2 parts
19	Holder for pressing piece	RVS	16		2 parts
20	De-airating vent hole	RVS			

1 INTRODUCTION AND ACKNOWLEDGEMENT

In order to investigate the stochastic character of two-phase flows in the low frequency range (0 - 20 Hz) from differential pressure measurements, it is a necessaty to avoid spectrum noise and signal distortion. However, it is difficult if not impossible to keep the usual tapping lines systems to evaporator tubes free of gas and vapour.

Therefore, in 1982, I conceived a new tapping lines system. The system had to be closed by thin diaphragms and to be filled up with silicone oil. Differential pressures of the order of 0,5 cm water column were to be measured at a pressure level of about 150 bar. Also, two-phase flow temperatures of about 270 $^{\circ}$C had to be dealt with.

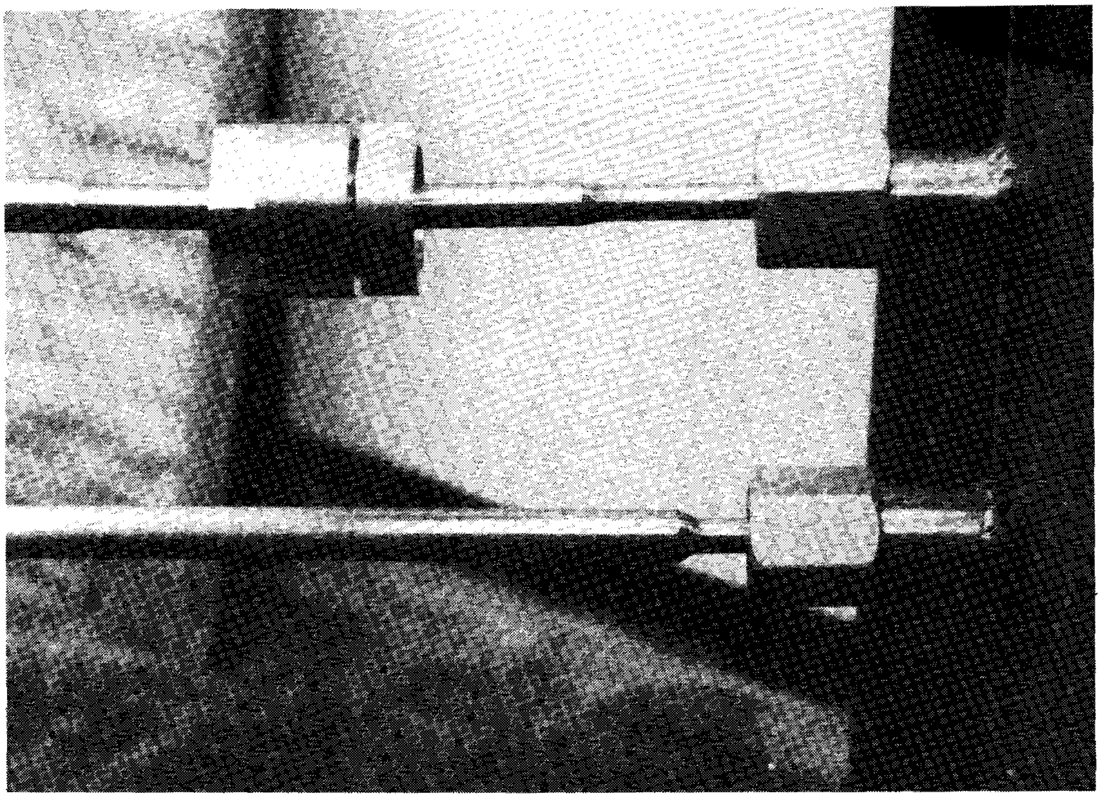


Figure 1.1

June 1982: First attempt with oil-filled tapping lines.

Test section, Conax couplings and electrically isolating connection.

These design requirements are not easily met. The first concept had a long way to go: several times adaptations were imposed (see figures 1.1 through to 1.4; some more historical details can be found in Reference 2). Each time, experiments were needed to learn the system behaviour and its responses to pressure drops and temperature changes. This interaction between experiment and design and construction required a flexible arrangement between experimentators and manufacturers. For their benevolent cooperation in this I am still gratefull to Mr. P. Brinkgreve and Mr. J. Groot of the Central Technology Department (CTD) of the Eindhoven University of Technology (TUE).
Both of them and Mr. T.A.M. Jansen (Technical Staff, group WOP-WET of the Faculty of Mechanical Engineering, TUE) took part in the first 'design sessions', during which I started by putting forward my design sketches. Subsequently, new design ideas were added, a critical analysis took place, and details were made amendable to construction. I learned a lot from these well-experienced people. Mr. Jansen eventually made the drawings, and Mr. R. v.d. Berg manufactured the early tapping lines sytems. It is fair to say that both of them improved the construction procedure during the process.

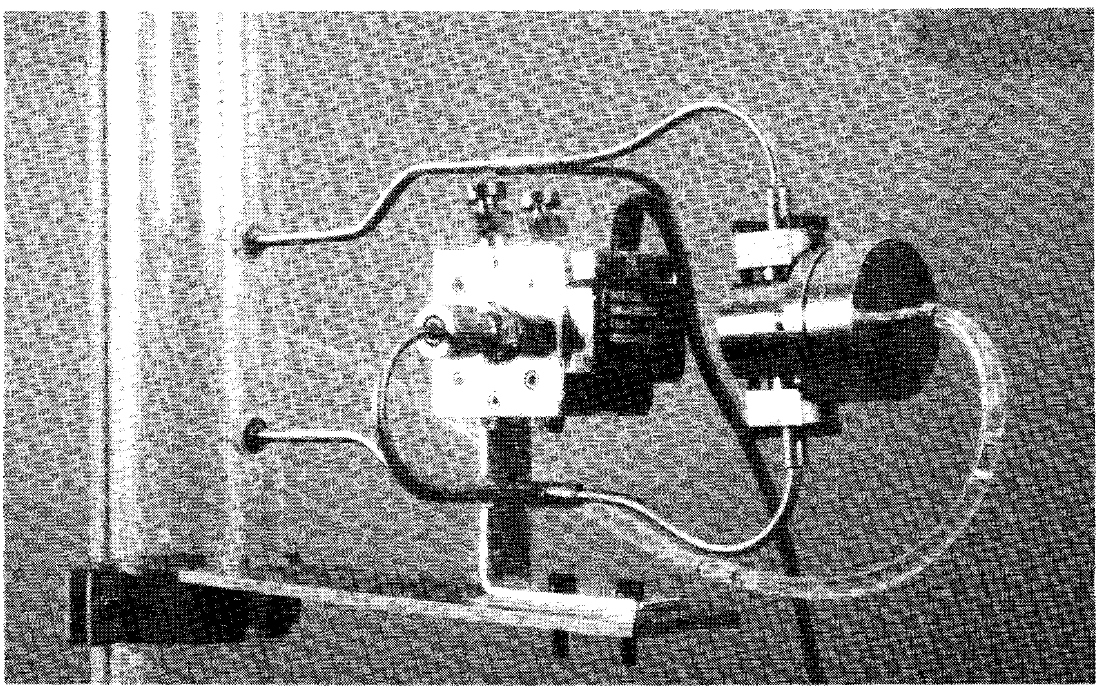


Figure 1.2
Operational oil-filled tapping lines (OFTAL) on perspex test section.

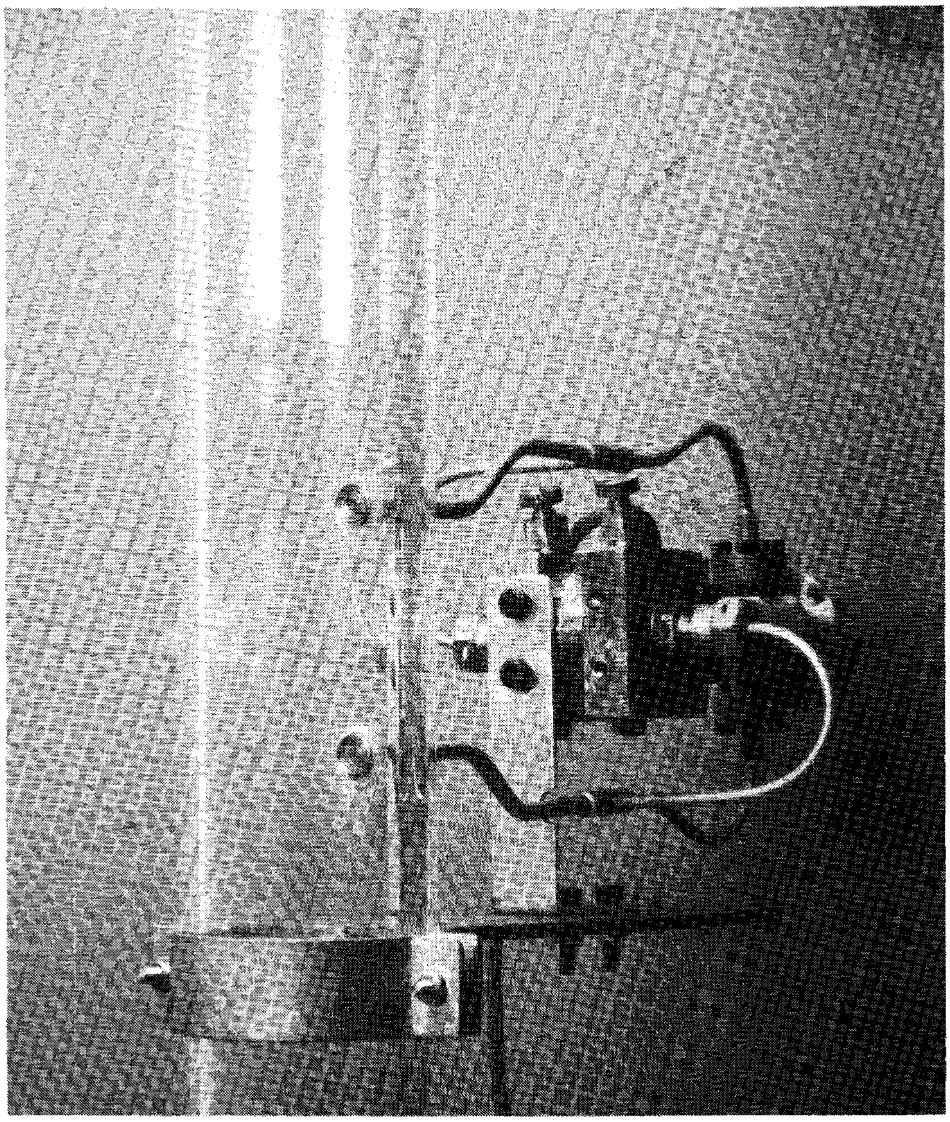


Figure 1.3

View on front membranes of OFTAL on perspex tube.

The first completely satisfactory experiments were performed in a small transparent test section (see figures 1.2 through to 1.4). At this time, the trial concept had already evolved into a useful tapping lines system. Thereafter, several tapping lines systems for use in evaporator tubes were manufactured (see figures 1.5 through to 1.7). At this time, Mr. v.d. Schoot (WOP-WET) manufactured some parts, and he and mr. P. Boot also added some construction improvements.

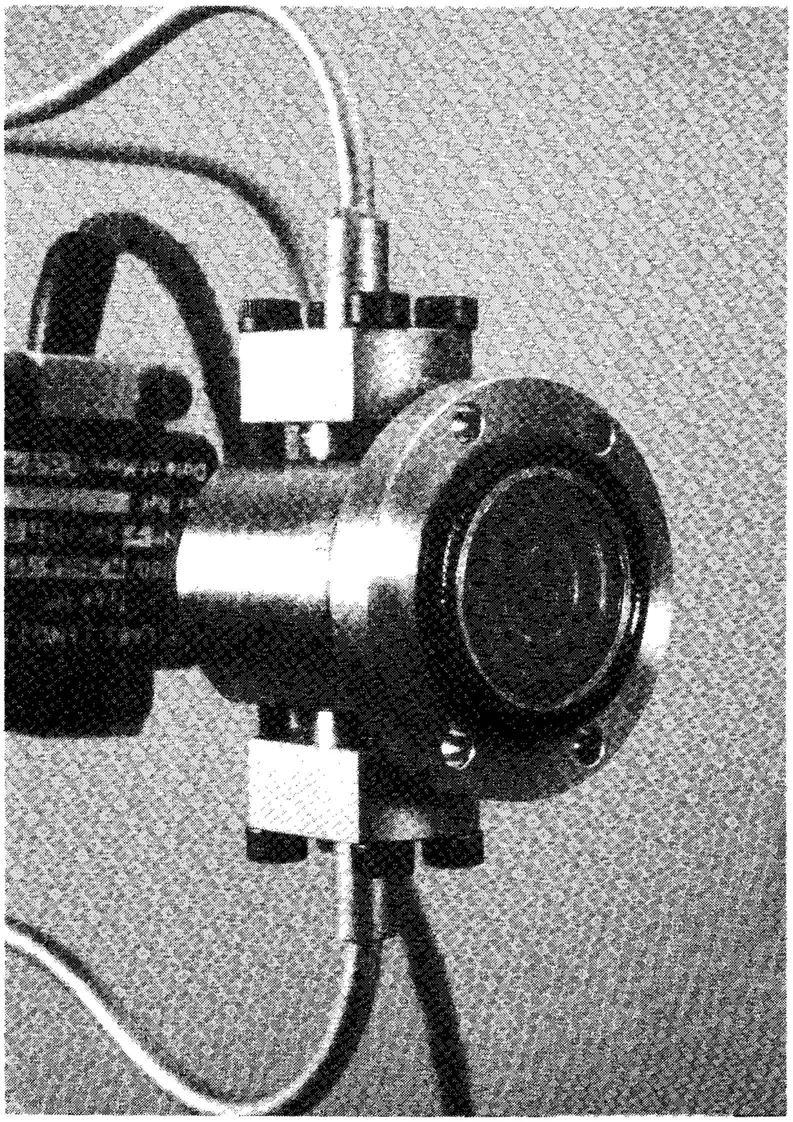


Figure 1.4
View on compensation membrane of OFTAL on perspex tube.

The above historical notes make clear that I am much obliged to my co-authors. Mr. R. v.d. Berg, Mr. P. Boot and Mr. T. Jansen helped me compiling the information that is contained in the following chapters. Mr. T. Jansen made the original A1-drawing (see Appendix), which was basic material for many other figures.

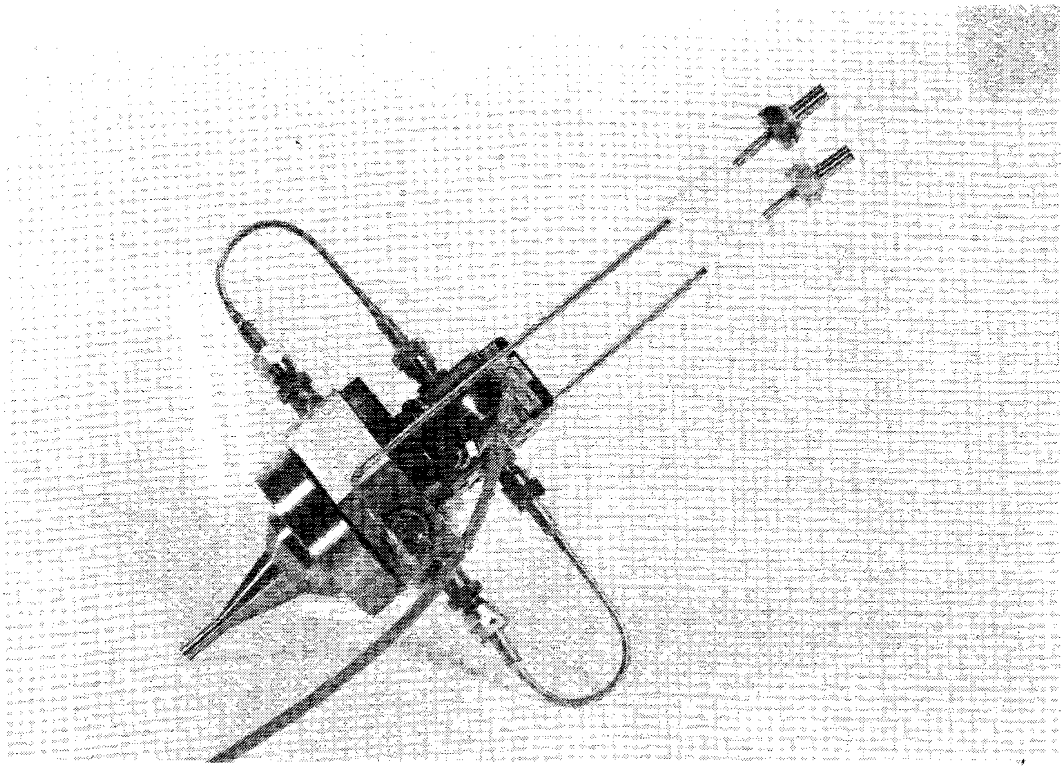


Figure 1.5

View on OFTAL with lava sealants and membrane chamber.

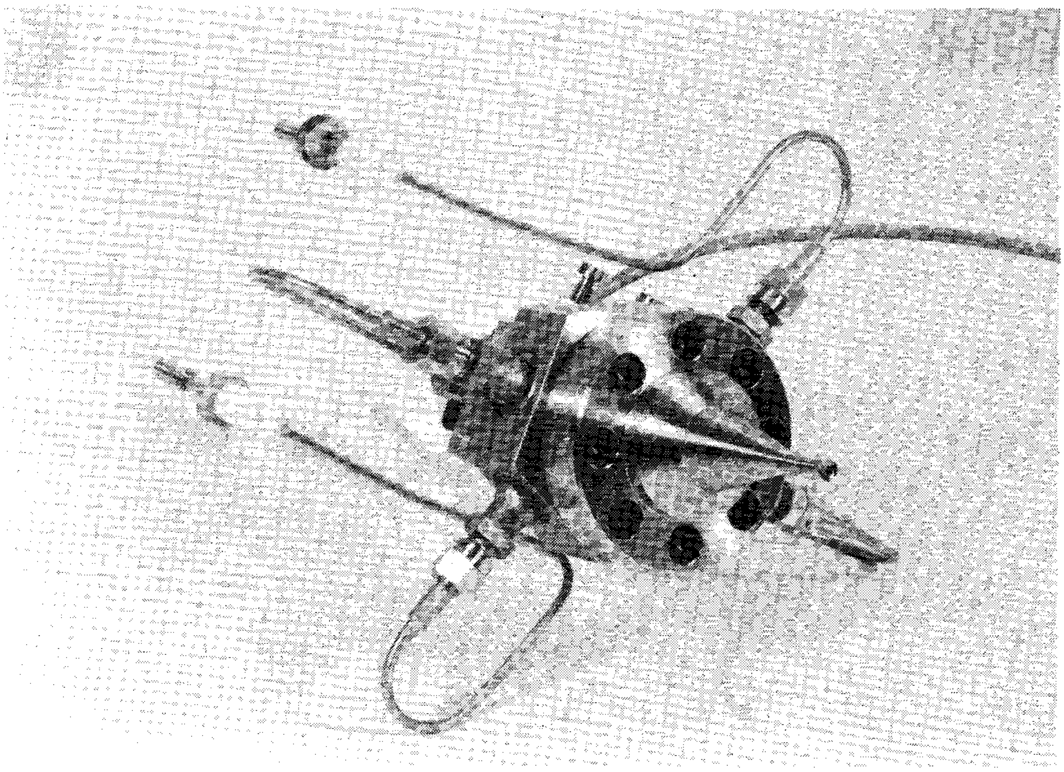


Figure 1.6

View on OFTAL.

I am also indebted to prof. ir. C.W.J. van Koppen and Mr. M. Verduin, at that time dane of the Faculty of Mechnanical Engineering, who encouraged and supported the design and development of this instrument.
Financial support was given by the Netherlands Organization for the Advancement of Pure Research (ZWO).
My Italian collagues from ENEA, especially Mr. M. Annunziato, stimulated the writing of this report.

C.W.M. van der Geld
Oktober 1987

2 WORKING PRINCIPLE

The working principle of the oil-filled tapping lines system for flow regime recognition was introduced in Reference 2 and further explained in Reference 1.

The tapping lines system is closed off by thin, flexible diaphragms, and is filled up under vacuum with silicone oil. In this way the content of the tapping lines is prevented from becoming two-phase, and unwanted pressure fluctuations do not occur.

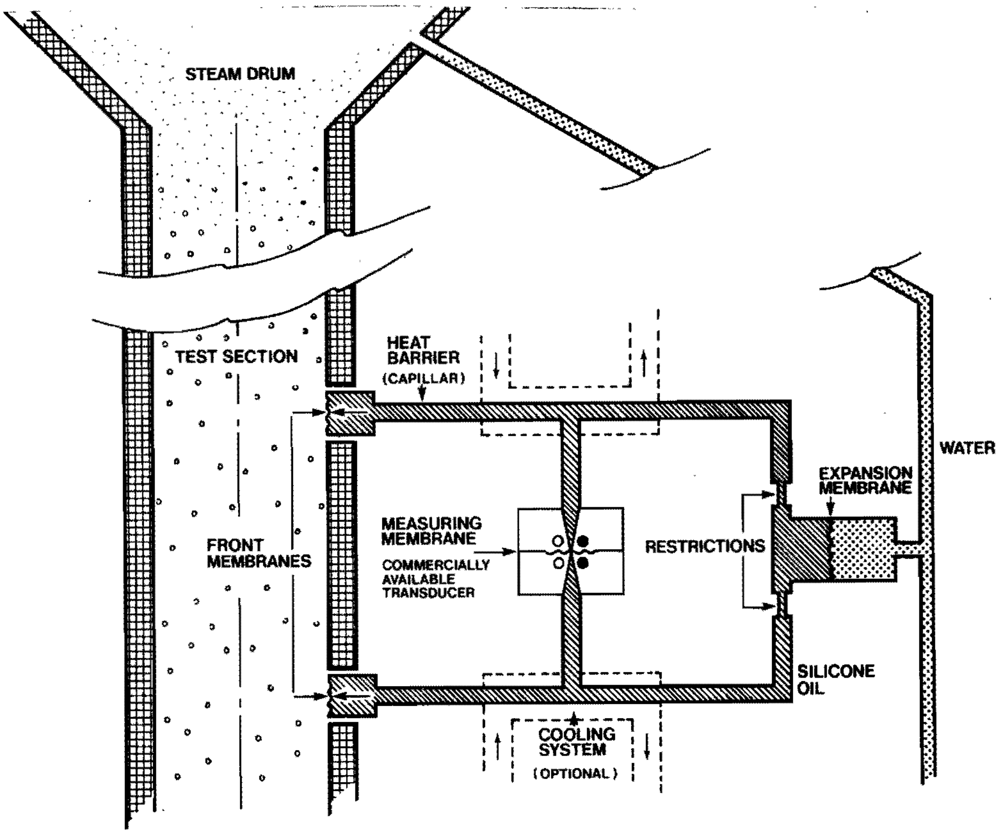


Figure 2.1
Schematics of OFTAL

The silicone oil used withstands temperatures up to 330 ^{0}C and has a good heat conductivity : 0,163 W/mK, which hampers local overheating of the content. The capillary tubes directly behind the front membranes minimize heat conduction from the heated test section and are easily cooled by air currents or a fan. Still the thermal expansion of the oil has to be accounted for. Therefore a flexible, large expansion membrane was introduced. The

back side of the expansion membrane is kept under system pressure with the aid of a back lead towards the steam drum (see Figure 1.7). If the oil expands, the expansion diaphragm takes up another position, whereas the position of the much smaller front membranes is less easily affected.
Two copper restrictions, small narrow channels, guarantee that static pressure drops are annihilated via the restrictions and some tension in the front membranes. The latter, undesirable tension has to be minimised by placing the front membranes only a small distance apart.
Because of fluid inertia and viscosity are pressure drop fluctuations with frequencies higher than about 0,25 Hz still being detected by the measuring membrane of the commercially available differential pressure transducer (SE 1130).

3 CONSTRUCTION OF THE MEMBRANES

3.1 Manufacturing membranes

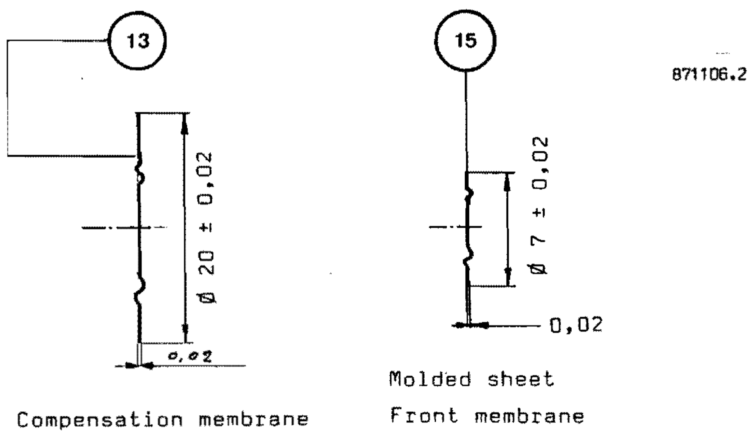


Figure 3.1
Diaphragms with dimensions

Each thin (0,02 mm), corrugated diaphragm is made of stainless steel (number 1.4310) and are deformed with the aid of a die (mold) in order to press concentric circles in it (height 0,25 mm, width 0,7 mm, largest outer diameter 5,3 mm). The latter increases its flexibility.
No tiny ruptures or distortions should occur on the diaphragm.

3.2 Some details of the membrane carriers

The Vitan O-ring that is used for shielding requires a space or chamber with measures that are presribed by the O-ring manufacturer or distributer. The silicone O-ring used withstands temperatures up to 230^{0} Celsius, is low cost (1,5 Dutch Fl.), and has order number 120 with Eriks.

3.3 The welding procedure of the membranes

In order to fix such a flexible diaphragm on a stainless steel (316 Ti) carrier, a piece of tube (see Figure), plasma welding was applied. This procedure requires an additional mounting piece, also a tubing, to ensure a straight and tidy fixing of the membrane on its carrier (see Figure). The

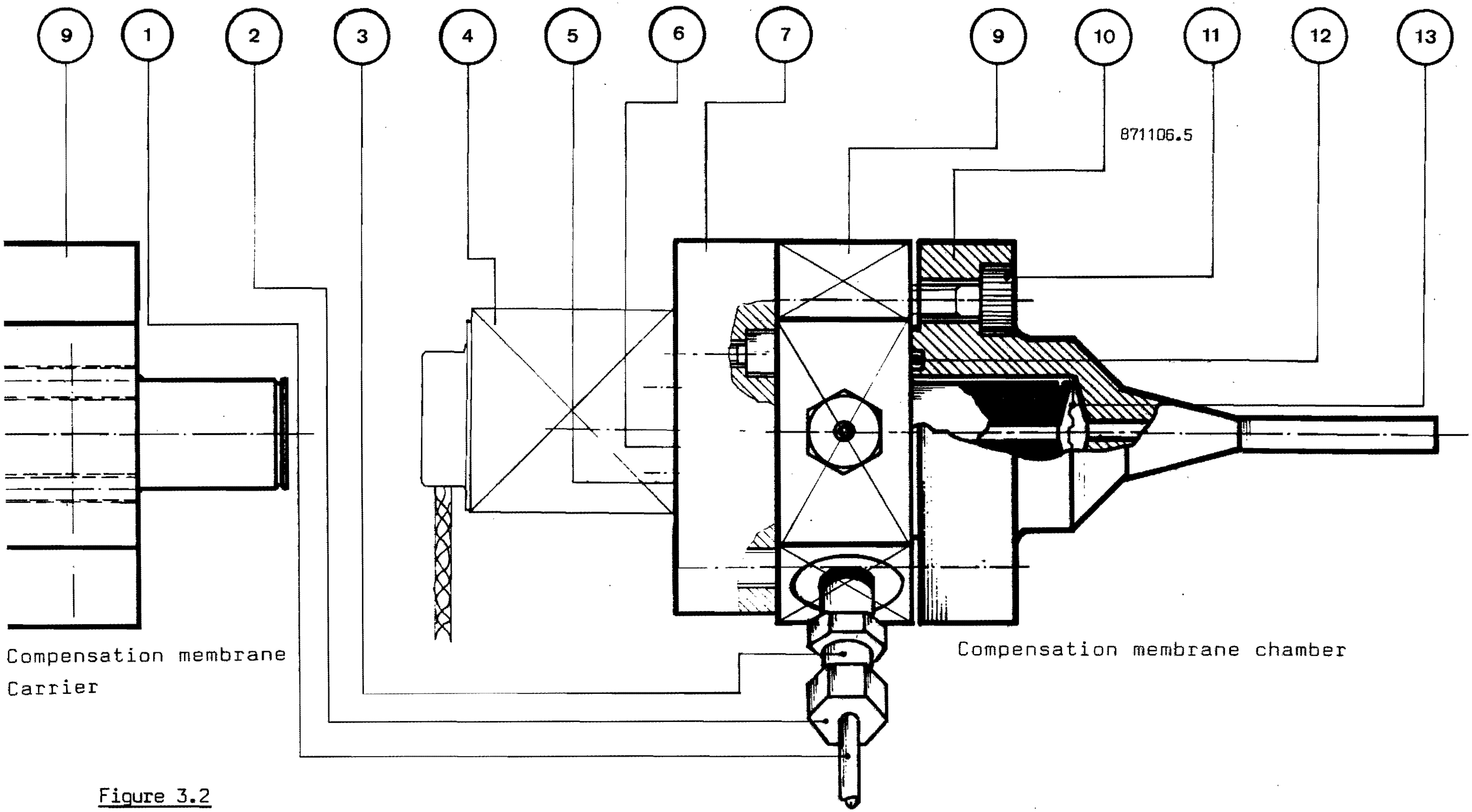


Figure 3.2

Assembly of compensation membrane carrier

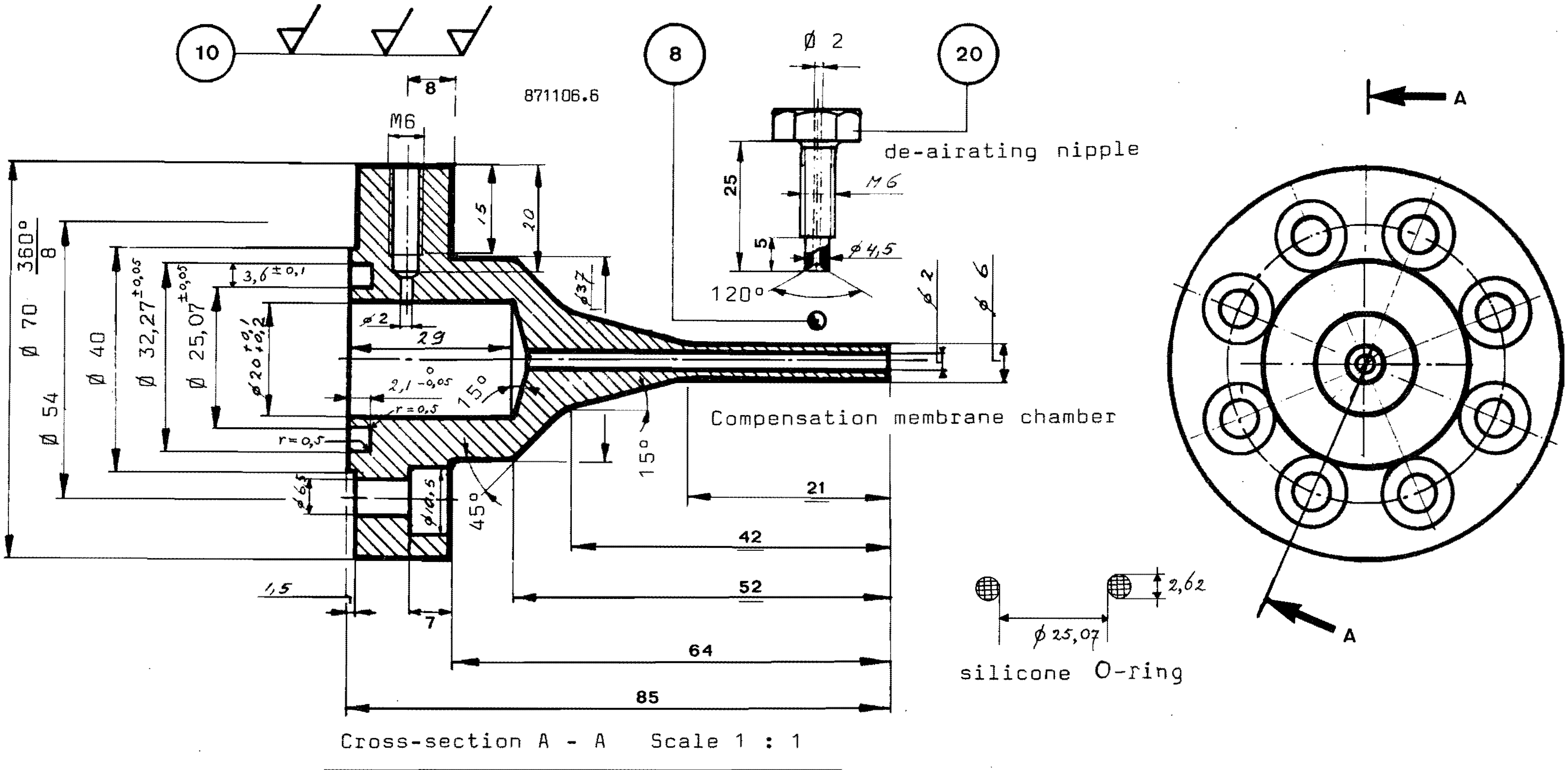
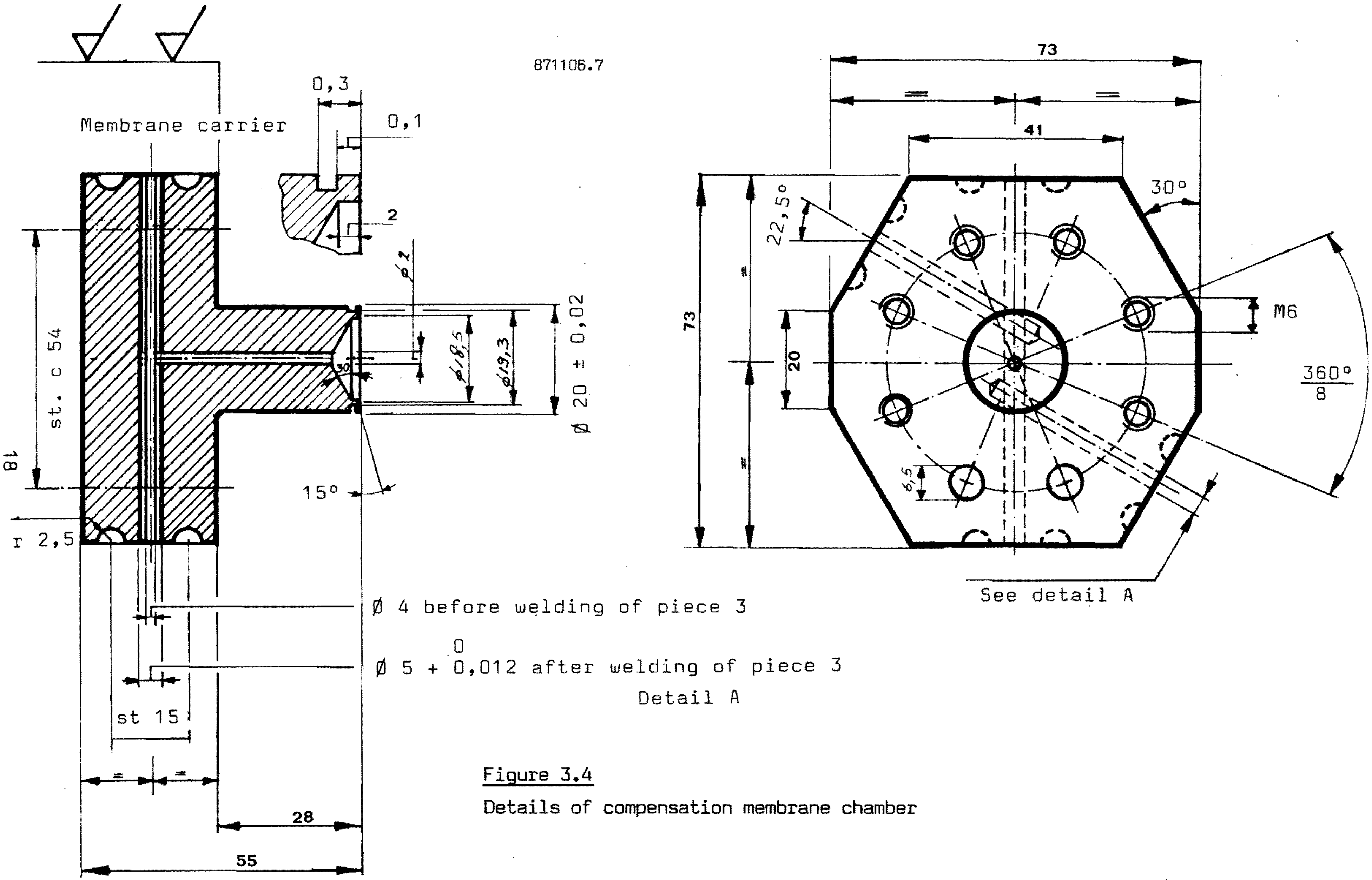


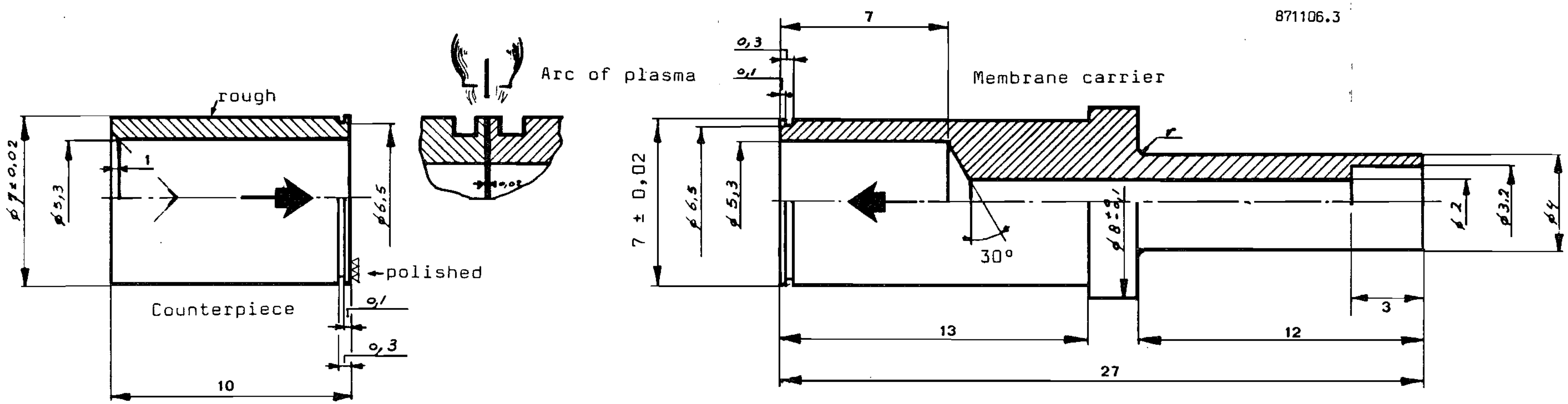
Figure 3.3

Compensation membrane chamber with dimensions



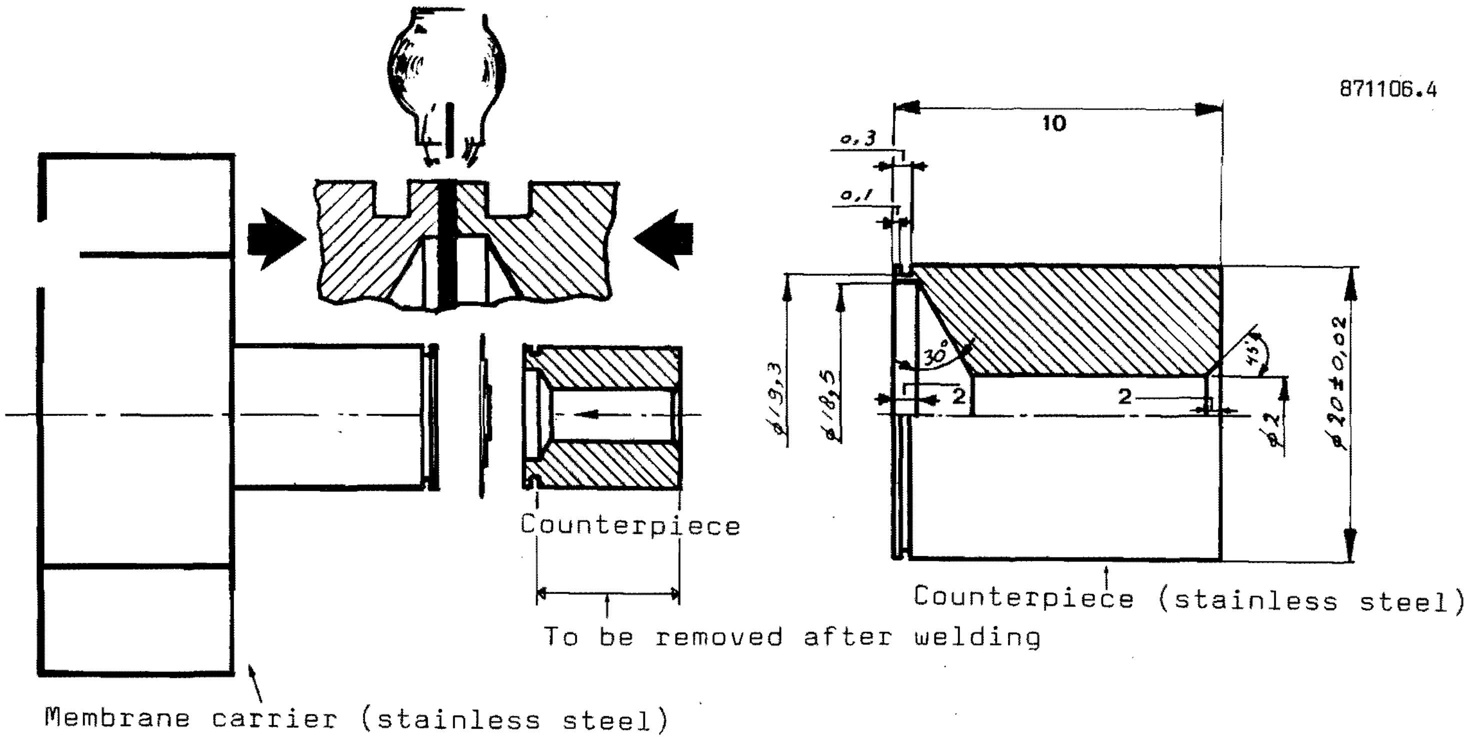
<u>Figure 3.4</u>

Details of compensation membrane chamber



<u>Figure 3.5</u>

Front membrane carrier with counterpiece for welding



<u>Figure 3.6</u>

Compensation membrane carrier with counterpiece for welding stainless steel (316 Ti) additional mounting piece thus keeps the membrane in place.

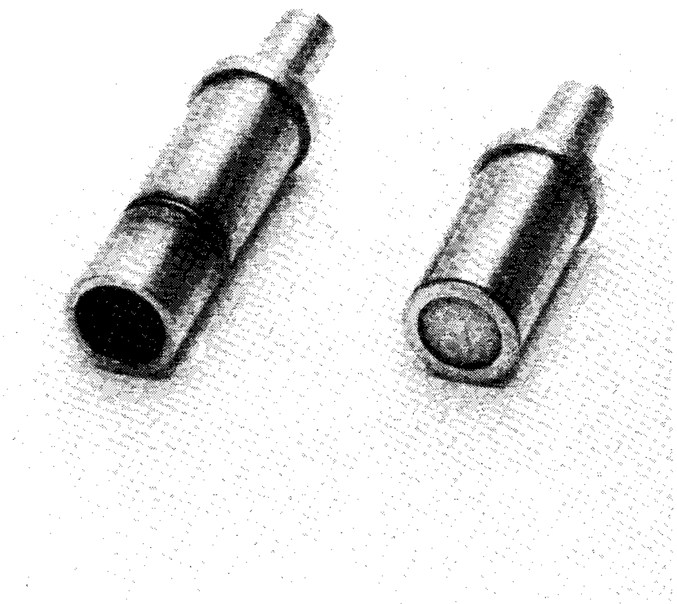


Figure 3.7

View on membrane welded inbetween counterpiece and holder.

The procedure is as follows.

1. Accurate manufacturing of each part.

2. The welding. Both carrier and counterpiece are rotated during welding, and are therefore clamped inbetween two mounting pieces of a bench. The alignment of carrier and counterpiece has to be done very carefully. Each unbalance induces malposition of the welding arc and hence temperature gradient in the membrane.

3. The removal of the counterpiece without inflicting the membrane. Measures and finishing off of the welding have to get particular attention.

4. Vacuum leakage testing of carrier with membrane.

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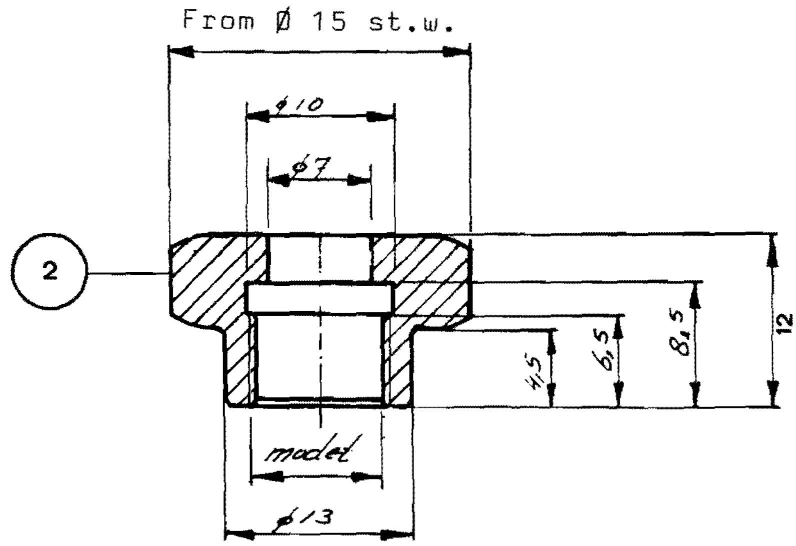
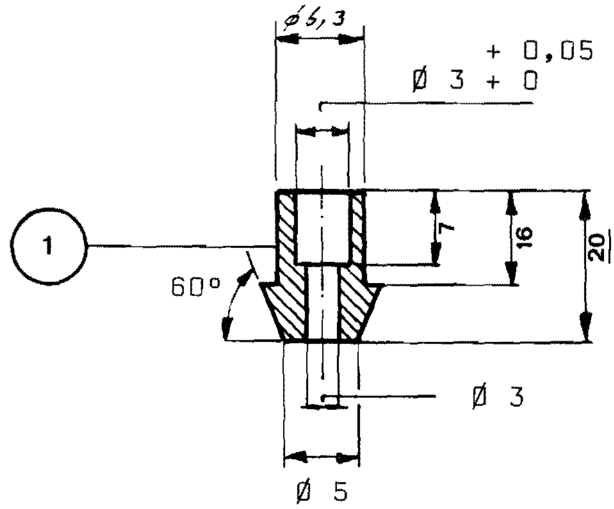


Connecting piece for welding stainless steel capillary tube into



Scale 2 : 1

Figure 3.8

Details of connecting pieces

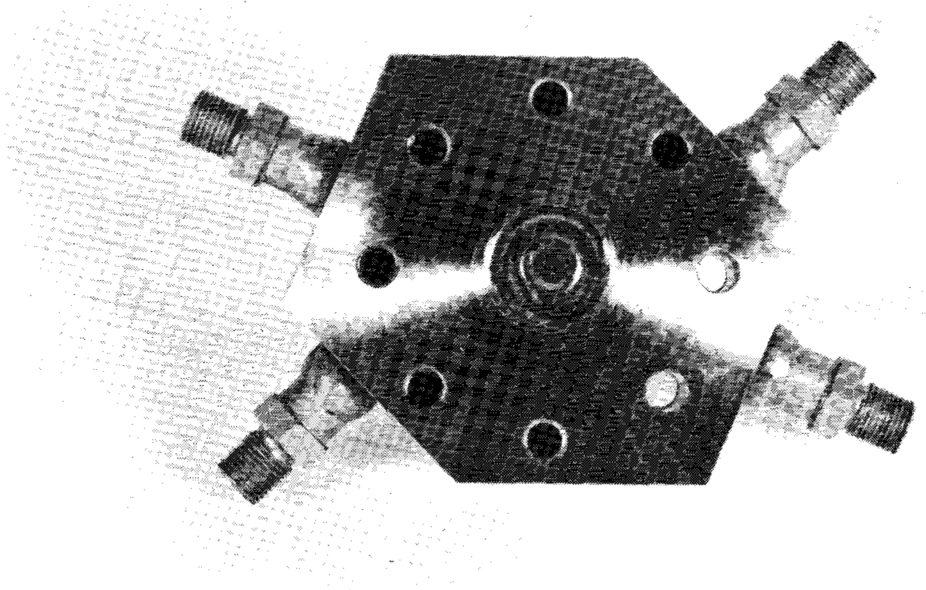


Figure 3.9

View on compensation membrane of OFTAL

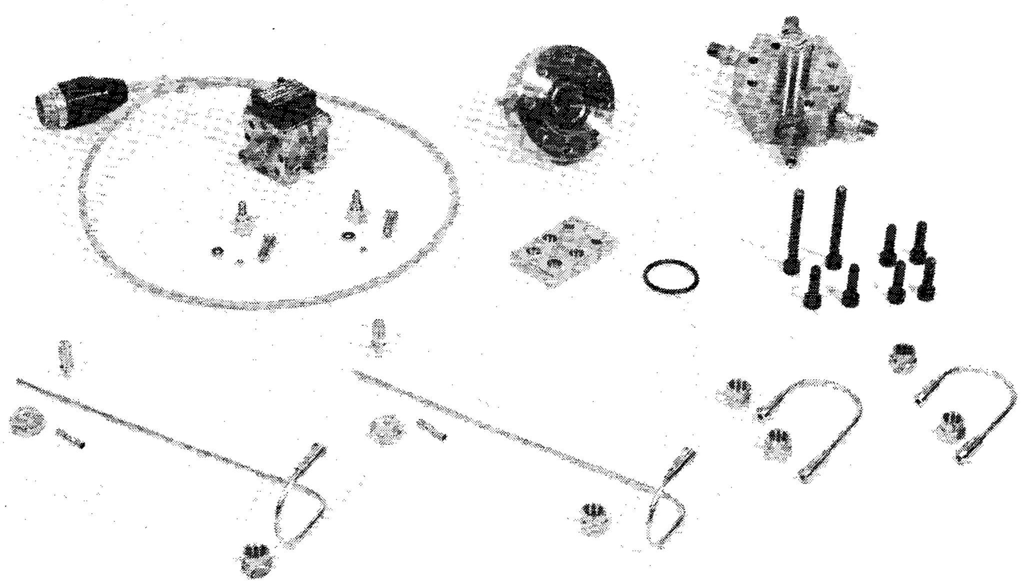


Figure 3.10

View on all collected parts of OFTAL

4 THE RESTRICTIONS

The dimensions indicated for the copper restrictions are such, that they only fit tightly into the circular channel. The latter has to be cleared from irregularities after drilling up to the place where the restriction should be located.
In order to put each restriction in place, an especially adapted small tube or bar and a light hammer can be used. The restriction should gradually be driven towards its proper location.

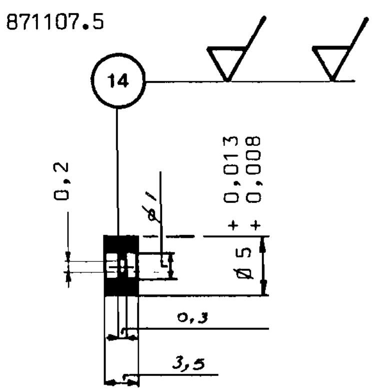


Figure 4.1
Dimensions of a restriction

In order to ensure a proper functioning of the restrictions it is very important to have all other channels much wider in cross-sectional area. If one employs the SEL differential transducer like we did, this requires a severe adaptation of the transducer. The tiny channels in it, leading towards the measuring membrane, have to be enlarged!!
In addition to this channel broadaning we adapted the closure of the transducer : thin O-rings were implemented that fit tightly into their holes. At high pressures these O-rings are now hardly expelled outwards, whereas the conventional shielding was not convincing on this point.

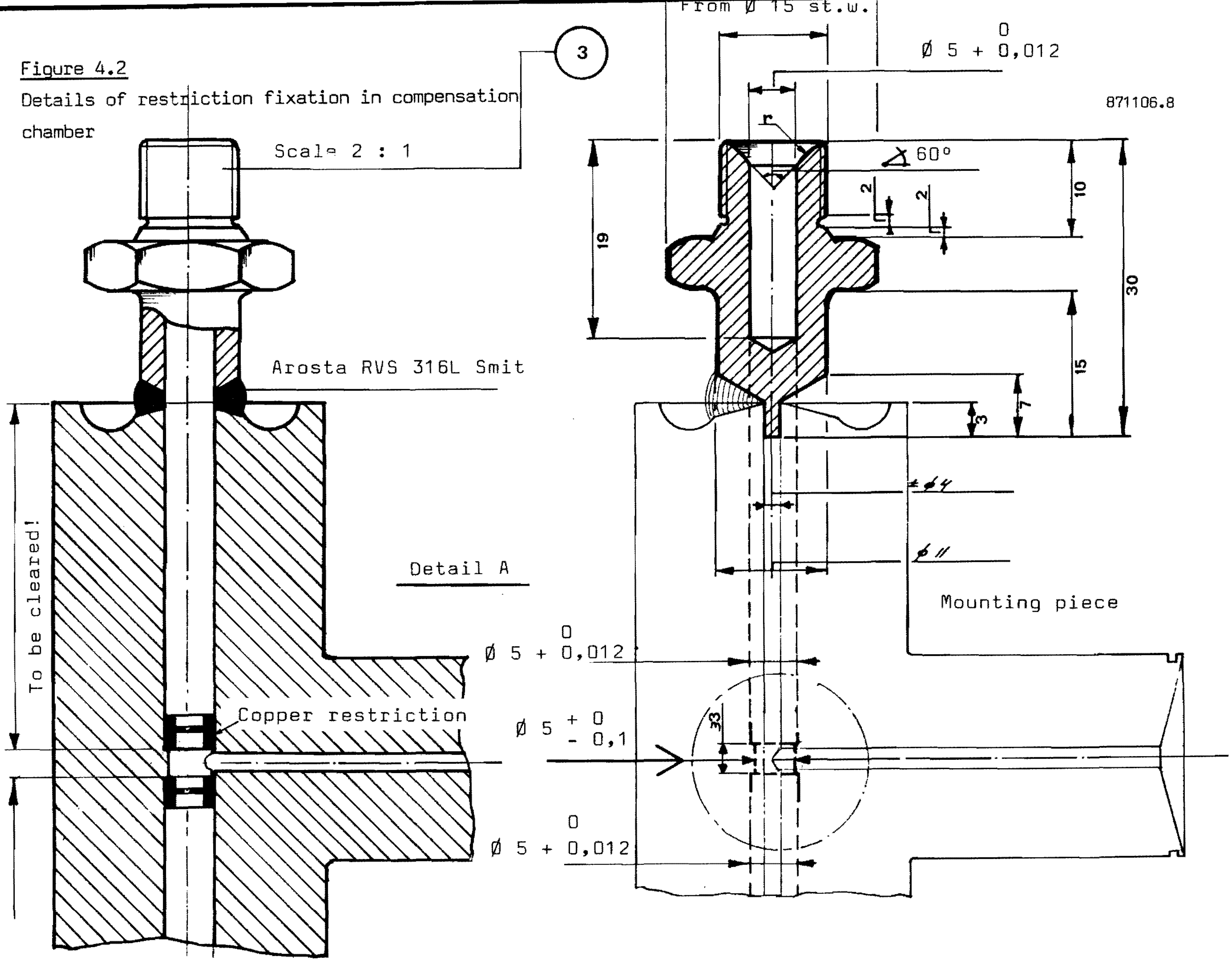


Figure 4.2
Details of restriction fixation in compensation chamber

5 THE FILLING WITH OIL OF THE TAPPING LINES SYSTEM

After the construction of the tapping lines system, it has to be carefully tested under vacuum for leakages (see Figure). Thereafter the system can be filled with silicone oil (Baysilone-Ole-M). Compressibility of the oil can be ignored, since the relative volume change is only 0,05 % if the system pressure is increased from 1 to 169 bar. The silicone oil withstands temperatures up to 330 ^{0}C and has a good heat conductivity : 0,163 W/mK. The capillary tubes directly behind the front membranes minimize heat conduction from the heated test section and are easily cooled by air currents.

Figure 5.1

View on leakage testing equipment

The filling procedure is as follows.

1. Additional filling aid A is mounted over the front membranes (see drawing and Figure). The entire tapping lines system is made vacuum before the actual filling with oil. In order to prevent the diaphragms to distort

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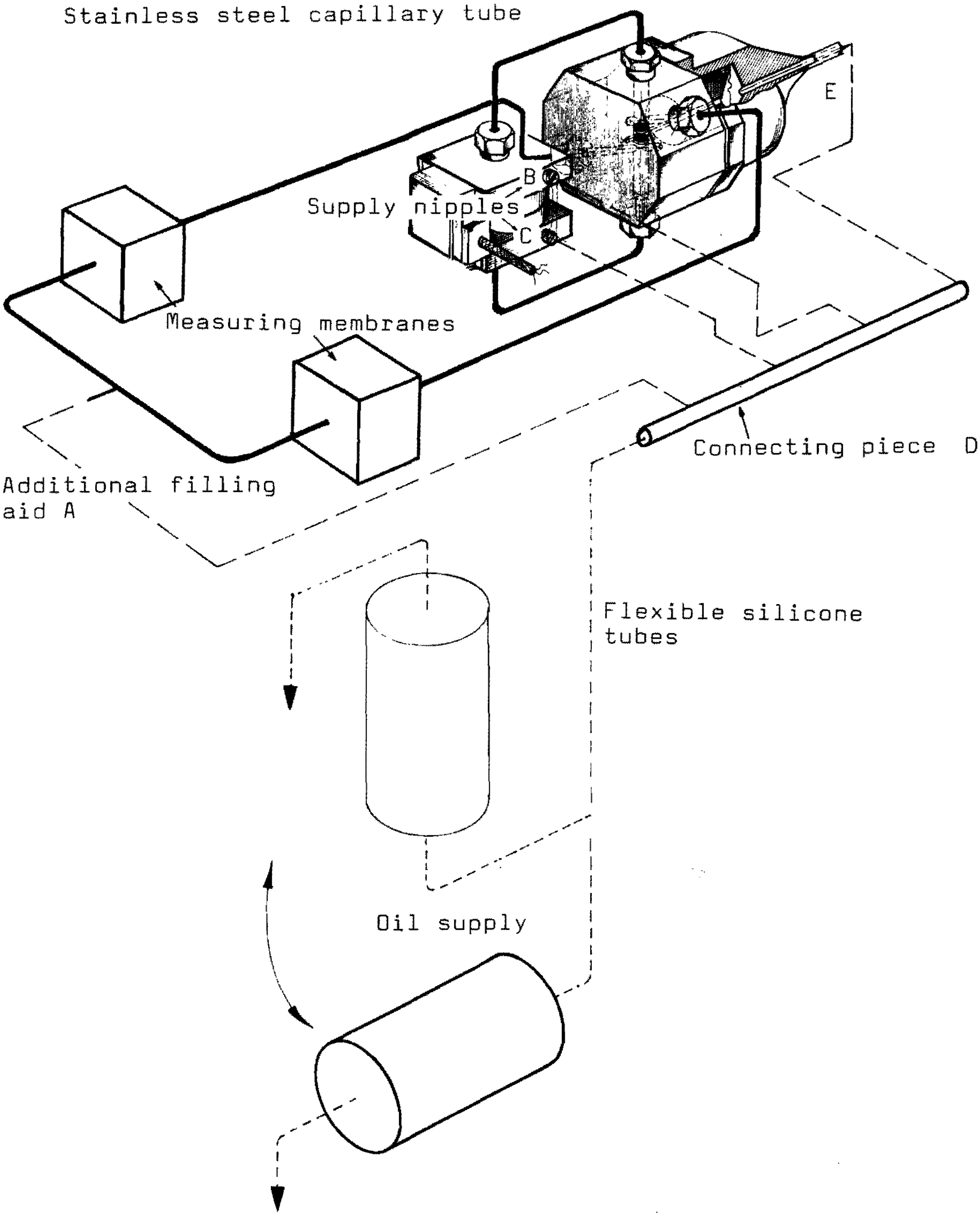
Stainless steel capillary tube
E
B
Supply nipples
C
Measuring membranes
Connecting piece D
Additional filling aid A
Flexible silicone tubes
Oil supply

sides of each diaphragm are made vacuum. To this end the additional filling aid A was manufactured.

2. Flexible silicone leads connect filling aid A as well as the backside of the compensation membrane, marked with E in Figure 5.2, with a connecting piece.

3. In the important supply nipples, marked B and C in Figure 5.2, connecting pieces are screwed, on which flexible silicone leads are easily attached.

4. Flexible silicone leads connect B and C with the connecting piece.

5. One end of a small oil container is connected to the connecting piece. The other end is connected to the vacuum pump. During the vacuum pumping the oil container is in horizontal position and the oil content does not block the air flow from the connecting piece towards the pump.

6. Without oil in the container all leads and connecting pieces are vacuum tested for leakages with special leakage testing equipment (see Figure 5.1). Any leakage has to be located and closed before the actual filling can start.

7. Thereafter the oil container is filled for one third with Baysilone-Ole-M (some oil of Bayer). No oil may enter the flexible silicone tubes of course.

8. During a long time, at least one day, the system has to be pumped high vacuum. No air or gas should remain in the tapping lines. Under some circumstances the tapping lines system may even be slightly heated to foster the air withdrawel.

9. Put the oil container in vertical position. The oil now blocks the passage to the vacuum pump.

10. Shut off the vacuum pump.

11. On both sides of each membrane now vacuum pressure holds. Next the air supply valve towards the vacuum pump has to be slowly opened. Now 1 atmosphere is pressing the oil out of the container into the tapping lines system.

12. The connecting pieces in B and C are removed. Small bullets are placed into the supply nipples. Small srews are forced to fix the bullets in place. It is noted that both B and C have to be the highest points of the entire system. In this way no oil will be moistured from the supply nipples during the filling process.

13. All filling aids are removed. The system is now ready for testing in dedicated test loops.

6 MOUNTING THE DESIGN ON A TEST SECTION

6.1 The lava sealant

The lava sealant is commercially available, but its shape has to be adjusted according to Figure 6.1. Lava sealants can be used several times if lava remainders are collected after use, and subsequently molded together with addition of some glue.

6.2 Manufacturing Stenan parts

Stenan is a material that is easily shaped according to Figure 6.2. Afterwards the Stenan parts have to be cintered in a stove according to the following procedure.

1 Use 30 minutes to increase temperature from 20 to 100 degrees Celsius.
2 Use 30 minutes to increase temperature from 100 to 150 degrees Celsius.
3 Use 60 minutes to increase temperature from 150 to 200 degrees Celsius.
4 Use 120 minutes to increase temperature from 200 to 300 degrees Celsius.
5 Use 180 minutes to increase temperature from 300 to 400 degrees Celsius.
6 Use 180 minutes to increase temperature from 400 to 460 degrees Celsius.
7 Use 180 minutes to increase temperature from 460 to 500 degrees Celsius.
8 Use 600 minutes to increase temperature from 500 to 600 degrees Celsius.
9 Use 3000 minutes to increase temperature from 600 to 850 degrees Celsius.
10 Use 420 minutes to increase temperature from 850 to 920 degrees Celsius.
11 Use 420 minutes to increase temperature from 920 to 1200 degrees Celsius.
12 Keep temperature constant at about 1200 degrees for ca. 48 hours.
13 Switch heating power off to the stove.
14 Keep the Stenan parts for 36 hours in the stove without opening the stove. During this time temperature is now gradually decreasing.

6.3 Electrical isolation and mounting aids

The test section we used was heated with Joule's heat. The electrical resistance had therefore not to be affected by a pressure transducer mounted on

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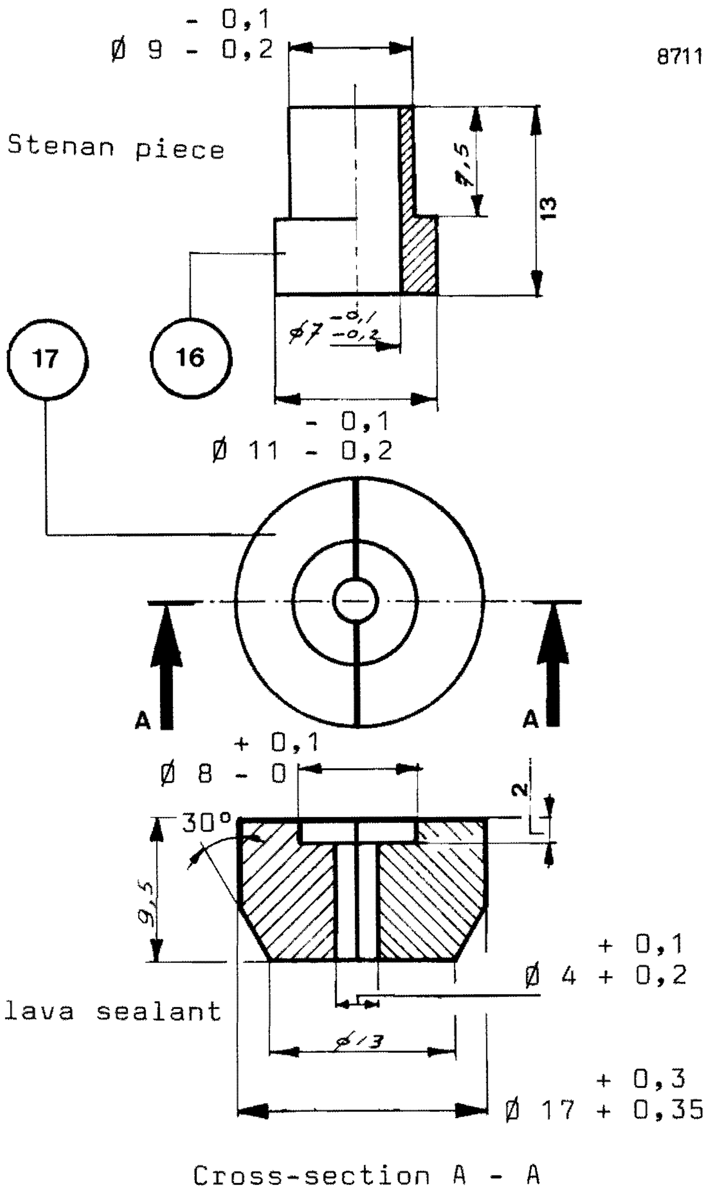

Figure 6.1

Construction details of lava sealant and Stenan piece

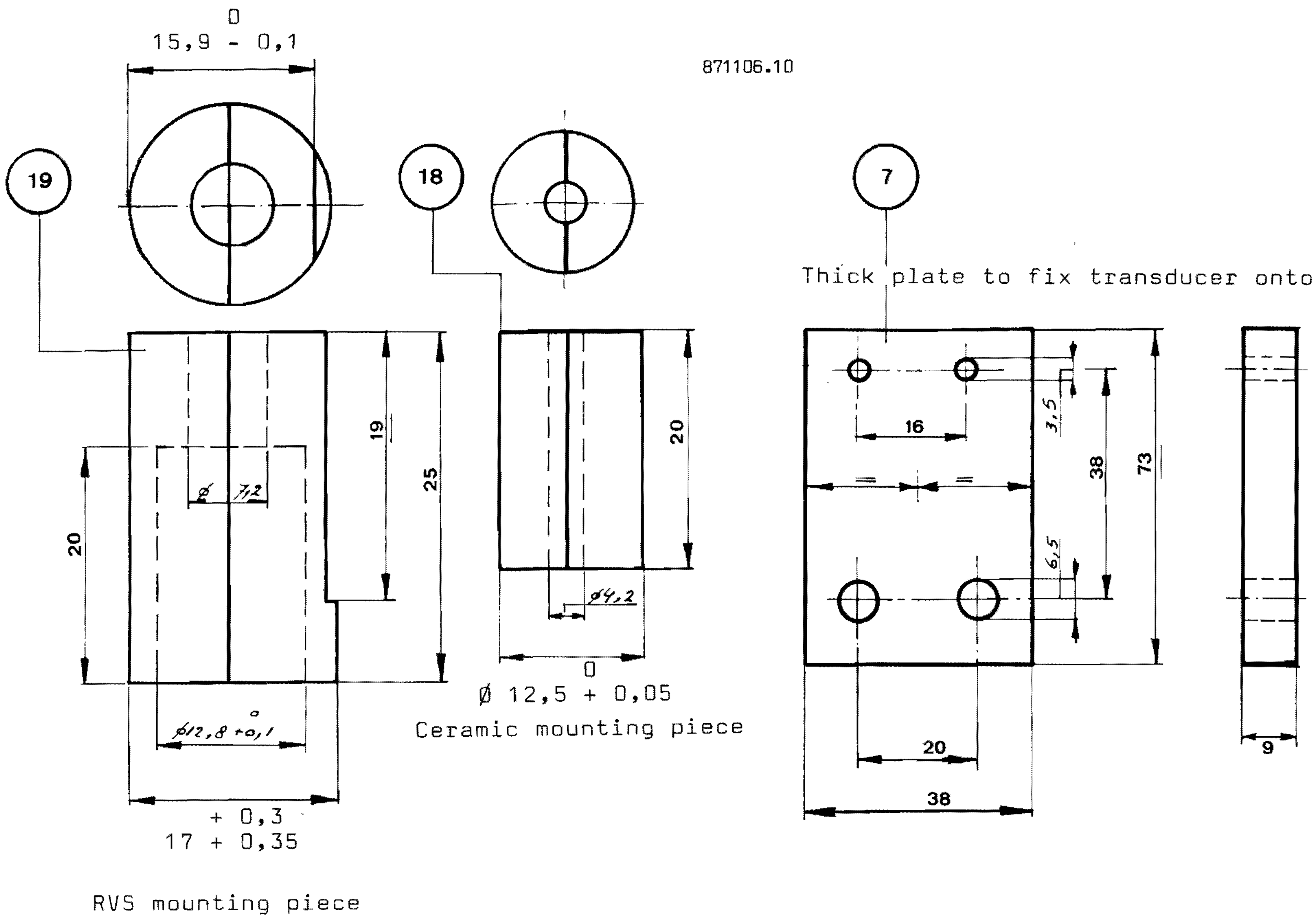

Figure 6.2

Some fixation aids

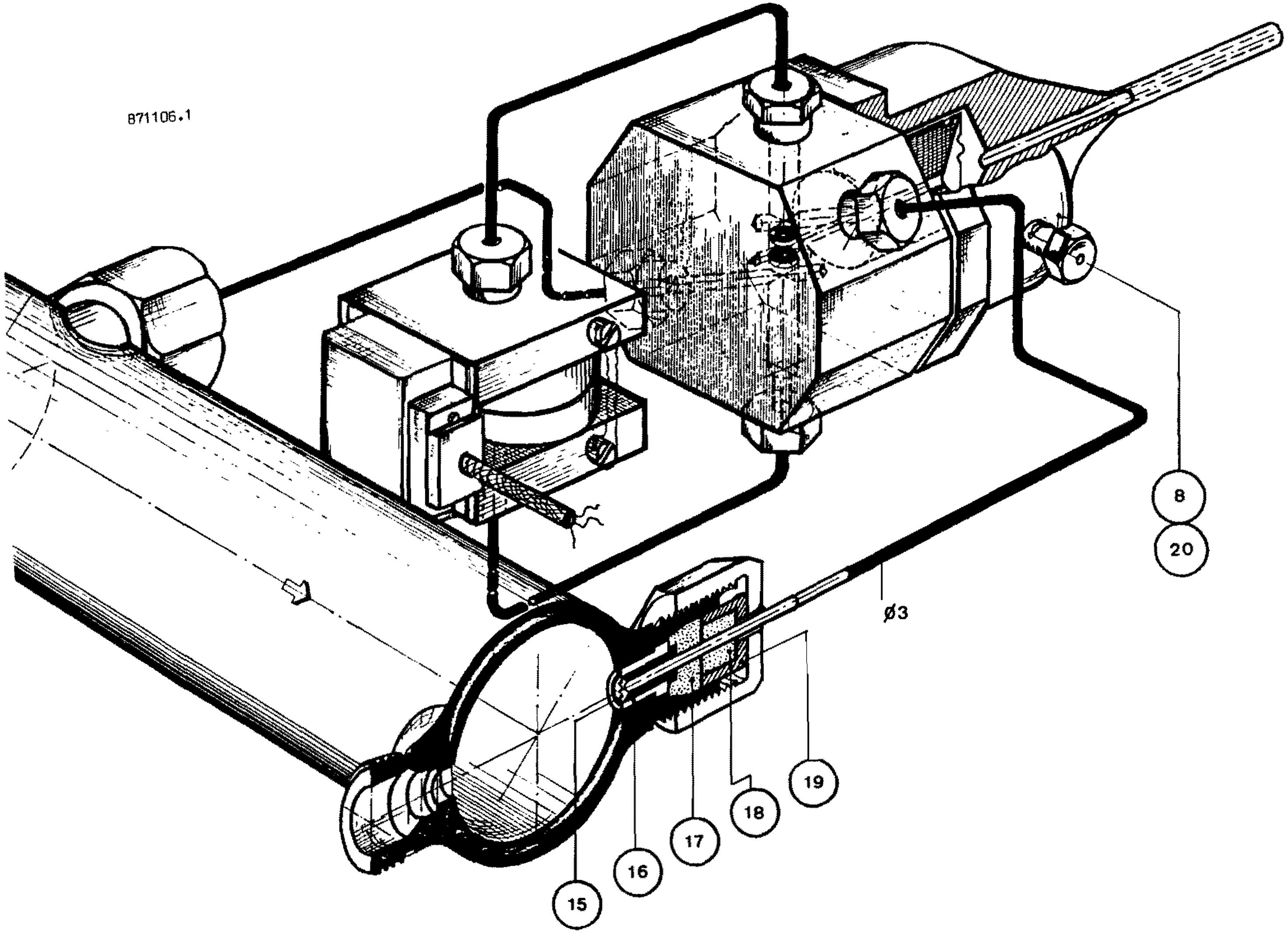

Figure 6.3

Schematics of OFTAL mounting on a test section

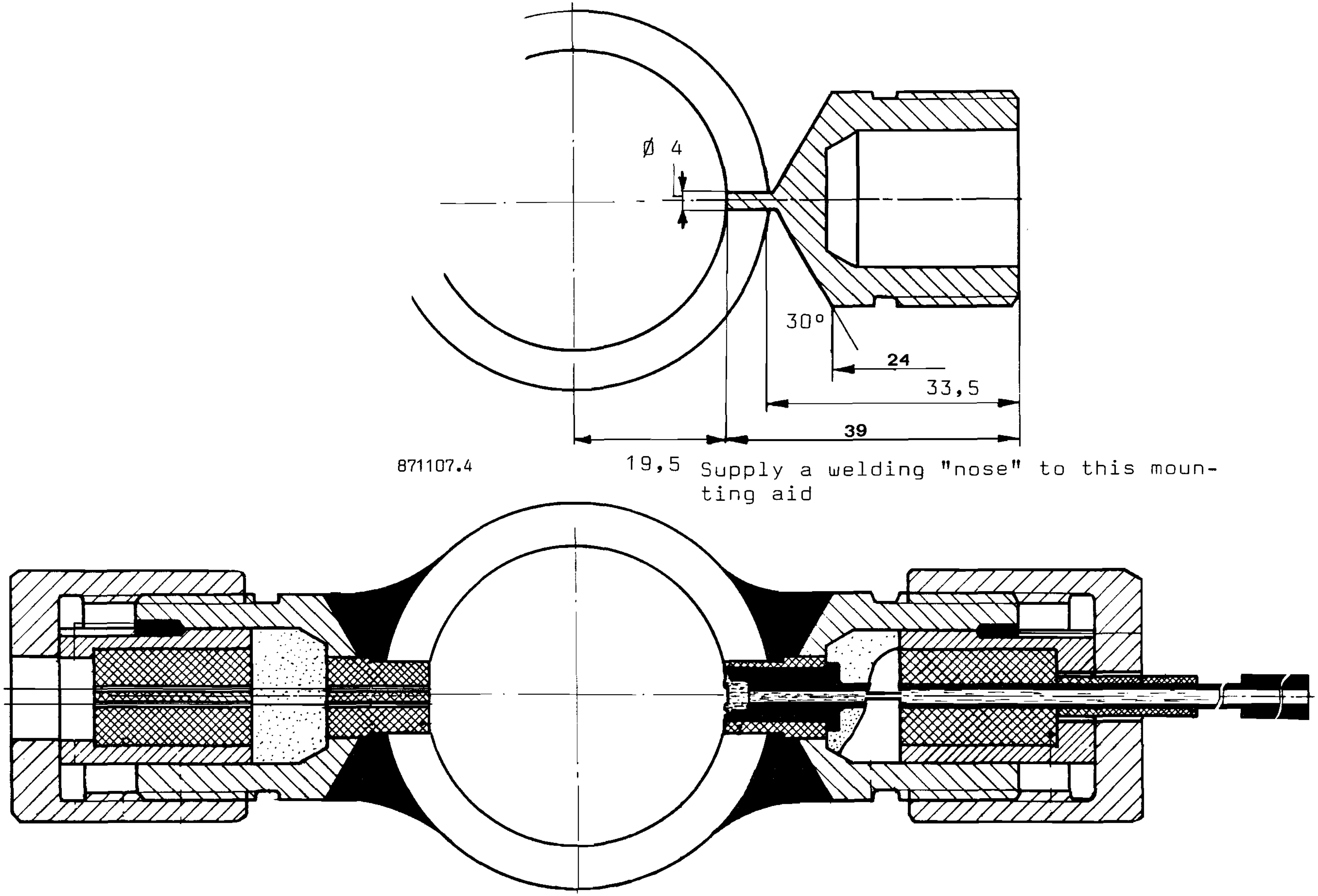

Figure 6.4

Mounting aid to be welded on a test section

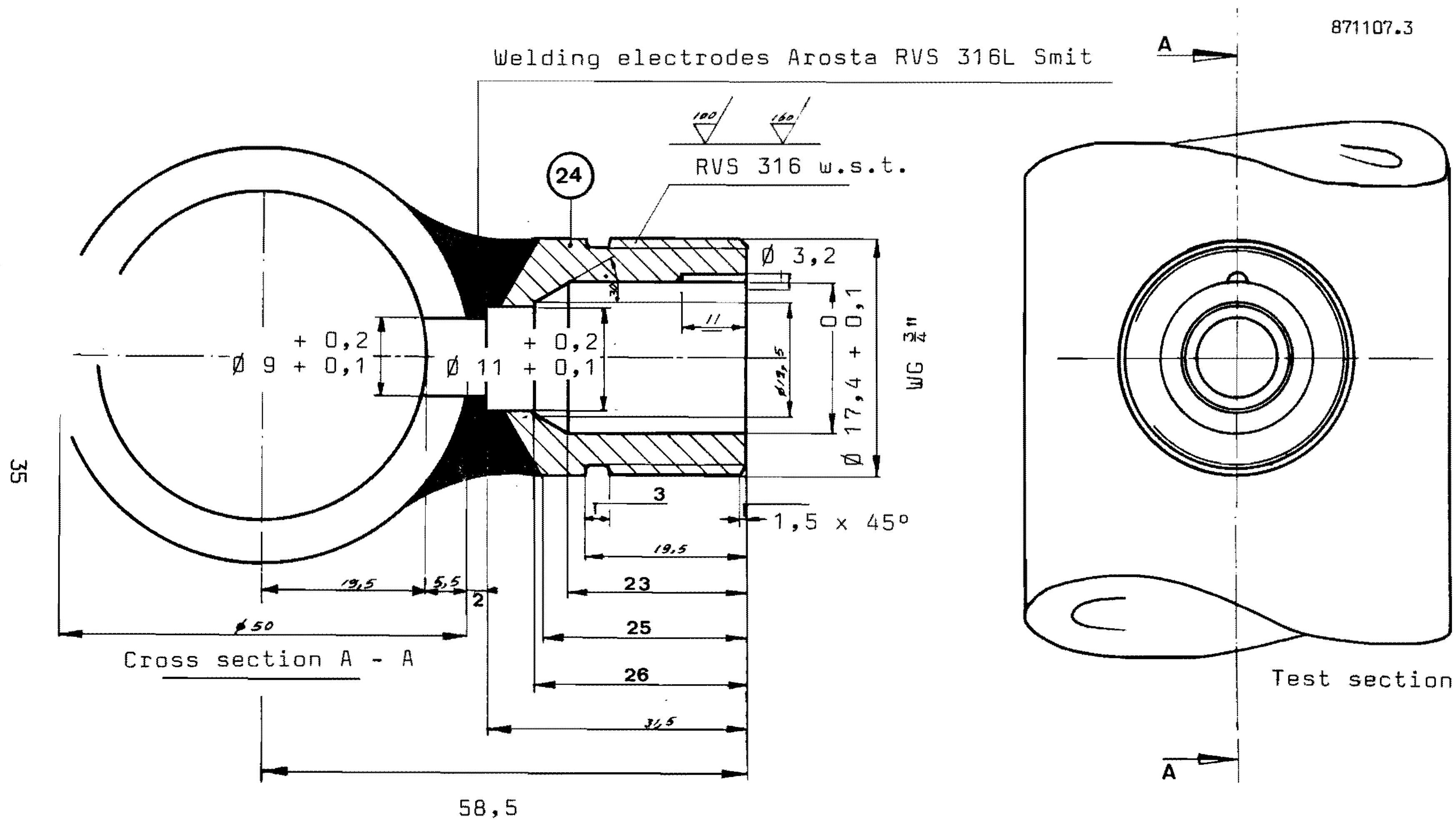

Figure 6.5

Dimensions of mounting aid to be welded on test section it. For this reason the tapping lines system was electrically isolated from the test section :

1 Ceramic and Stenan parts and Teflon (PVC) tubings isolate the front membranes and the capillary tubes from the test section;

2 In the mounting aid that was used to fix the apparatus tightly on the test section, several Backelite plates were applied. These isolating plates resemble hard thick paper and are also used as packing material at other places in the test rig.

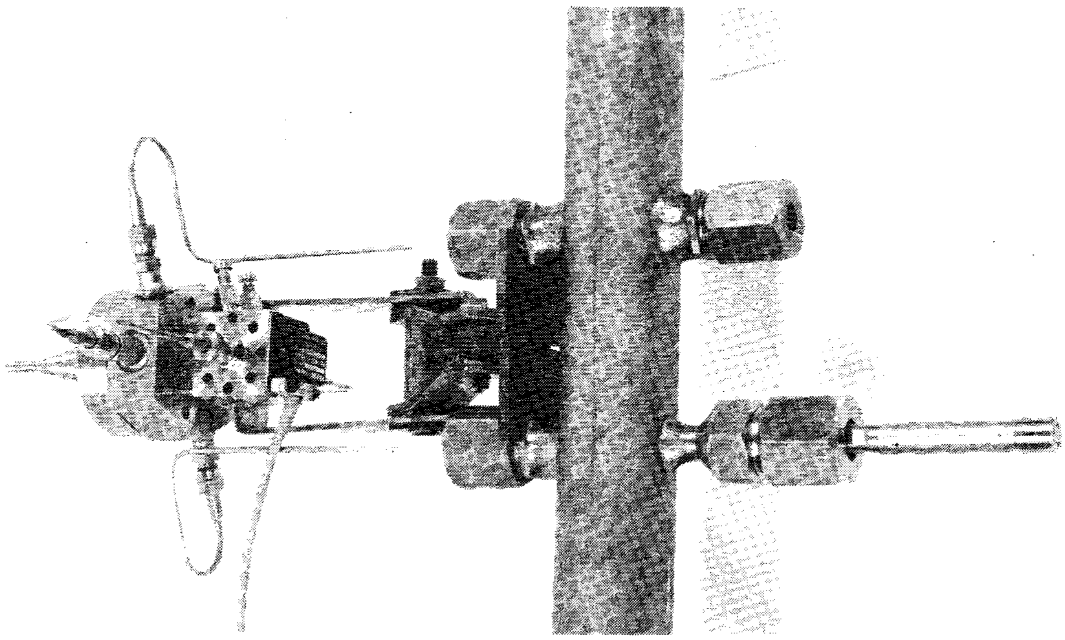

Figure 6.6

View on OFTAL with pressure transducer mounted on test section.

7 TESTING

7.1 Testing at ambient pressure

It is very informative and absolutely necessary to test each OFTAL at ambient pressure in a dedicated test rig. This testing shows if the transducer was accidentally damaged or if the filling procedure had not quite succeeded.

Some typical results are shown in Figures 7.1 and 7.2. Two tests were performed:

1 response measurement with uncovered front membranes;

2 response measurement with front membranes covered tightly by some teflon piece.

In each case the value of P_{max} was established to determine the maximum gain of the electrical conditioner. Afterwards this gain was kept constant. Values of P_6 and P_3 were measured at several superficial velocties of the Nitrogen flow.

Figure 7.1 shows that :

1 it is really necessary to use P_{noise} to calibrate the measurement results according to

$$P_{\%} = (P_6 - P_{noi}) / (P_{max} - P_{noi})$$

2 the front membranes and the tapping lines dimensions are such, that the OFTAL system can respond easily to two-phase flow pressure drop fluctuations. The response differences for the above mentioned two test cases is satisfactory large. It is noteworthy that the test section was shaking due to severe pumping activities during these tests. Pressure fields are conducted via the walls and the tapping lines towards the measuring membrane, but do not seem to hamper accurate two-phase flow recordings.

Data for Figure 7.2 were established using the same OFTAL and the same electrical gain. The fluctuations in this case did not occur symmetrically around 0 Volt, like the usual fluctuations like those used for Figure 7.1. Instead, almost all fluctuations were found to occur in the range (0; 0,01)

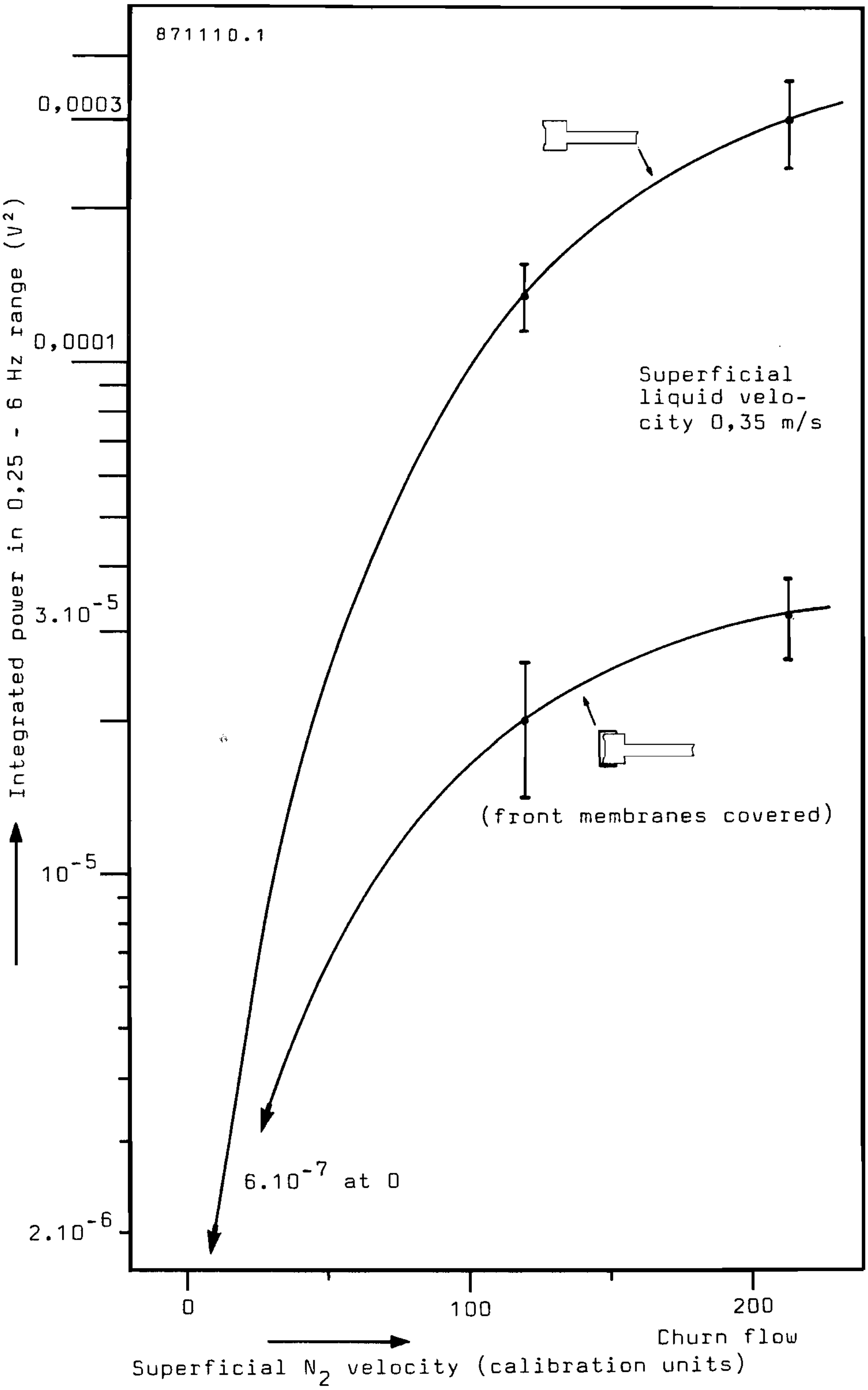

Figure 7.1

Integrated power versus superficial Nitrogen velocity for two test cases.

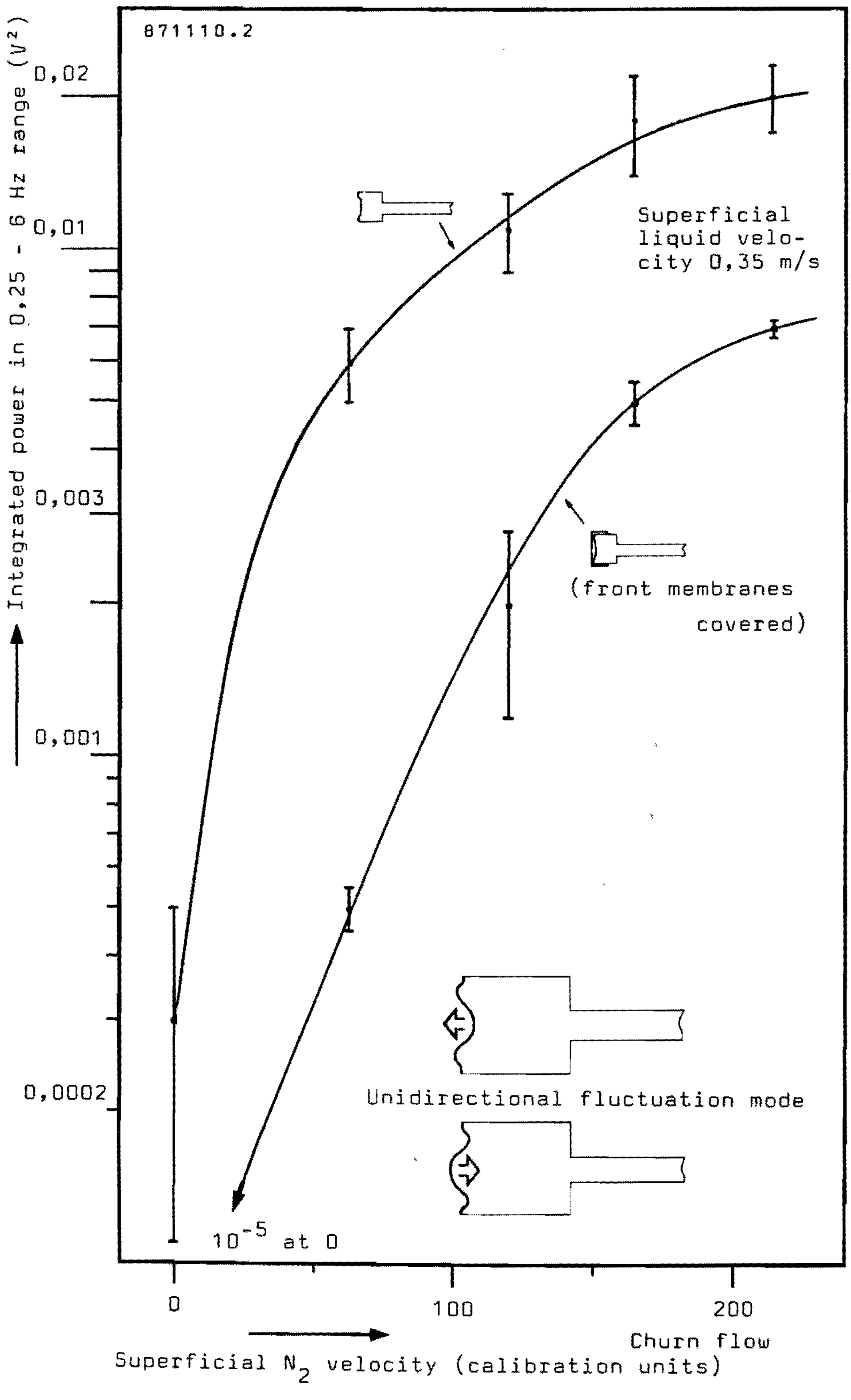

Figure 7.2

Integrated power versus superficial Nitrogen velocity for two test cases.

Volt. This means that the measuring membrane is force to move only in one direction from its regular zero-position. This unidirectional fluctuation mode can be understood from a different setting of the front membranes (see Figure 7.2) due to some severe pressure shock flipping the front membranes into another rest position.
Afterwards the normal rest position was taken up, as was noticed from the change to normal, bidirectional fluctuations around zero.
During measurement one should be aware of the possibility of two fluctuation modes, although at high pressures its occurrence is more unlikely and was never established sofar. Fortunately the unidirectional mode is easily recognized from the signal of the transducer.

In the near future some more tests are planned, with even larger front membranes, to investigate the multiple fluctuation modes even further.

7.2 Testing at elevated pressures

Each OFTAL was adiabatically tested at system pressures up to 10 MPa (100 bar). All membranes were put under pressure of course. This testing revealed possible leakages, especially of the vent-way connections.
Afterwards the testing at ambient pressure was performed.

8 CONCLUSIONS

A new, closed tapping lines system was developed, that can be used as an intrusive probe. Purging of tapping lines or the introduction of condensation chambers became unnecessary. Thin, flexible diaphragms allow for an accurate registration of small pressure drops even at elevated pressures.
Results obtained at 30 and 40 bar were highly satisfactory.

<u>9 REFERENCES</u>

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2 Flow regime recognition at elevated pressures.
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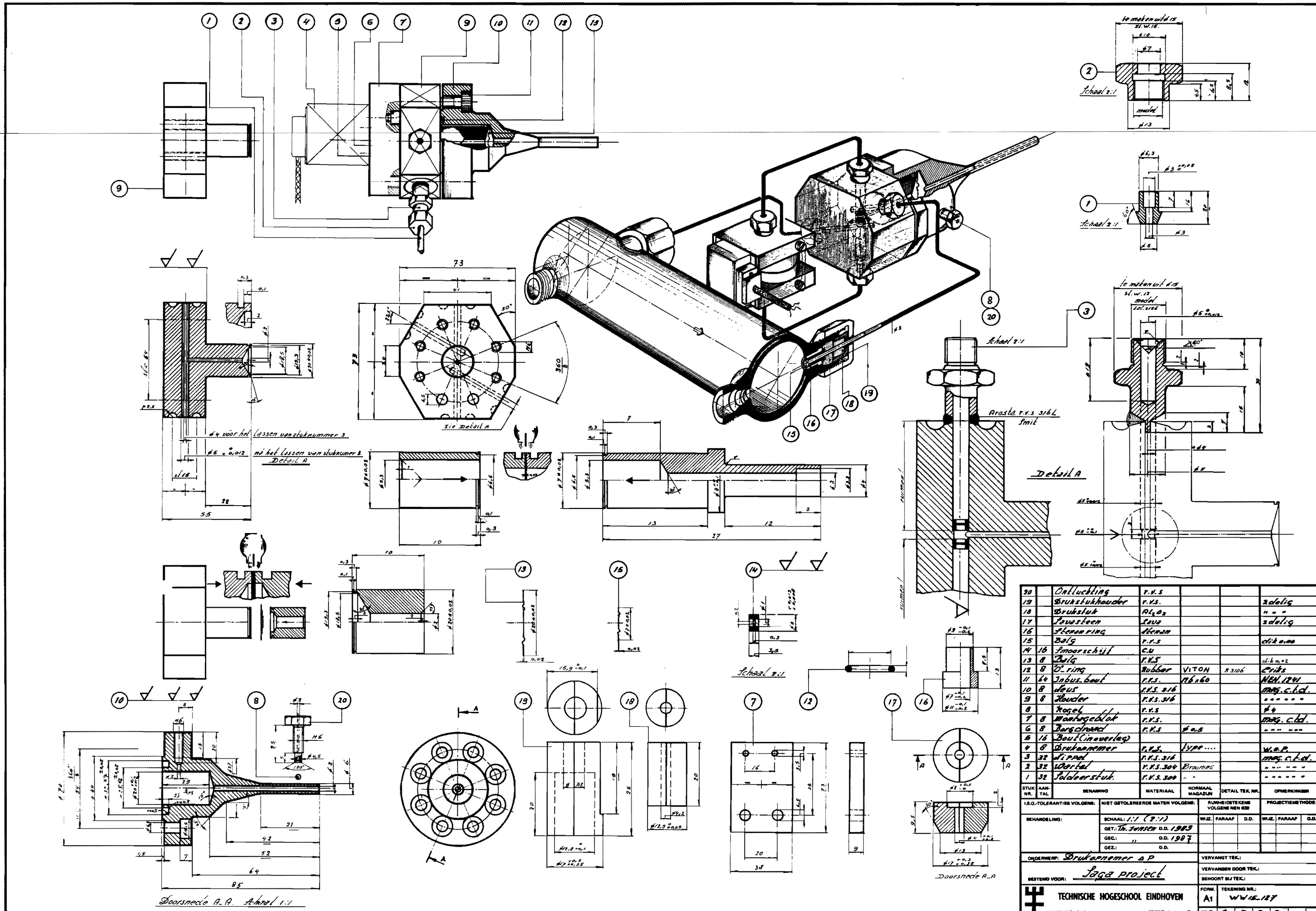
APPENDIX

A copy of the original technical drawing, comprising all parts to be manufactured.



STUK NR.	AANTAL	BENAMING	MATERIAAL	NORMAAL MAGAZIJN	DETAIL TEK. NR.	OPMERKINGEN
20		Ontluchting	r.v.s			
19		Drukstukhouder	r.v.s.			2delig
18		Drukstuk	Al_2O_3			" " "
17		Lavasteen	Lava			2delig
16		Stenen ring	Steen			
15		Balg	r.v.s			dik 0,00
14	16	Smoorschijf	Cu			
13	8	Balg	r.v.s			dik 0,02
12	8	"O"-ring	Rubber	VITON	R 3106	Eriks
11	64	Inbus-bout	r.v.s.	M6x60		NEN 1241
10	8	Neus	r.v.s. 316			mag. c.t.d.
9	8	Houder	r.v.s. 316			" " " " " "
8		Kogel	r.v.s			⌀4
7	8	Montageblok	r.v.s.			mag. c.t.d.
6	8	Borgdraad	r.v.s	⌀0,5		" " " " " "
5	16	Bout (in overleg)				
4	8	Drukopnemer	r.v.s.	type		W.O.P.
3	32	Nippel	r.v.s. 316			mag. c.t.d.
2	32	Wartel	r.v.s. 304	Browning		" " " " " "
1	32	Soldeerstuk	r.v.s. 304	" "		" " " " " "

I.S.O.-TOLERANTIES VOLGENS:	NIET GETOLEREERDE MATEN VOLGENS:	RUWHEIDSTEKENS VOLGENS NEN 630	PROJECTIEMETHODE:
BEHANDELING:	SCHAAL: 1:1 (2:1)	WIJZ. / PARAAF / D.D.	WIJZ. / PARAAF / D.D.
	GET.: Th. Jansen D.D. 1983		
	GEC.: " D.D. 1983		
	GEZ.: D.D.		

ONDERWERP: Drukopnemer ΔP

VERVANGT TEK.:

BESTEMD VOOR: Saga project

VERVANGEN DOOR TEK.:

BEHOORT BIJ TEK.:

TECHNISCHE HOGESCHOOL EINDHOVEN

AFDELING: W

SECTIE: W.O.P.

FORM. A1

TEKENING NR.: WW 16-127

WIJZ. A B C D