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MATERIAL AND CONSTRUCTION OF PRIMARY COMPONENTS FOR THE SNR 300

10/12

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Abstract

The construction of SNR's requires specific properties of the materials, i.e. high strength at temperatures of 600°C, adequate creep rupture strength, low long-time embrittlement. Aspects are given for optimalization of the mentioned properties with regard to safe manufacture especially good weldability.

The austenitic material X6CrNi1811 similar the type AISI 304 ss finally was chosen. Besides the fundamental analysis of the material properties it will be reported about the experiences gained during the manufacturing of the essential components.

Introduction

The main part of the work on the reactor vessel including internals for the prototype nuclear power plant with sodium cooled fast breeder reactor SNR 300 presently under construction at Kalkar/ West Germany has now been completed.

Given the high safety requirements of such components, design, dimensioning, material development and manufacturing technology have particular importance. The following is a brief summary of the construction of the component and of the most important experiences gained in this context.

Reactor vessel and internals (Fig.1)

They serve mainly as supporting structure for fuel- and breeding elements and as flow guidance for the coolant sodium. Liquid sodium enters the tank at a temperature of appr. 370°C through three inlet pipes, passes the gas bubble separator inside the lower accumulator tank, core support plate, fuel-and breeding elements, is heated up to 540°C and leaves the tank via three outlet pipes.
Under normal operating conditions the reactor vessel basically is not pressurized. The wall thicknesses of the tank resulted from hypothetical considerations. The main loads at normal operating conditions are based principally on different temperatures in the various vessel zones. The characteristic feature of the design and layout of the vessel is the arrangement in double shells and the installation of thermal shock baffles to protect the bearing structures.

Base metal and weld matal

The main aspects, resulting from the above mentioned functions and requirements apart from the behaviour under conditions of radiation and possibly sodium corrosion, are:

- o strength properties high enough to permit a reasonable technical and economical solution, even at high operating temperatures (up to about 540°C and for short periods about 700°C;
- o sufficient toughness under operating conditions, especially after long-time operation;
- o workability, especially weldability of the materials used.

Because measures which improve one property often are detrimental to others, an optimal compromise must be found. Thereby the range of the tolerable limits of the guaranteed values is restricted severely and it is necessary to establish priorities for the requirements in connenction with each project of such type and to select the metallurgical methods for the production of the steel accordingly.

In order to meet these requirements, there was a principal choice between the unstabilized austenitic steels X6CrNi 1811 and X6CrNiMo 1713. Owing to the limited susceptibility to long-time embrittlement, the Mo - free grade X6CrNi 1811 was finally chosen. The principal guaranteed properties of this steel are listed in the German VdTÜV-Werkstoffblatt (Material Data Sheet) 12-312 and can be seen in Table 1. Although the mechanical property values specified in the VdTÜV Material Data Sheet are restricted to plates of 50 mm maximum thickness, these values were also required for greater wall thicknesses, such as, for instance, 160 mm thick plates. Additional limitations with respect to analysis, were imposed by the customer (INTERATOM).

These limitations applied mainly to maximum carbon-content, as well as to maximum contents of the undesirable elements Mo,Ti, Ta and Nb. The mechanical properties of this steel can be seen in Table 1.

In conclusion it can be said that this steel is an unstabilized fully austenitic steel with the specified high temperature properties, whose chemical composition is designed to give low susceptibility to delta ferrite precipitation, so as to limit to a minimum the decrease of ductility produced by long-time application of high temperature.

The mechanical properties requirements for the weld metal are identical with those for the base metal. To avoid the risk of hot cracking, a delta ferrite content of the weld metal of approximately 5 percent was specified. The Cr and Ni limits specified by VdTÜV Material Data Sheet were therefore modified as follows for the weld metal: 17.5 to19.5 percent Cr and 9.0 to 11.0 percent Ni. P was limited to 0.025 percent and S to 0.015 percent.

Manufacturing and nondestructive testing

In the manufacture of the vessel including internals wall thicknesses up to 160 mm had to be welded. The basic wall thicknesses of the vessel, which has a diameter of 6.7m and a height of 15m, are around 40 mm in the cylindrical part and around 60 mm in the semispherical bottom.

Manual electric welding and tungsten inert-gas welding (TIG) are considered as the usual welding methods for the fabrication and construction of experimental components of the same material up to a wall thickness of 45 mm.(Ref.1). With these techniques there is background of experience and additionally data are available on long-time behavior (Ref.2).

This experience with manual electric welding has been extended to greater wall thicknesses. Available welding consumables with a defined delta ferrite content in the weld metal of appr. 5% met all the requirements mentioned above. When the conservative maximum weld interpass temperature of 150°C and the specified approved welding parameters (maximum heat input) are adhered to, no hot cracking is been observed.

Experience in submerged arc welding of austenitic steels (Ref.3) plus the economic benefits and improvement in qualitiy assurance led to its adopt. on for some of the welds in the vessel. Tests verifying hot cracking resistance were of primary importance in the development of weld consumables, i.e. flux and wire electrodes. Extensive welding tests with various wire flux combinations were based primarily on welding behavior and susceptibilty to cracking. On the basis of the test results a neutral agglomerated flux was selected. Thus, the chemical composition of the weld metal is determined by the wire only. Further tests with the selected wire-flux combination served the purpose of clarifying the following problems.

- o Determination of optimum welding parameters and of the effect of deviations from these parameters,
- o Influence of interpass temperature, in particular on the amount and distribution of delta ferrite,
- o Dependence of delta ferrite and susceptibility of hot cracking on weld buildup and re-use of the flux (Ref.4).

The tests showed that only in the welding of the root there is a marked degree of dependence of delta ferrite on heat input, interpass temperature and fused base metal (Fig.2). In the filler pass and the final pass no strong influence was observed (Fig.3). For this reason, there was a heat input requirement to weld the root from both sides by manual electric welding to obtain lower fusion, thus ensuring an adequate delta ferrite content and absence of hot cracking.

Because of the absence of long term data on weld behavior at temperatures greater 450°C, those areas having service temperatures above this value were made entirely by manual electric welding. Results now available from long-time tests, however, enable us to predict that the submerged-arc weld metal will show similar embrittlement characteristics to those of manual weld metal (Fig.4)

Thus, the decision made at that time must be considered highly conservative.

During manufacturing special precautions were imposed by the high requirements regarding dimensional accuracy, by numerous restrictions made by independent experts and by cleanliness requirements. Just a few examples:

Reactor tank bottom (Fig.5)

One factor that made assembling and welding of the tank and particularly of the welded bottom very difficult was the prohibition by the independant expert TÜV, to use conventional tack welding for assembly attachments. To achieve optimal dimensional accuracy the effects of any longitudinal and angular shrinkage had to be compensated by optimized welding sequences determined in preliminary tests. Moreover during welding continuus dimensional checks were carried out.

Core support plate (Fig.6)

The heart of the internals is the core support plate, which is the actual support structure for the fuel-and breeding elements. The plate consists of two heavy plates which are joined by 118 tubular shear elements and which contain a forged central piece. Sketch 1 of Fig.7 shows the welded connenctions of the tubular shear elements with the upper and lower rings. The K-Weld for the upper ring, for which a special type of backing strip was used, required a systematic procedure,because the assembling sequence of the tubular elements, the problems of welding shrinkage and accessibility had to be solved in an optimum way. After completion the welding seams were subjected to liquid penetrant testing and X-ray control.

Due to the particular design the weld connection between the tubular shear elements and the lower ring could only be

carried out through the bottom hole of 75mm diameter.
Sketch 2 of Fig.7 illustrates the welding which the fabricator originally planned in view of the experiences in the fabrication of the moderator tank bottom of the nuclear power plant Atucha. The root is welded by the TIG process with gas shielding of the root on the outer surface, the following passes by manual arc welding. The varying root face of 5:1.5 mm served the purpose of creating a shrinkage compensation for the other welds on the plate.
Actually it was not convenient to choose the same shape of root faces, because the increased heat dissipation caused by the wider root face might have led to higher heat input and therefore to a possible risk of breakthroughs. As in the meantime the risk of radial shrinkage causing displacement of welding edges has been eliminated thanks to the experience gained before, the guiding idea was to form the root faces in such a way as to obtain approximately equal heat dissipation on either side (Sketch 3 of Fig.7). Appropriate annular build up welds insured an ideal shape of the root faces.
Root welding was done by one single welder, who had been trained on numerous expensive test pieces. The satisfactory results have fully justified these investments.

On all welds of the tank the following tests were carried out as standard procedure:

- o Liquid penetrant testing and ultrasonic testing of the welding edges of the base metal.
- o Checking of joint preparation and misalignment of edges.
- o Liquid penetrant testing of the root in the case of TIG welding, or, in the case of manual electric welding, liquid penetrant testing of the opposite side after it had been ground smooth.

o A liquid penetrant test and radiographic examination as intermediate tests on completion of appr. 50% of weld volume.

o After making flush dressing the plate in the vicinity of the weld by grinding and after stress-relieving (640°C): visual examination, dimensional checking by ultrasonic wall thickness measurements), raiographic examination and ultrasonic testing.

Ultrasonic testing

Ultrasonic testing of the austenitic welds was carried out for the first time. The technique using transmitt/receiver probes with longitudinal waves (2 MHz) uses the same principle as in the testing of austenitic cladding on ferritic pressure vessels for under-clad cracks. These probes operated by converging the acoustic beams to a focal point (Fig.8). By focusing, i.e., convergence of the acoustic beam, an advantage over the pulse-echo method is that the scatter echoes (which are typical of the austenitic weld metal) only interfere from the focal area in which the directional lobes of transmitter and receiver converge. A disadvantage is that this technique permits only limited coverage of depth, thus the weld to be tested must be divided into scanning zones of 15 to 20 mm width (Ref.5). Past experience with this testing technique and comparison with radiographic testing have shown that even relatively small defects in the longitudinal produced ultrasonic indications.However, the detection of transverse defects is not yet possible, since the placing of the probes on the weld metal produces a very unfavorable signal-to-noise ration, so that it is impossible to interpret the echoes accurately (Ref.6). Despite some drawbacks, the ultrasonic testing performed has proved successful insofar as a comparison between ultrasonic and radiographic testing reveale that the respective indications were in good agreement. On the whole, this ultrasonic testing technique seems to deserve further development to qualify it for future use in austenitic welds.

Conclusions

Some of the special construction features of a vessel intended for the fast breeder reactor SNR 300 havebeen described. On the whole, it is concluded that extensive testing and regular production control have permitted the construction of a reactor vessel designed for highest reliability and having the highest qualitiy.

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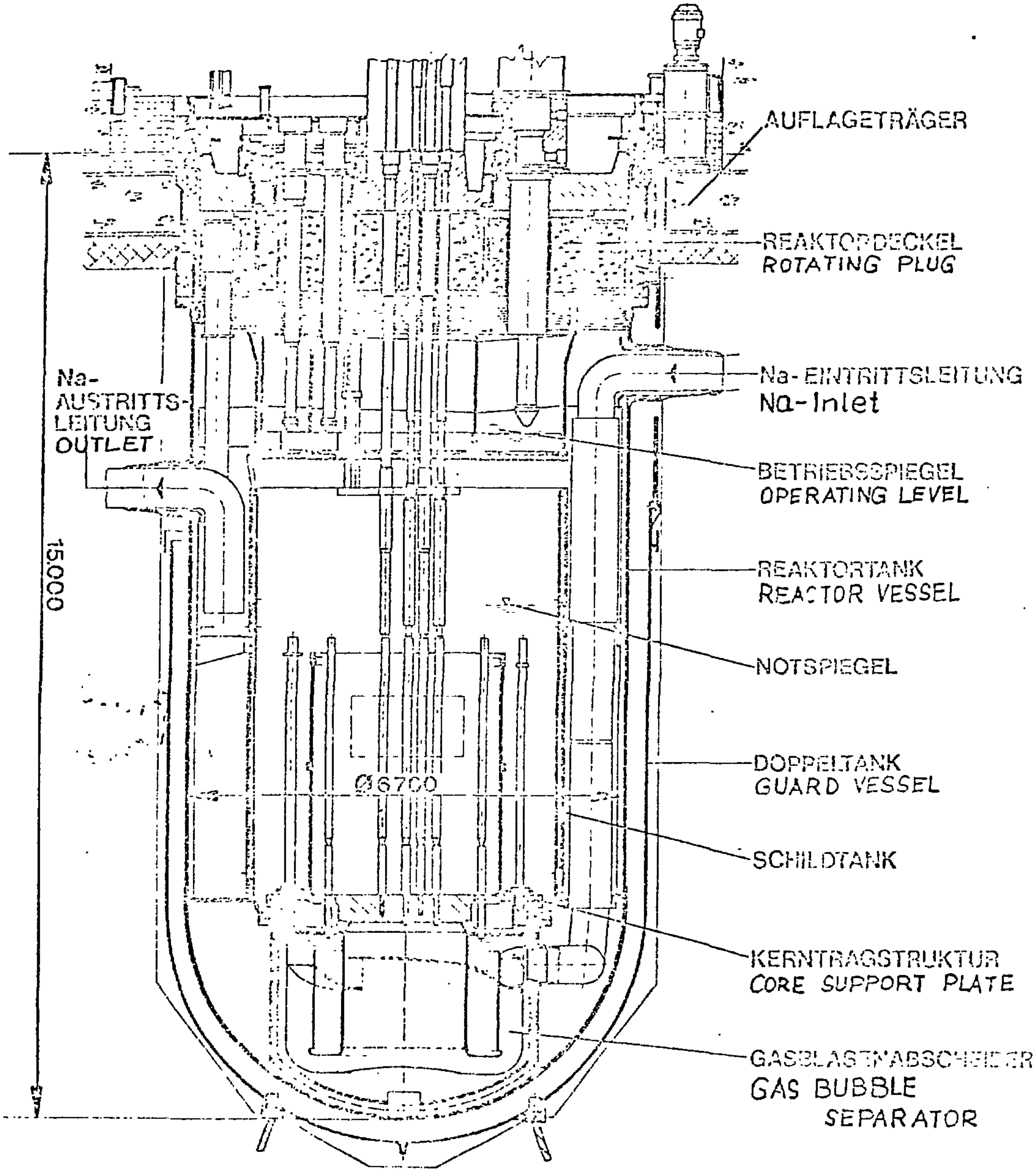

AUFLAGETRÄGER
REAKTORDECKEL
ROTATING PLUG
Na-EINTRITTSLEITUNG
Na-Inlet
Na-
AUSTRITTS-
LEITUNG
OUTLET
BETRIEBSSPIEGEL
OPERATING LEVEL
REAKTORTANK
REACTOR VESSEL
15.000
NOTSPIEGEL
DOPPELTANK
GUARD VESSEL
Ø6700
SCHILDTANK
KERNTRAGSTRUKTUR
CORE SUPPORT PLATE
GAS BUBBLE
SEPARATOR

FIG. 1

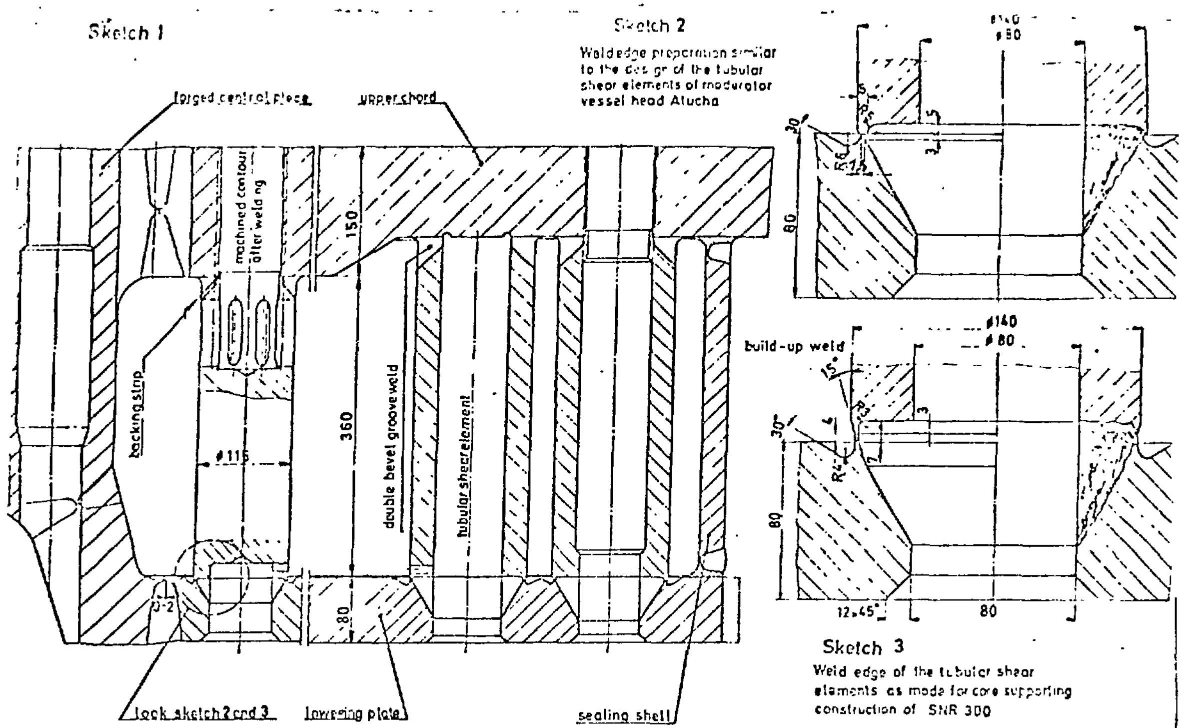


FIG. 7 - CORE SUPPORT PLATE

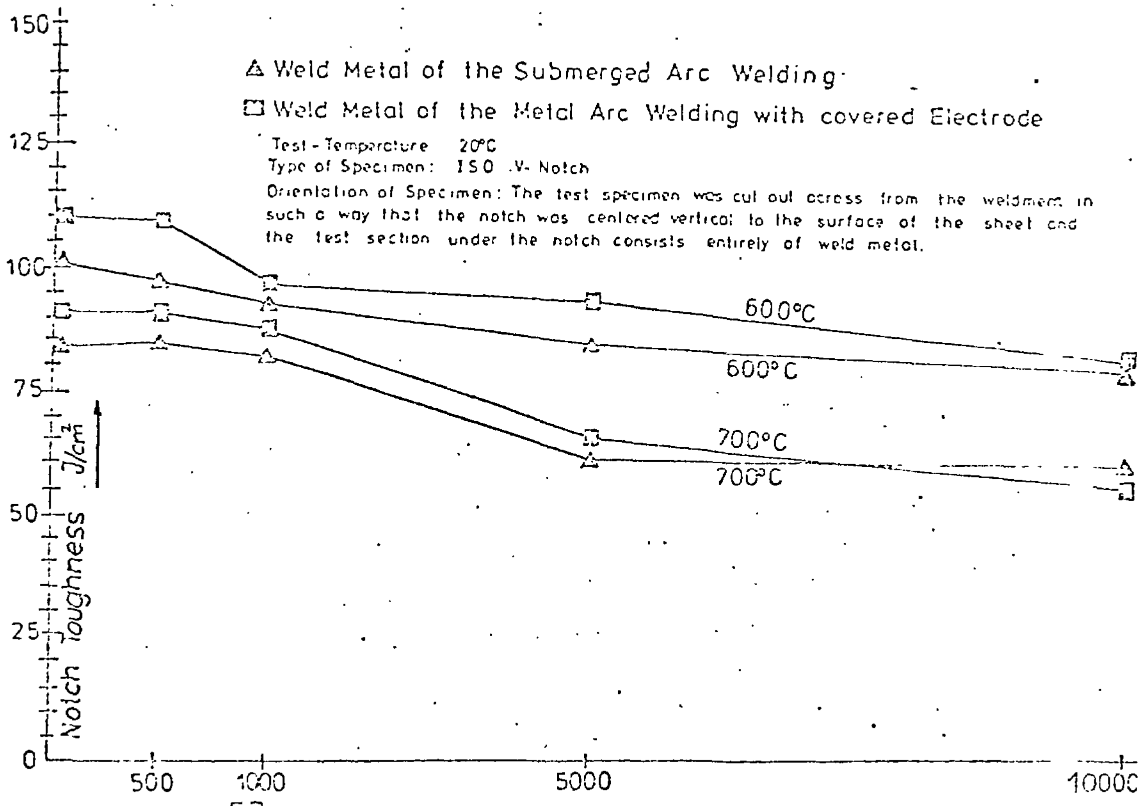


FIG. 4

Plate-Thickness: 50 mm

Tafel 1. Hochwarmfester austenitischer Stahl X 6 CrNi 18 11. Chemische Zusammensetzung.

	C	Si	Mn	Cr	Ni	Mo	P	S	Ti+Ta+Nb
					%				
Nach VdTÜV-Werkstoffblatt	0,04 0,08	≦ 0,75	≦ 2,00	17,9 19,0	10,0 12,0	k.A.[1]	≦ 0,045	≦ 0,030	k.A.[1]
Nach Spezifikation für SNR	0,04 0,06	≦ 0,75	≦ 2,00	17,9 19,0	10,0 12,0	≦ 0,50	≦ 0,030	≦ 0,020	≦ 0,10

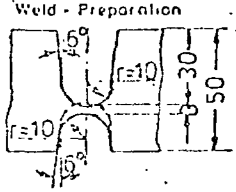
Hochwarmfester austenitischer Stahl X 6 CrNi 18 11.
Mechanische Eigenschaften an Querproben nach VdTÜV-Werkstoffblatt.

Blechdicke	Festigkeitseigenschaften					Kerbschlagzähigkeit
	Raumtemperatur				600 °C	ISO-V, +20 °C
mm	$\sigma_{0,2}$	σ_1 kp/mm²	σ_B	δ_5 %	$\sigma_{0,2}$ σ_1 kp/mm²	kpm/cm²
≦10 >10 ≦20 >20 ≦158	19	23	50–70	37 34 30	8,0 (11,0)	14 9 6

Hochwarmfestes austenitisches Schweißgut für Stahl X 6 CrNi 18 11.
Chemische Zusammensetzung nach Spezifikation für SNR.

C	Si	Mn	Cr	Ni	Mo	P	S	Ti+Ta+Nb
				%				
0,03 0,07	≦0,75	≦2,0	17,5 19,5	9,0 11,0	≦0,5	≦ 0,025	≦0,015	≦0,10

Welding-Process	Interpass Temperature
Submerged Arc Welding	······ 150°C – – – 250°C –·–·– 400°C
Manual Shielded Metal Arc Welding	——— 150°C



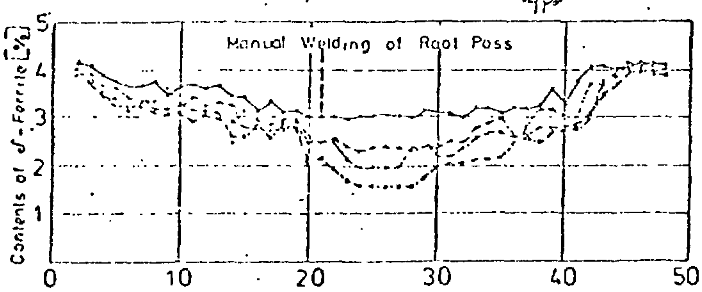


Fig. 2

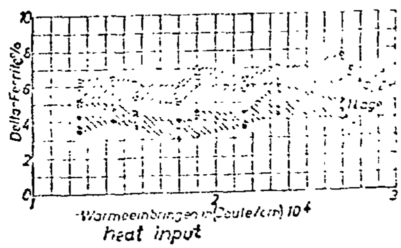
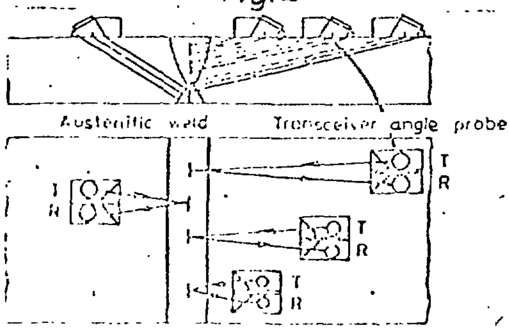
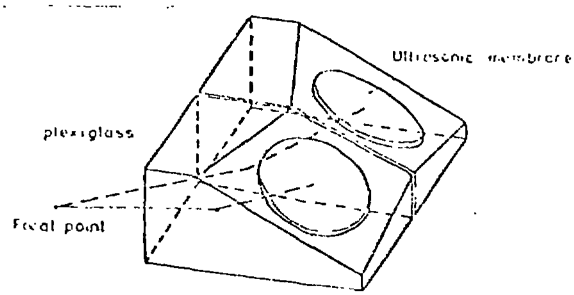


Fig. 3





ULTRASONIC TESTING OF AUSTENITIC STEEL WELD JOINTS

TRANSMITTER-RECEIVER ANGLE BEAM PROBE

FIG. 8