WELDING OF NIOBIUM CAVITIES AT CERN

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During the last years different methods for the fabrication of single cell and multi-cell cavities of quasi-spherical shape from niobium or copper sheet material have been considered at CERN. Hydroforming of cells with a ratio of outer to inner diameter above 3 as needed for our cavity design appears difficult and too expensive. Therefore, the forming of half cells by spinning with a welding of cells along their equator has been applied. For niobium cavities Electron Beam Welding (EBW) and Tungsten Inert Gas (TIG) welding has been used for equatorial welds and for the welding of irises. In the following we describe a few technical details and present some results.

1. ELECTRON BEAM WELDING

Since the start of the CERN feasibility study [1] of s.c. cavities for LEP, 17 cells of 500 MHz (including one 5-cell, one 4-cell and one 2-cell cavity), 2 monocells of 350 MHz and 22 monocells of 3 GHz have been assembled by EBW. This corresponds to a total weld lenght of ~ 50 m.

In table 1 and fig. 1 a few details of the three different methods of welding applied are presented.

Before welding all niobium parts are subbmitted to a CERN standard degreasing and to a chemical polishing of ~ 70 μm. After this treatment the contact of welding planes with other materials and in particuliar with plastic or aluminium foils is avoided as much as possible. All weldings are performed in a vacuum chamber where a final vacuum of 5-8 × 10^{-5}mbar can be reached with a oil diffusion pump preceded by a water baffle.

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Heavy coloration and black deposits at large cavity regions are common, especially if more than one welding is performed in a cavity. These contaminations are mainly due to hydrocarbons and for their removal a simple degreasing is not sufficient. However, an additional chemical polishing which is always applied to the inner surface of the cavities after welding leaves generally no traces of these layers.

1.1 RF losses of weldings

It is remarkable that at present the r.f. losses of the weldings and their neighbouring parts are undistinguishible from the uniform r.f. losses of other cavity regions. This is illustrated in fig. 2, where the T-map of a 2-cell, 500 MHz cavity with $Q_o = 10^9$ at 5.6 MV/m is shown.

1.2 Welding defects

The improvement of surface treatments, rinsing with ultra pure water and mounting under clean, dust free conditions [2] has allowed to avoid in 500 and 350 MHz cavities nearly all surface defects visible on the temperature maps up to field levels of 5 MV/m. By now 90% of all cavities are limited at the first measurement by defects at the weldings [1]. Different types of welding defects have been observed:

- Defects due to contamination of the welding seam by material (Cu, Al) evaporated from support systems hit by the electron beam.

- Welding projections of niobium which can be found sometimes far away from the welding region. In fig. 3 a typical Nb projection is shown which limited the field to 6.8 MV/m (250 G).

- Holes or other welding irregularities presumably due to inclusions of foreign materials or voids inside the sheet material (fig. 4). Such irregularities can also be produced if the beam current is switched off too rapidly (fig. 5).

The observation of such irregularities lead us to methods whereby defects are removed before the first r.f. measurements.

Cavities and in particular weldings are always carefully inspected after the final weldings and surface irregularities are removed by mechanical or chemical local treatments [2]. If a region has been reground a new Chemical Polishing (CP) is applied and the region is inspected again before the final rinsing.

For mechanical removal two methods were tried. Grinding with a hard metal (tungsten carbide) tool at ~ 20 000 t/min was applied. Although with this method inclusions from the tool in the niobium surface were negligible and therefore made no subsequent CP necessary, the results were poor because the surface structure remained to coarse. At present a second method using rotating emery paper is applied. Emery paper with decreasing grain size is used (quality 80 to 120) and allows to reach a much smoother surface. Tests have shown that there remain inclusions from the emery paper, therefore one applies always a chemical polishing (or a local electropolishing) after this treatment.

Welding projections are hard to detect visually and the finger tip method still is considered best. Fortunately, welding projections are concentrated near the weldings; at greater distance they stick not as tightly to the surface and can be removed normally by CP. We note that we do not apply systematic remachining to all weldings but do only parts pasts where defects can be seen or may be suspected. The application of guided repairs to the welding defects has allowed to increase field steadily and to reach reliably accelerating fields above 5 MV/m (H = 200 G).

Recently cavities have been fabricated from Nb sheet material with increased heat conductivity(*) (λ = 30 W/mK instead of 10 W/mK). It is expected [3] that defects are "stabilized" in a more effective way so that the critical field of the Nb around a defect is reached only at higher fields. First measurements performed in a 500 MHz cavity have demonstrated this effect and fields of 13 MV/m were reached. Only one welding defect became visible at a field in excess of 8.6 MV/m but did not limit the field at higher values (fig. 6).

(*) Produced by W.C. Heraeus G.m.b.H., Hanau, W. Germany.

For the welding of a new 350 MHz 4-cell prototype cavity for LEP we intend to use an internal gun(*). This is made possible because of the large iris opening (200 mm) of the new cavity layout [4]. For reasons of mechanical stability we have to use a wall thickness of ~ 3 mm [5] and it has been tested that welding projections are difficult to avoid by a "through weld" from outside in niobium material with a thickness in excess of 2 mm. With an internal gun one does not need to produce a complete through weld. Therefore, less energy has to be deposited at the welding region and the melting pool can be kept more stable. Also the surface quality of the side, where the electron beam impinges is generally superior. One can use external supports which avoid not only the danger of contamination or scratches of the inner surfaces, but which allow also to handle in a more efficient way deformation problems at the iris regions. It is hoped that multi-cell cavities can be assembled from individual cells by performing all iris weldings in one pumping cycle. A first welding with an internal gun has been performed on a 350 MHz, single-cell test cavity and allowed to reach acceleration field of 5.6 MV/m and $Q_0 = 3.2 \times 10^9$ at 4.2 K [6], the fields were not limited by the weldings.

2. TUNGSTEN INERT GAS (TIG) WELDING

TIG welding has been applied at CERN because it offers an alternative and economic method for assembling niobium parts of thin wall thickness ($d < 2$ mm) and of complicated shape and allows larger mechanical tolerances than EBW. For reasons of economics and for greater flexibility we have not used TIG welding inside a glove box. In table 2 a few welding parameters are given and in fig. 7 a schematic layout of a gas protection system is shown. It must be stressed that such a system has to be matched to every welding geometry and it is one of the drawbacks of TIG welding that contaminations with other gases, in particuliar water vapour cannot be avoided easily and reliably. We have applied TIG welding successfully to the welding of 3 GHz cavities and to higher-order mode couplers. Most of the circular and linear weldings were done on a welding machine, but some weldings were also done manually. A total of ~ 10 m of TIG weldings have been applied up to now. TIG welding has been applied once

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(*) Kindly lent to us by Sciaky Paris.

to a 500 MHz cavity but the result was not conclusive, partly because a large hole had been produced which had to be repaired by some additional Nb material. In fig. 8, a temperature map of the 500 MHz cavity is shown.

Two temperature signals can be seen at the weld, one at the accident region and another at a different position which finally limited the field to $E_{acc} = 4.2$ MV/m. A later inspection revealed many fissures at both weldings presumably due to an unsufficient gas protection.

3. CONCLUSION

EBW is considered a sufficiently economic and simple method for assembling large single-cell and multi-cell cavities. It has attained a degree of reliability which is considered satisfactory for LEP applications. TIG welding can replace advantageonsly EBW for small complicated Nb parts with thin wall thicknesses, or for parts not exposed to high r.f. fields. More investigations will be necessary to apply TIG welding to large cavities with a degree of reliability compared to the one already achieved in EBW.

Acknowledgments

The developments in TIG and EB welding at CERN were possible because of a very fruitful collaboration with G. Girel and B. Thoeny and their groups. We would like to thank them for their skillfull and perseverant work. We would like to thank also A. Scharding from our group who constructed and applied most of the inspection and repairing facilities.

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[2] D. Bloess, this Workshop.

[3] H. Padamsee, IEEE Mag 19,3 (1983) 1322.

[4] E. Haebel, P. Marchand and J. Tückmantel, CERN/EF/RF 84-2 (1984).

[5] I. Wilson, CERN, private communication (we would like to thank I. Wilson for performing the stability calculations).

[6] C. Benvenuti et al, this Workshop.

TABLE 1

Some EB welding parameters

Thickness	Voltage	Current	Speed	Remarks
2 mm Nb	55 kV	16.5 mA	6.3 mm/s	External welding without full penetration
"	55 kV	12 mA	6.3 mm/s	Cosmetic welding from inside
"	25 kV	65 mA	2.3 mm/s	External welding with full penetration
3 mm Nb	25 kV	70 mA	3 mm/s	Internal gun, without full penetration
3 mm Nb	60 kV	62 mA	13 mm/s	External welding without full penetration
"	63 kV	43 mA	13 mm/s	Cosmetic welding from inside

TABLE 2

Some TIG parameters

Thickness	Voltage	Current (pulsed with 5 Hz)	Speed	Remarks
1 mm Nb	15 V	60 A	4.8 mm/s	Welding from outside
2 mm Nb	15 V	190 A	5.3 mm/s	Internal welding without full penetration

FIGURE CAPTIONS

Fig. 1 EBW schemes. Cavity axis always in the horizontal plane: dimensions in millimetres:

(a) External-internal welding.

(b) External welding only; the angle of 43°30 is chosen for a better stabilization of the welding pool.

(c) Welding by internal gun.

Fig. 2 Temperature map of a 500 MHz two-cell cavity taken at $E_{acc} = 5.6$ MV/m with $Q_o = 10^9$ at 4.2 K. The losses shown are due to an external magnetic field of 130 mG and to electrons (cell 1). Each cell has two equatorial welds, whose location is indicated by arrows. The iris weldings (located in a region of high electric field) also do not show increased losses.

Fig. 3 Typical welding sphere loosely bound to the Nb surface; diameter ~ 75 µm.

Fig. 4 Hole inside a welding causing a fast quench at ~ 130 G.

Fig. 5 Welding irregularity at overlap at the end of a circular weld. The second weld besides the first one has been produced by accident. The steel ball is used for localising the quench region after dismounting.

Fig. 6 As fig. 2 for a cavity made from Nb material of high thermal conductivity. $E_{acc} = 12.6$ MV/m. Two defects at the lower equatorial welding can be seen. Except for these defects the r.f. losses at the welding cannot be distinguished from the surrounding regions.

Fig. 7 Example of TIG welding layout with gas protection system. Welding with a torch from inside. Gas protection by an outer ring and an internal gas trail filled with titanium particles.

FIGURE CAPTIONS (Cont'd)

Fig. 8 As fig. 2 for a TIG welded 500 MHz cavity. Defects in both equatorial welds can be seen. The defect at the upper weld corresponds to the repaired region. Hp = 150 G.

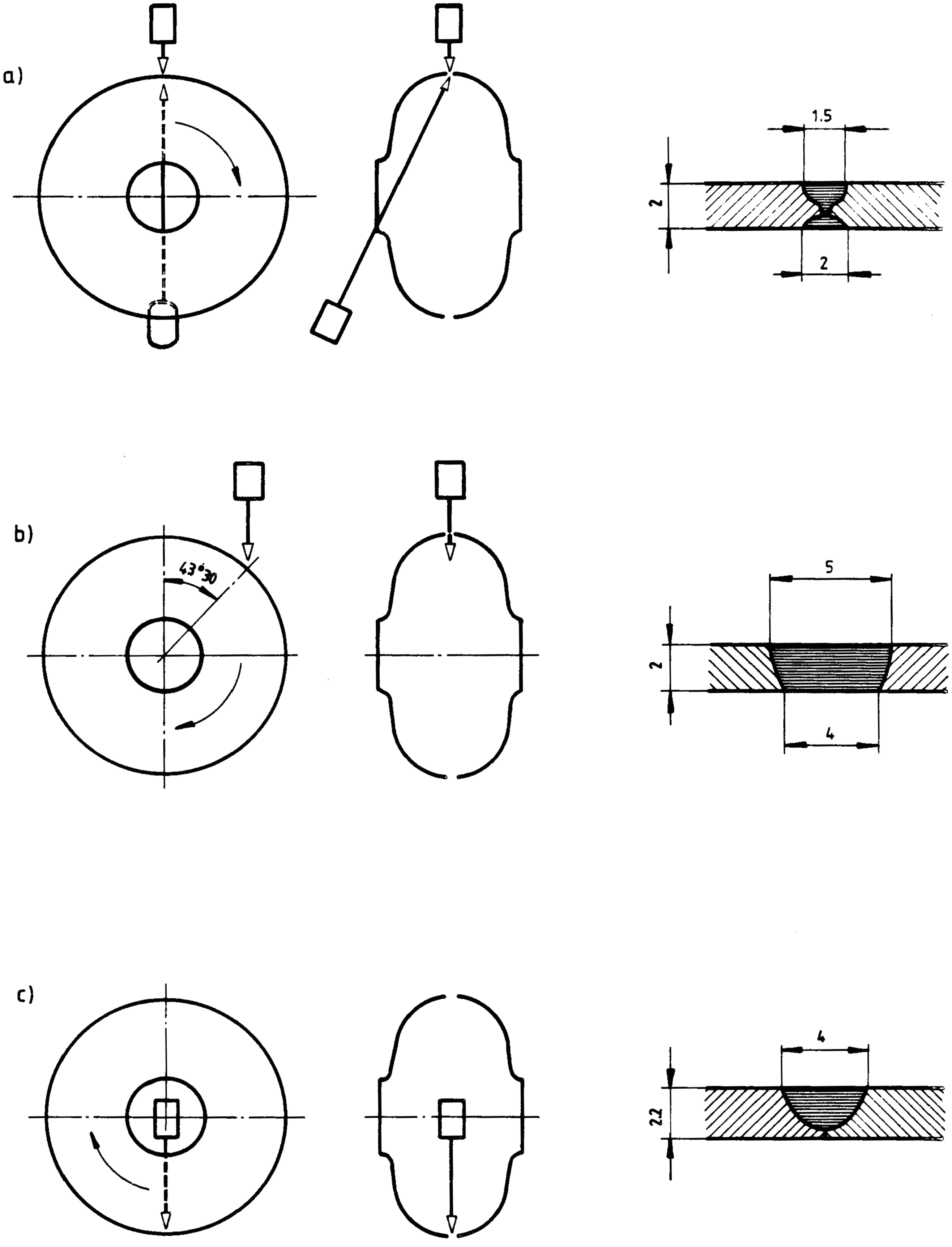
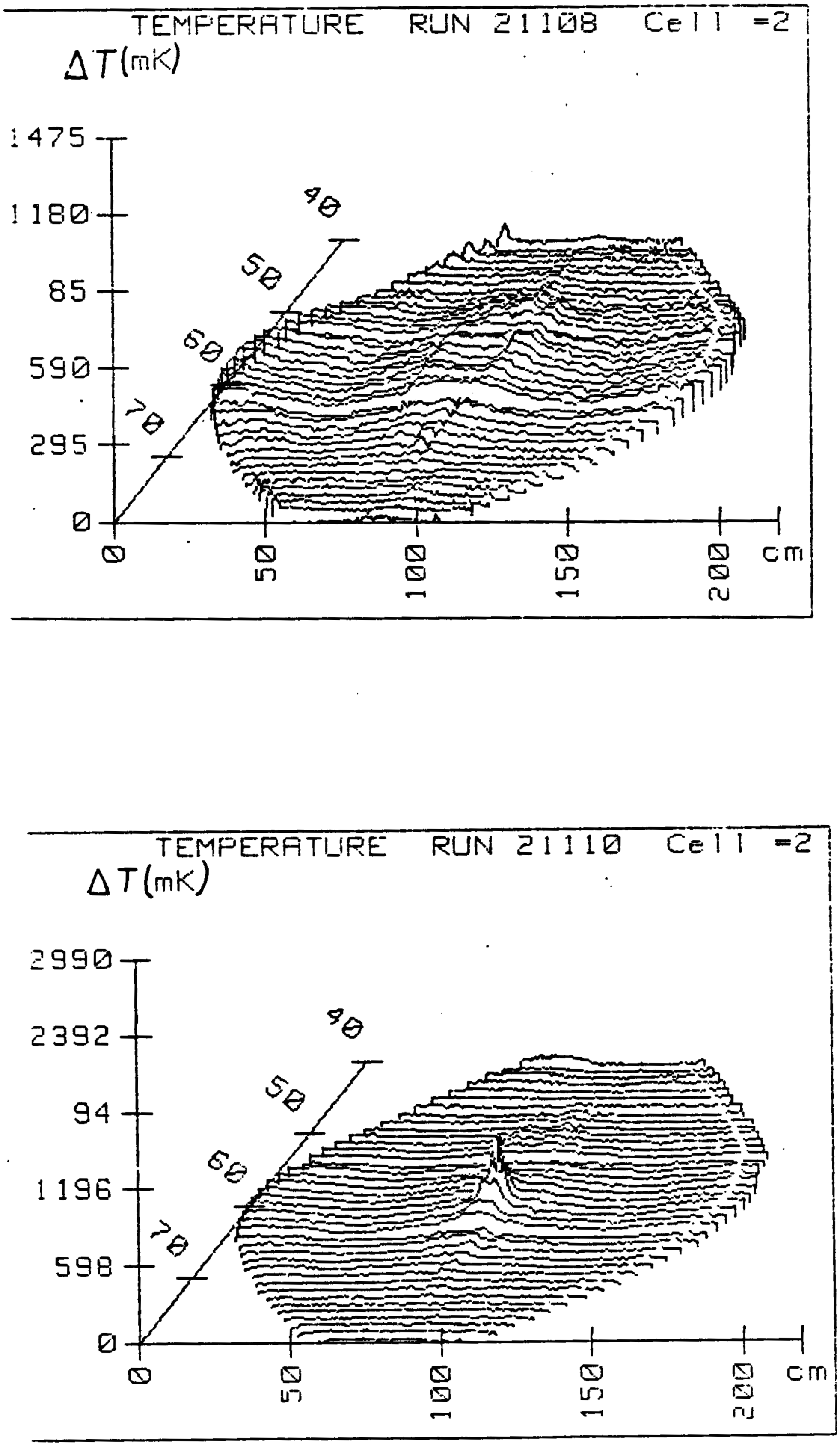


FIG 1 — DIFFERENT METHODS OF E.B.W —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ΔT(mK)
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Fig.2

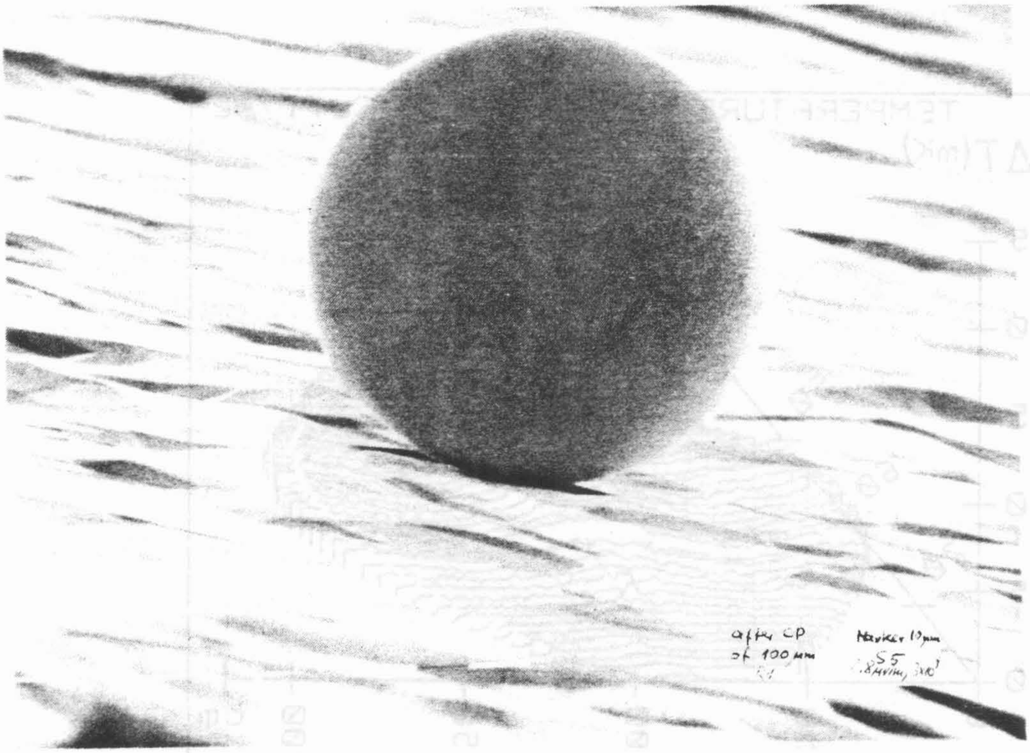

Fig. 3

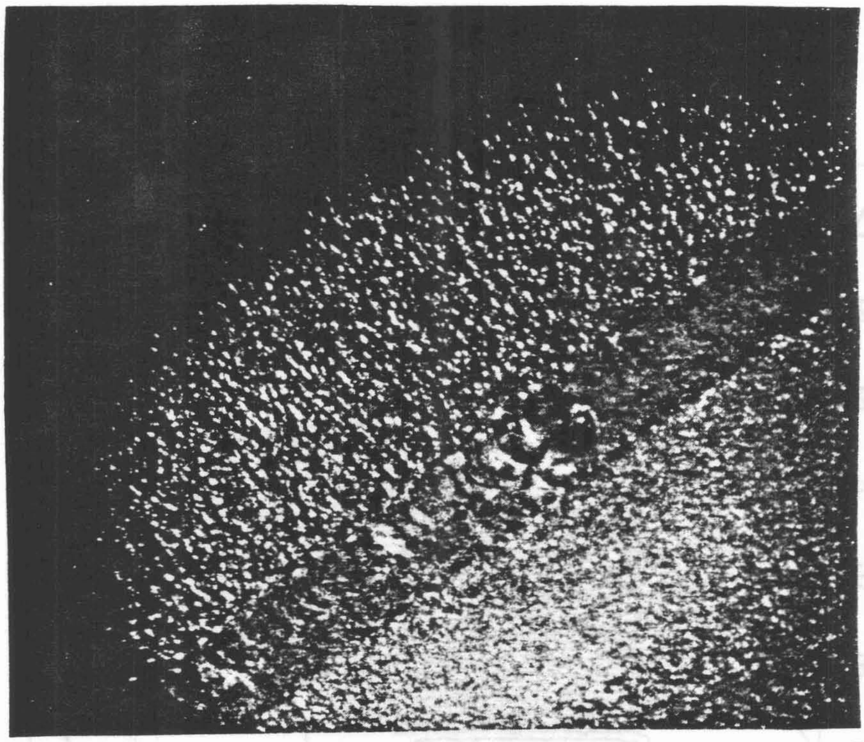

Fig. 4

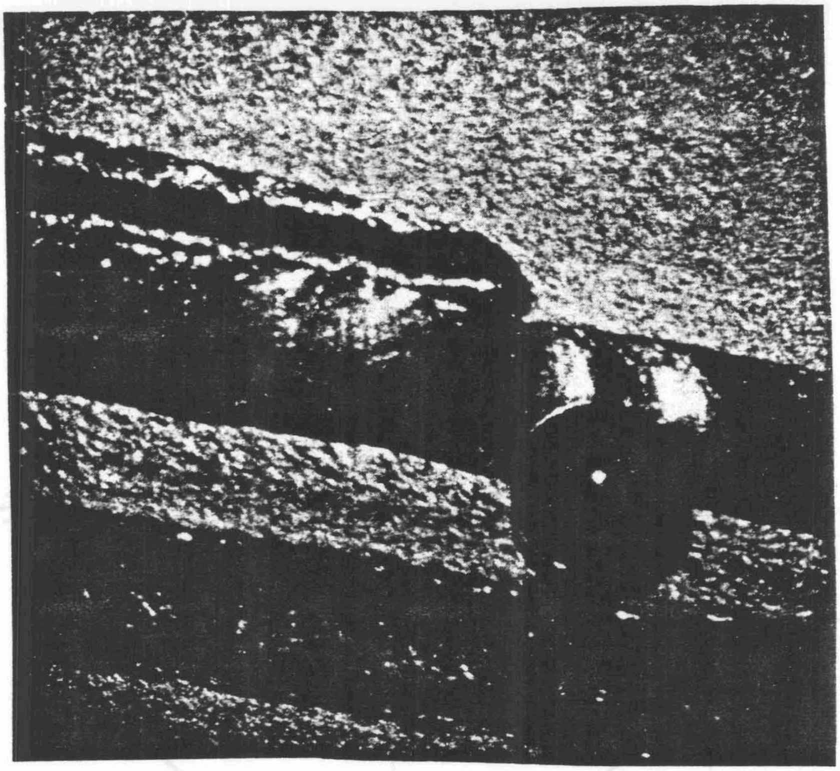

Fig. 5

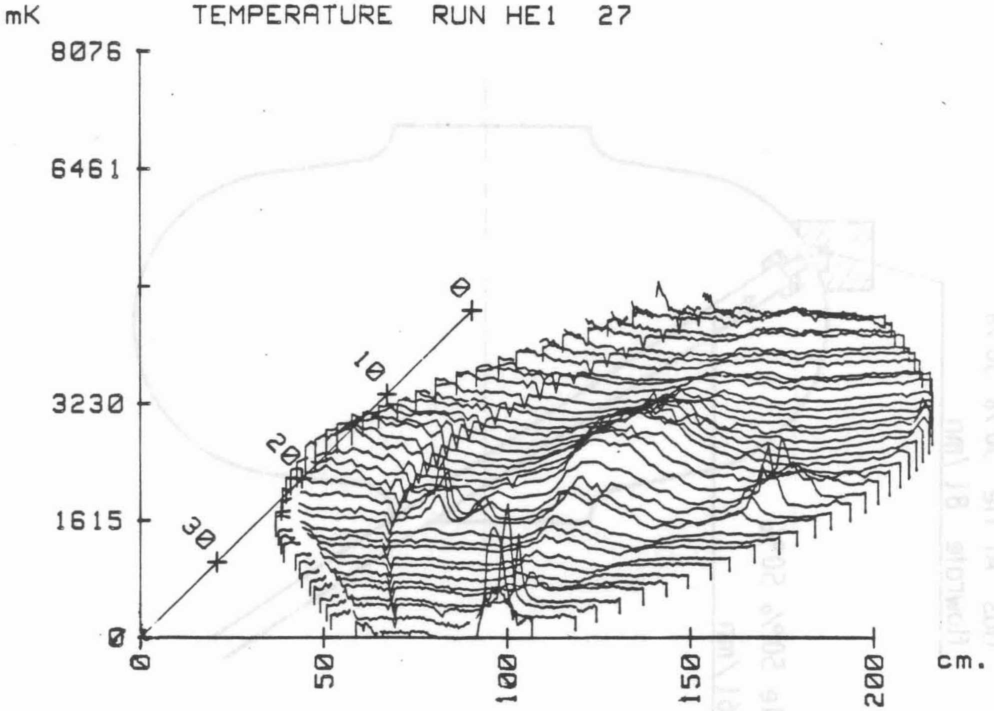
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Fig. 6

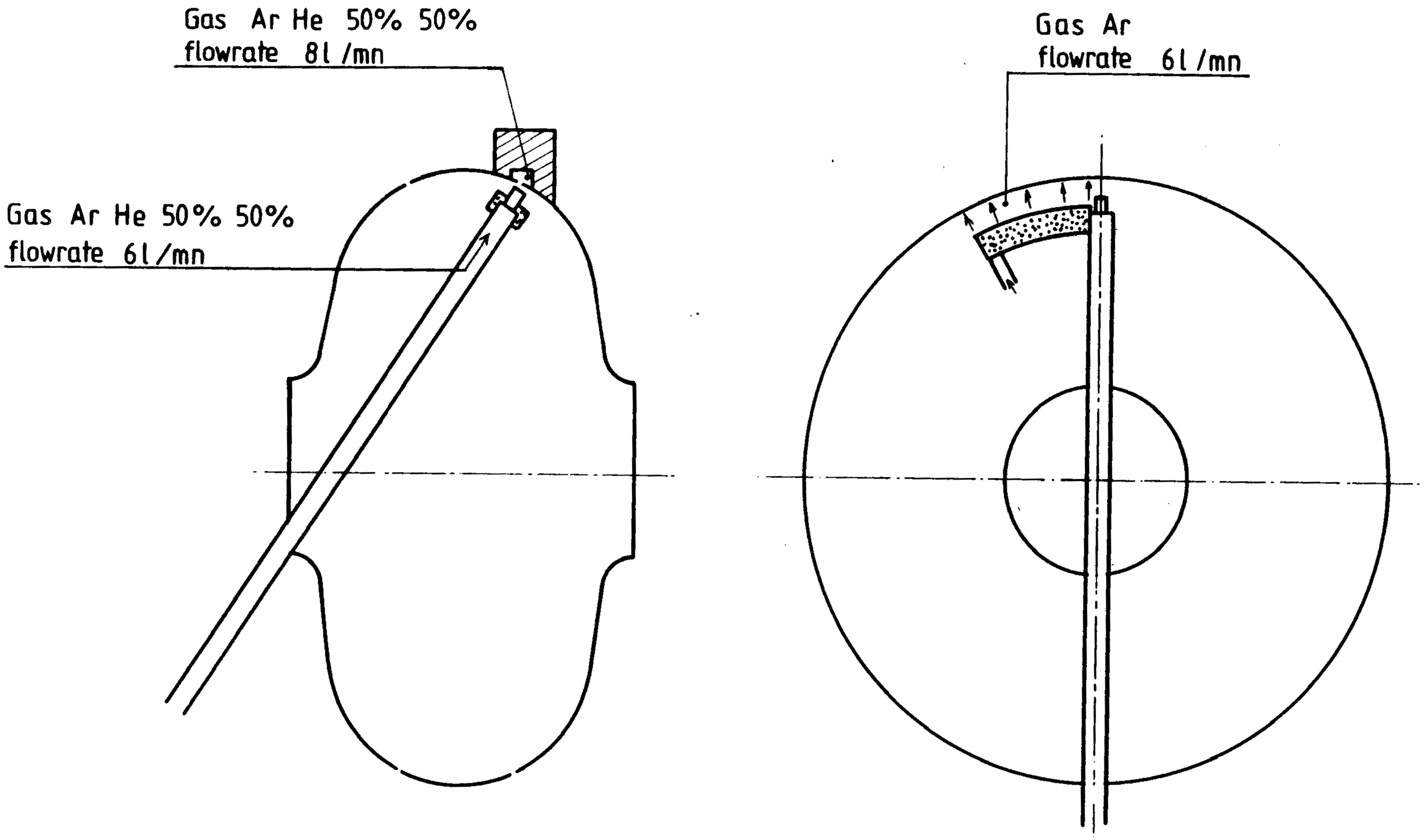

FIG.7 METHOD OF T.I.G. WELDING

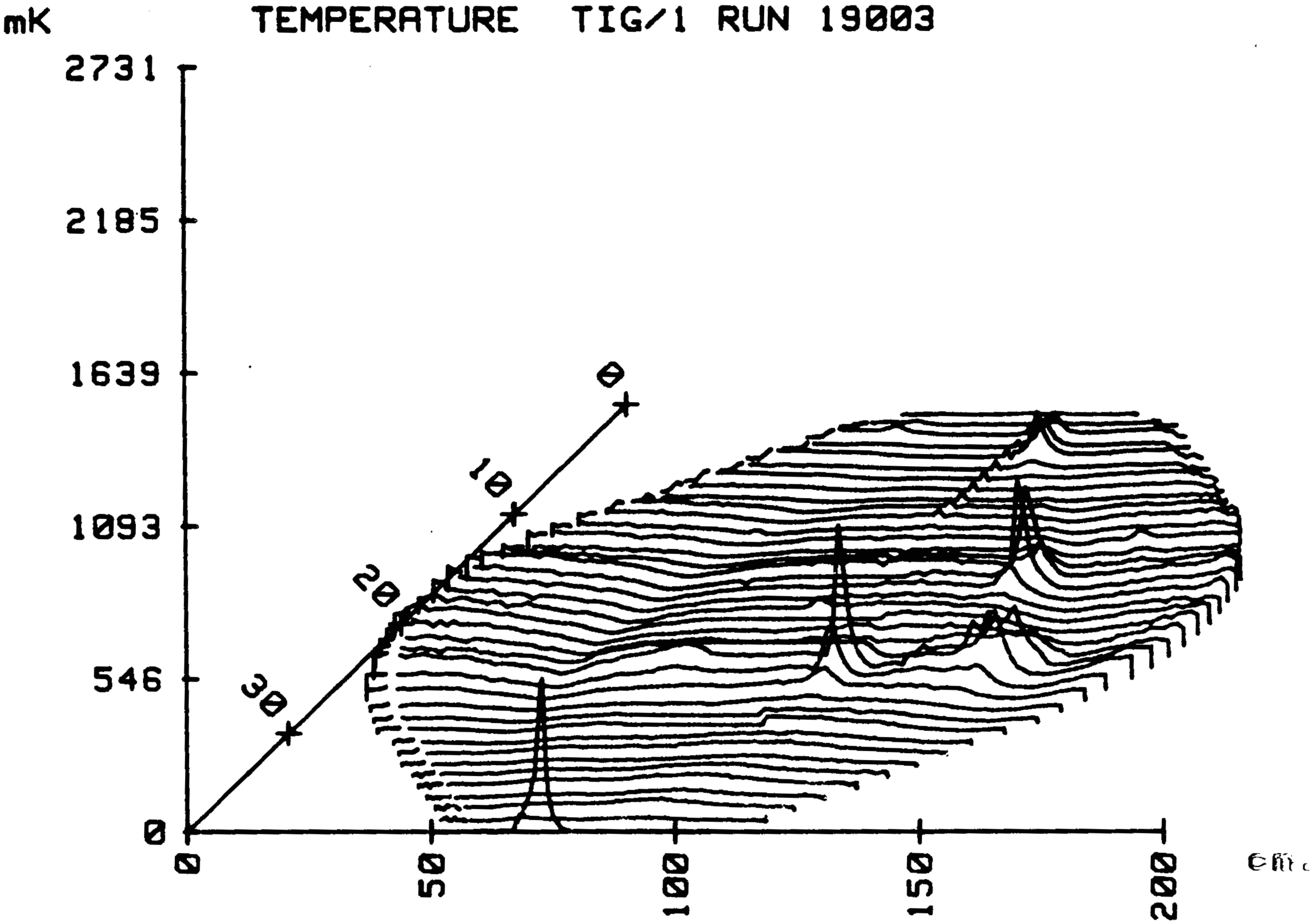
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Fig.8