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# DEVELOPMENT IN FABRICATION METHODS

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Abstract.

Some recent developments and results in the fabrication technology of Niobium cavities at different laboratories and companies are presented in this report. It reviews mainly some present material selection possibilities, their joining techniques and costs.

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## 1. Review of fabrication methods and costs.

A comparative table shows the present methods of fabrication for niob superconducting cavities. It is based on a design of a 1Ghz/9cell structure with rectangular waveguide couplings. The corresponding prices (kDM) for manufacturing one structure are real if not shown in parenthesis. The manpower costs are based on a wage rate of 50.-dm/hr. The tooling and fixture costs have been prorated for a production of 10 complete cavities.

| | Nb1 | Nb2 | Nb1/2 galv.coat | Cu-Nb sputter |
|---|---|---|---|---|
| Material | 18 | 36 | 18/36 | (3) |
| Tooling for deep-drawing | 5 | 5 | 5 | (5) |
| 18 half-cells" " & CP | 4 | 4 | 4 | (4) |
| 9-cell structure, mech.preparation & EB-weld | 27 | 27 | 27 | (27) |
| RF-tuning,tumbling & CP | 6 | 6 | 6 | (6) |
| Sputtering of Cu on Nb, incl. fixture | | | | ( ) |
| 1-cell galvanic coating Ag | | | 4 | |
| 9-cell " " " | | | (50) | |
| Waveguides " " " | | | (20) | |
| 1-cell brazing of coolg.tubes | | | 2 | |
| Cavity compl." " " " | | | (15) | |
| Temperature mapping fixture | 5 | 5 | 5 | (5) |
| RF cold-test(1300 l LHe) | 27 | 27 | 27* | (27) |
| First repair if defects, incl. fixture | 3 | 3 | 3 | ( ) |
| Tumbling and CP | 6 | 6 | 6 | ( ) |
| Repair sputtering of Nb | | | | ( ) |
| 2nd.RF cold-test | 27 | 27 | 27* | (27) |
| Material waveguide couplers | 12 | 24 | 12/24 | (2) |
| Waveguide couplers, mechanical prep., EB-welding and CP | 58 | 58 | 58 | ( ) |
| 9-cell struct.with waveguides, mechanical prep. and EB-weld | 7 | 7 | 7 | ( ) |
| Complete cavity, tumbl. & CP | 6 | 6 | 6 | ( ) |
| Cryostat manufacture (without waveguides & RF-window) | 120 | 120 | (60) | ( ) |
| Safety equipment | 10 | 10 | (2) | (2) |
| Cavity instl. in cryostat | 15 | 15 | (5) | ( ) |
| Vacuum test, room temperature | 2 | 2 | | |
| Vacuum test, cold | 11 | 11 | (3) | (3) |
| Total costs | 369 | 399 | 372/402 | |
| Cost per meter structure | 273 | 296 | 276/298 | |

Footnotes:

Nb1 = Reactor grade Niobium, deep-draw quality.

Nb2 = High-thermal-conductivity Niobium, deep-draw quality.

* : Test before galvanic coating.

## 2. Joining methods

### 2.1. Niobium Electron-beam welding.

The normal EB-welding procedure (inside and outside weld-bead) has shown to be a very reliable method of joining Niobium structures. Welds of this type have been made reliably at several places (ref.1,2,3,4,5). In places where it was not possible to make an inside weld the underbead was purposely made larger to avoid holes in the weld zone after the required grinding. The welds show no loss of thermal conductivity or superconducting properties.

A onesided weld with smooth underbead was also produced by using different welding parameters. This should eliminate the necessity of grinding the inside surface to obtain the required smoothness.
One 9-cell,1Ghz structure was manufactured in this manner (ref.6)and tested(ref.7). There was no performance difference compared with the two-sided welds.The welding parameters are unknown, but the wide weld is the ditinct feature compared to the classical EB-welds.
Also in view of obtaining a single sided, smooth underbead weld, a welding technique called "Rhombic Welding" (ref.8)was developed. The TIG-welding parameters were taken as the basis for determining the energy, energy distribution and welding speed. This way it is possible to work without a defocussed beam. A defocussed beam is more difficult to reproduce and tends to produce small holes in the weld.
The "rhombic weld" produces also an extremely wide weld. Typical welding parameters for 1.5mm material are: 50 KV, 35 mA, 7.5mm/s welding speed, 3mm max. traverse deflection, and 1.5mm max long.deflection. The resultant weld is about 5mm wide at the top and 4mm at the bottom.
More details and recommendations on EB-Welding in (ref.1) this workshop

### 2.2. Niobium TIG-Welding

It is used presently only for repairs and weldings in zones inaccessible to the EB. Not recommended because of poor reliability.

## 2.3. Brazing Niobium to Stainless Steel.

Very reliable joints are made with the 80Au-20Cu brazing material (ref.9). A good preparation of the pieces to be joined is essential. The brazing furnace must hold a vacuum better than 10-4 mbar at 960C and has to be equipped with a LN2 or Freon baffle to trap the water vapor. Fig.1 shows a typical mechanical preparation for a tube-flange brazing.
Only the first brazings were mechanically tested repeatedly at LN2 temperature with subsequent He-leak tests (ref.10) and they showed no failure.
The price of the brazing material is approx. equal to the gold price.

## 2.4. Explosive Bonding of Niobium to Stainless Steel.

To avoid clamps at flanges it is useful to have a material with higher strength to back up the Niobium. This can in some cases simplify the design and provide the required rigidity for the gaskets.
After a trial test, some 22mmSS/3mmNb plates were produced (ref.11) and used in the fabrication of the wave-guide flanges for 1GHz structures. The quality of the bond seems excellent and remained vacuum thight after several LN2 cycles before and after welding to connecting pieces. Fig.2 shows a cut thru the bonded surface. The small brittle splashes of SSteel mixed with Niobium can be easily avoided by changing some manufacturing parameters.

## 3.Hydroforming

In order to reduce the welding costs and to avoid uncertainties in the welds there was a great deal of work done to fabricate hydroformed Niobium structures. Although it has been demonstrated (ref.8,12,13) that this method of fabrication is feasible,it is not the most economical alternative for the quantities required at the present. The difficulty in obtaining Niobium tube shapes in deep-draw quality, the many intermediate annealing cycles required and the rather rough inside finish are the main negative factors.
The advantages of the hydroforming technique are not obvious since in the meantime the problems with the EB-welds have been reduced to a minimum .
For these reasons there is not much effort made in this direction at the present. Only one laboratory (ref.4) will actively continue this work

## 4. Surface Coatings

The readily formed Nb-oxides make it difficult to apply metallic coatings on Niobium or viceversa. Previous work (ref.14) show the great advantage that can be obtained by increasing the thermal conductivity of the material which carries the heat to the LHe. This improved thermal conductivity can be obtained by:

### 4.1. Niobium Sputtering on Copper

By sputtering a thin superconducting Niob coat on a material with high thermal conductivity, e.g OFHC-Cu .The details on this work will be reported in the next talk (ref.15)

### 4.2. Galvanic coating of Niobium

The galvanic coating has to have a high thermal conductivity at LHe-temperature,e.g.very.pure silver or Copper.
A Niobium 1-cell, 1 Ghz cavity was coated with a 0.3mm layer of pure silver with a specially developed method (ref.5).The cell was then tempered at 740 C at 5*10E-6 mbar to improve its thermal conductivity al low temperatures,chemically cleaned and then tested in a normal LHe cryostat. Results on fig.3.
The obvious next step was to attach cooling tubes on the structure for forced LHe coling thru pipes. This would replace the LHe bath cooling used presently and eliminate the costly LHe-bath cryostat with its inherent design complications and safety problems.
From the results in fig.3 it seemed that one pipe winding would be sufficient to do the cooling, but a redundant number of turns was brazed on the structure to account for eventual brazing defects and high thermal resistance regions in the brazing zones. Fig.5 shows a cut thru a brazing sample. It is intended to disconnect later some windings to evaluate their cooling capacity thru comparison with the fully wound structure. The results for the brazed structure as seen in fig.4 is shown in Table 1.
The thermal isolation of the structure in the vacuum vessel was very poor due to the small dimensions of the available tank.
The expected LHe-flow problems due to oscillations in the gas-liquid phase were overcome in this test with an increased flow rate (up to 30 l/hr). This flow rate would be greatly reduced with an adequate LHe-feed system. Since there was no obvious explanation for the discrepancy with the previous values, the structure was tested again in a LHe bath to narrow the choice of possibilities. Results on fig.6.
The discrepancy between both results could possibly be removed by one or more changes in the test procedure,e.g.:
-slower cooling rate near the transition temperature to avoid entrapped fields due to different material layers.
-better thermal isolation between cavity and cryostat. The tests were done without a cooled radiation shield.
-improved thermal conductivity in the cooling tube region.
-The temperature sensors must also provide more accurate readings to permit the measurement of temperature gradients on the surface between the cooling tubes.
Table 2 shows the measured RRR-values (ref.16) for the materials used. They show that improvement is possible.

### 4.3. Sprayed coatings on Niobium.

Plasma-sprayed coatings with pure copper are not possible due to the formation of oxides during the spraying process.
Vacuum Plasma Spraying (ref.17) has also not been successful until now. The cost of samples is very high due to the involved set-up procedure in the vacuum tank. Pure copper suited for spraying would cost approx. 8 times as much as the present silver price. The tests have not been completed yet, but they are not encouraging.

### 4.4. Chemical deposition of Niobium on copper.

Two test programs at different firms (ref.5,6) with different methods (chemical and electrochemical) gave negative results.

Table 1

| 1-cell,1Ghz cavity | LHe cooling | Qo*10-8 at Emax | Emax Mv/m |
|---|---|---|---|
| Nb1, w/o coating | bath | 3.7 | 5.3 |
| Nb1, with .3mm Ag-coat, tempered 740C, degreased | bath | 1.5 | 2.3 |
| above but new CP | bath | 6.8 | 5.4 |
| above with brazed cooling tubes and new CP | tubes<br>bath | 5.0<br>6.7 | 3.9<br>4.5 |

Table 2

| Probe | RRR before annealing | RRR after annealing | remarks |
|---|---|---|---|
| Ag-coat L | 19 | 42 | |
| ( " " S) | 5.6 | 6.3 | for ref.only |
| ( " " G) | 2.5 | 2.7 | " " " |
| (SF-Copper) | 5 | 5.4 | " " " |
| SE-Copper | 25 | 71 | |
| Incusil 15 | 1.7 | | |

## 5. Summary.

The reported developments widen the range of possibilities in some fabrication methods. The electron-beam welding, the brazing, and the explosive bonding techniques are reliable joining methods.
The hydroforming of Niobium cells, although possible, has been inactivated, perhaps as a result of the more reliable joining techniques.
Surface coatings have made great progress in the last year and the use of galvanic or sputtered coats present new practical design possibilities for Niobium superconducting cavities.

## 6. Acknowledgements.

The information presented herein recapitulates some of the work done by many people at different laboratories and companies. Their enthusiastic support and help made the reported development possible.

## 7. References.

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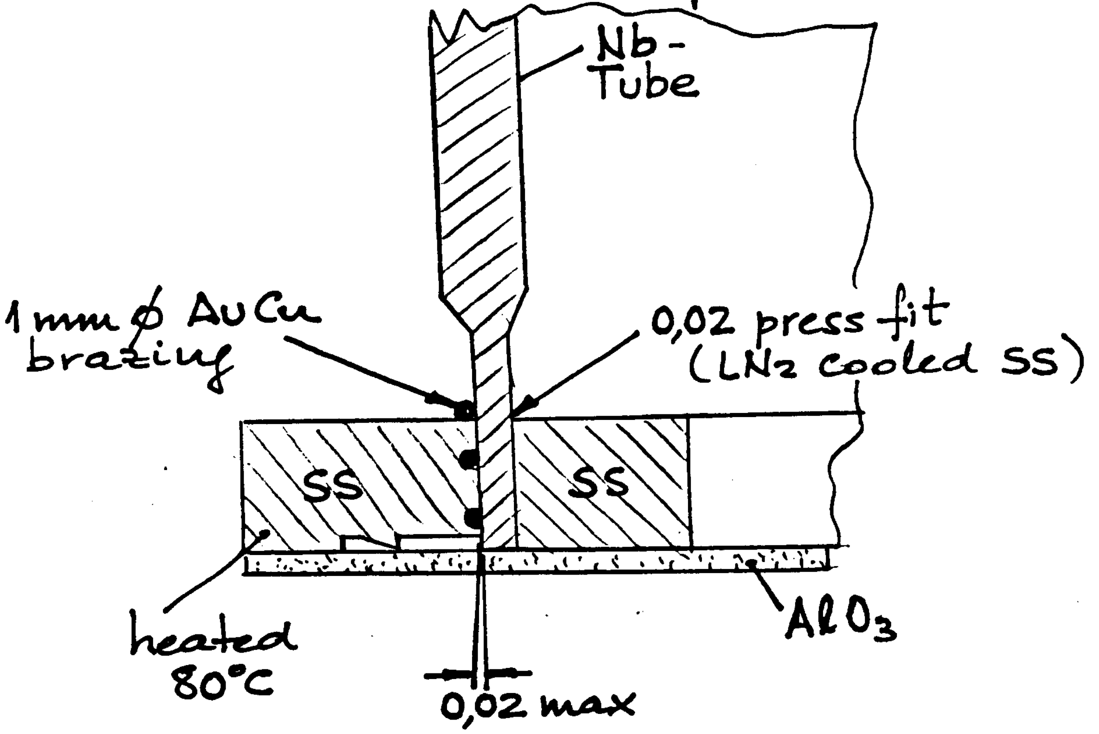
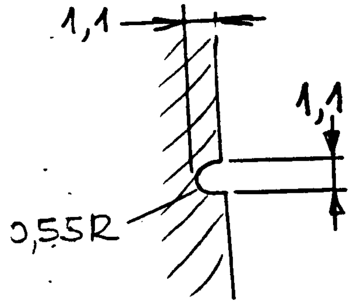
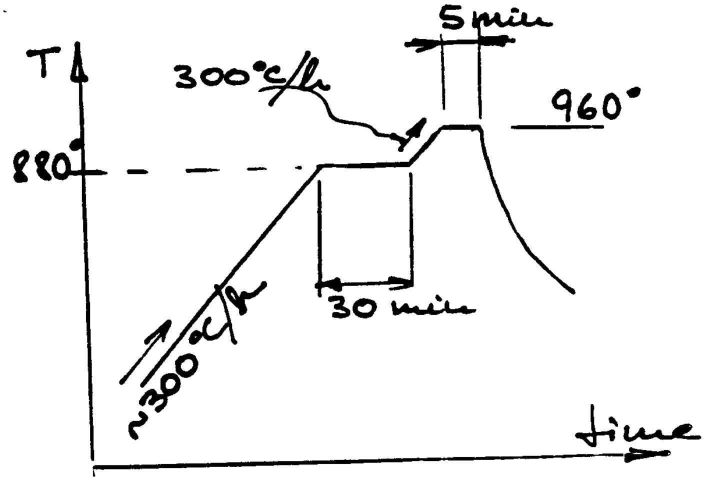
Fig. 1: Typical Brazing Parameters for Nb-SS joint: (B. Trincat, CERN, private commun.)





Groove prep.



Brazing cycle

- Vacuum $\sim 1 \times 10^{-5}$ mbar @ 960°C ($10^{-4}$ max!!
- Freon or $LN_2$-baffle to trap water vapor
- Nb and SS chemically cleaned before brazing
- Brazing material 80% Au - 20% Cu

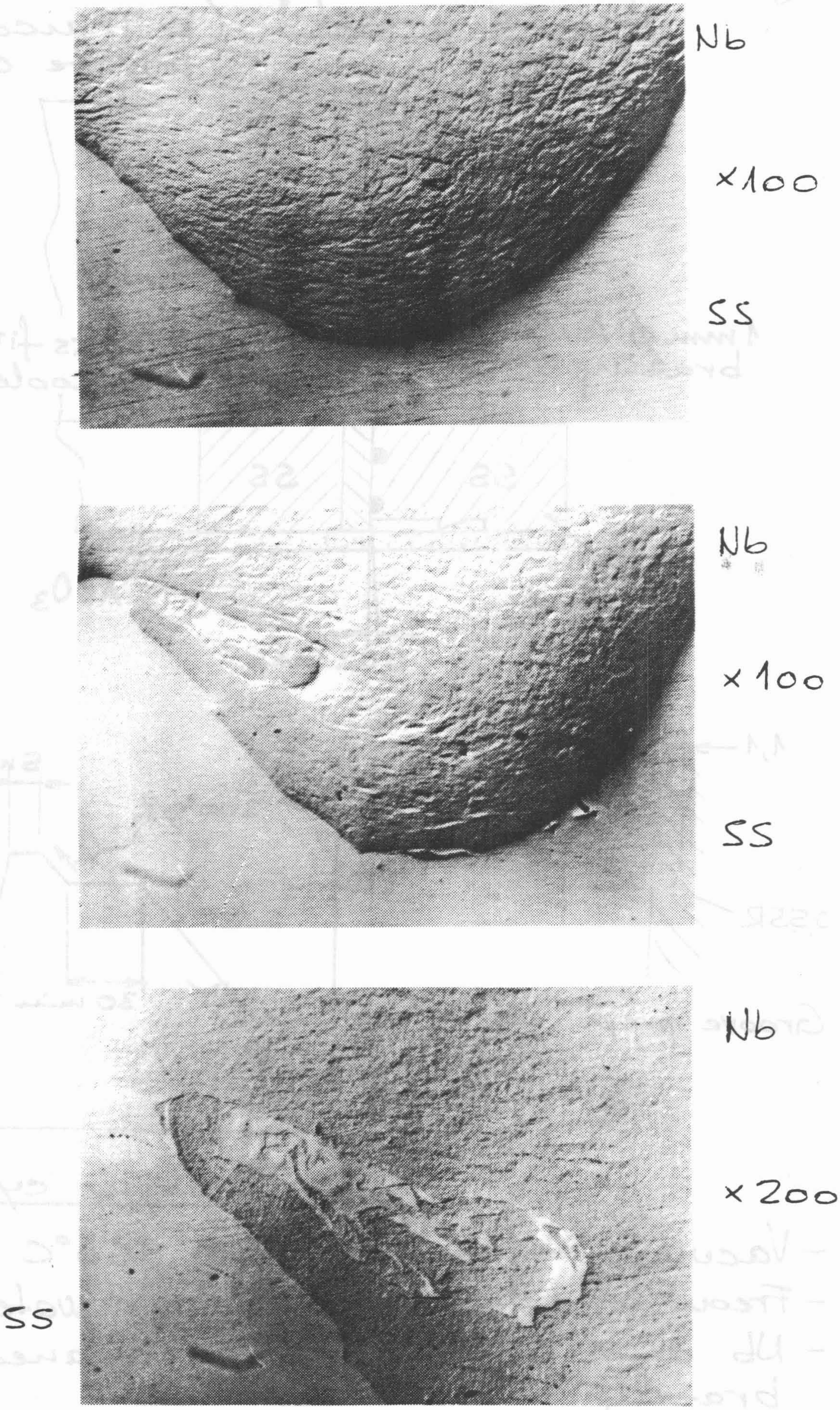
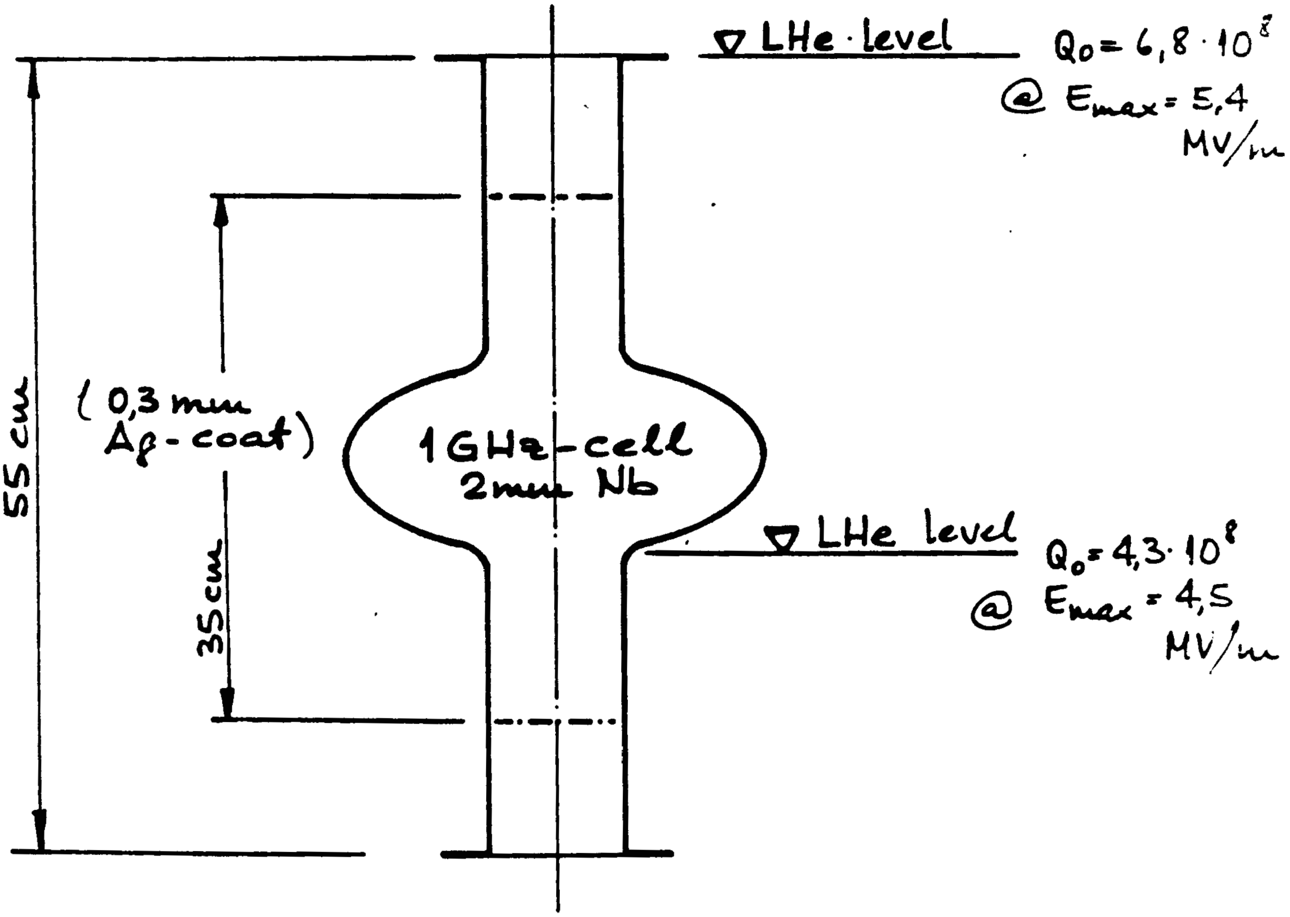


**Fig. 2** Explosive Bonding

# Fig. 3

Test of Ag-coated Niobium Cavity in LHe-bath cryostat.



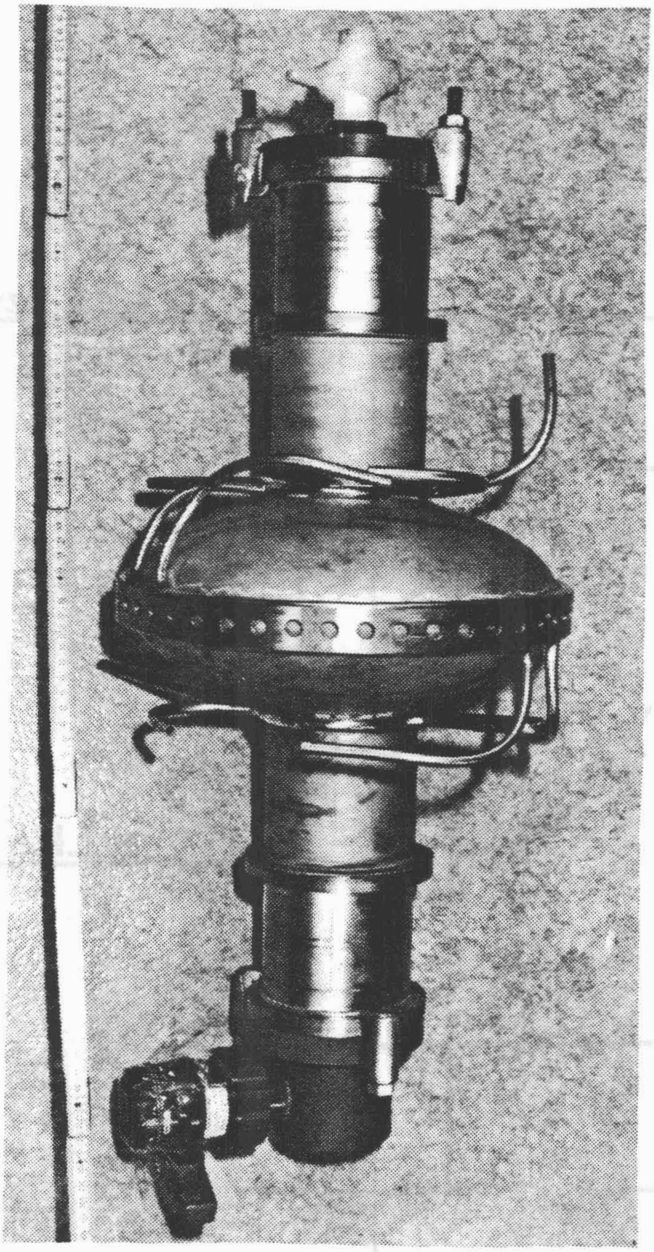
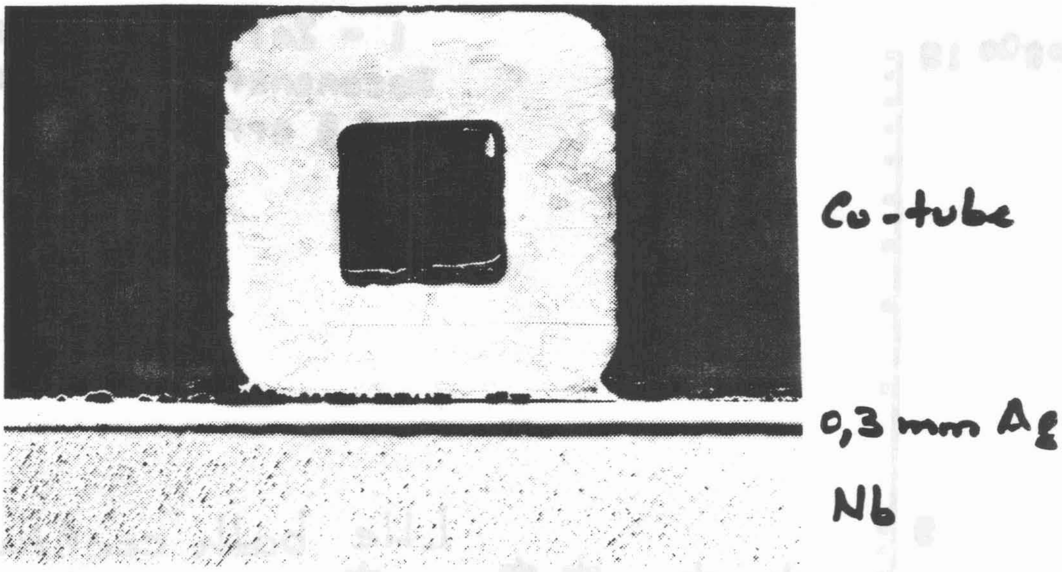
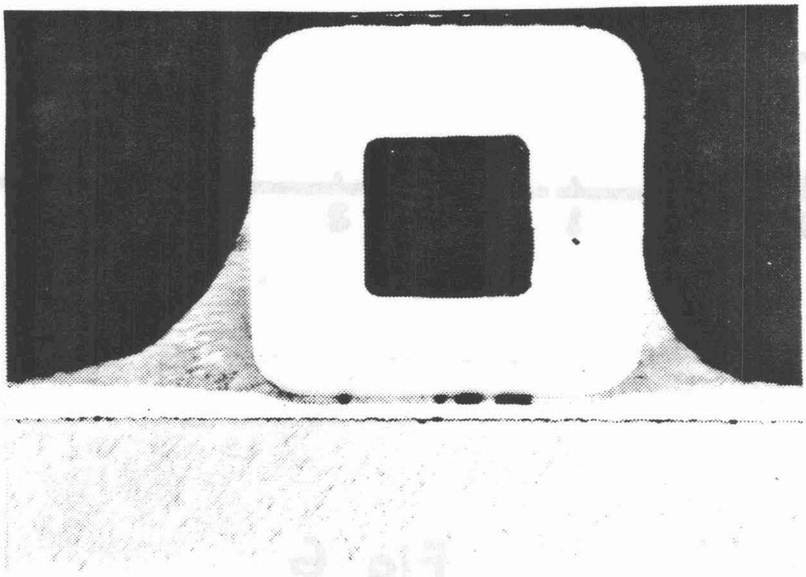


Fig. 4

1 GHz - Ag coated Niobium cavity with brazed cooling tubes.



with "CUSIL" (72 Ag - 28 Cu)



with "INCUSIL" (Ag 62 - Cu 23 - In 15)

Fig. 5

Test brazing of Ag-coated Niobium

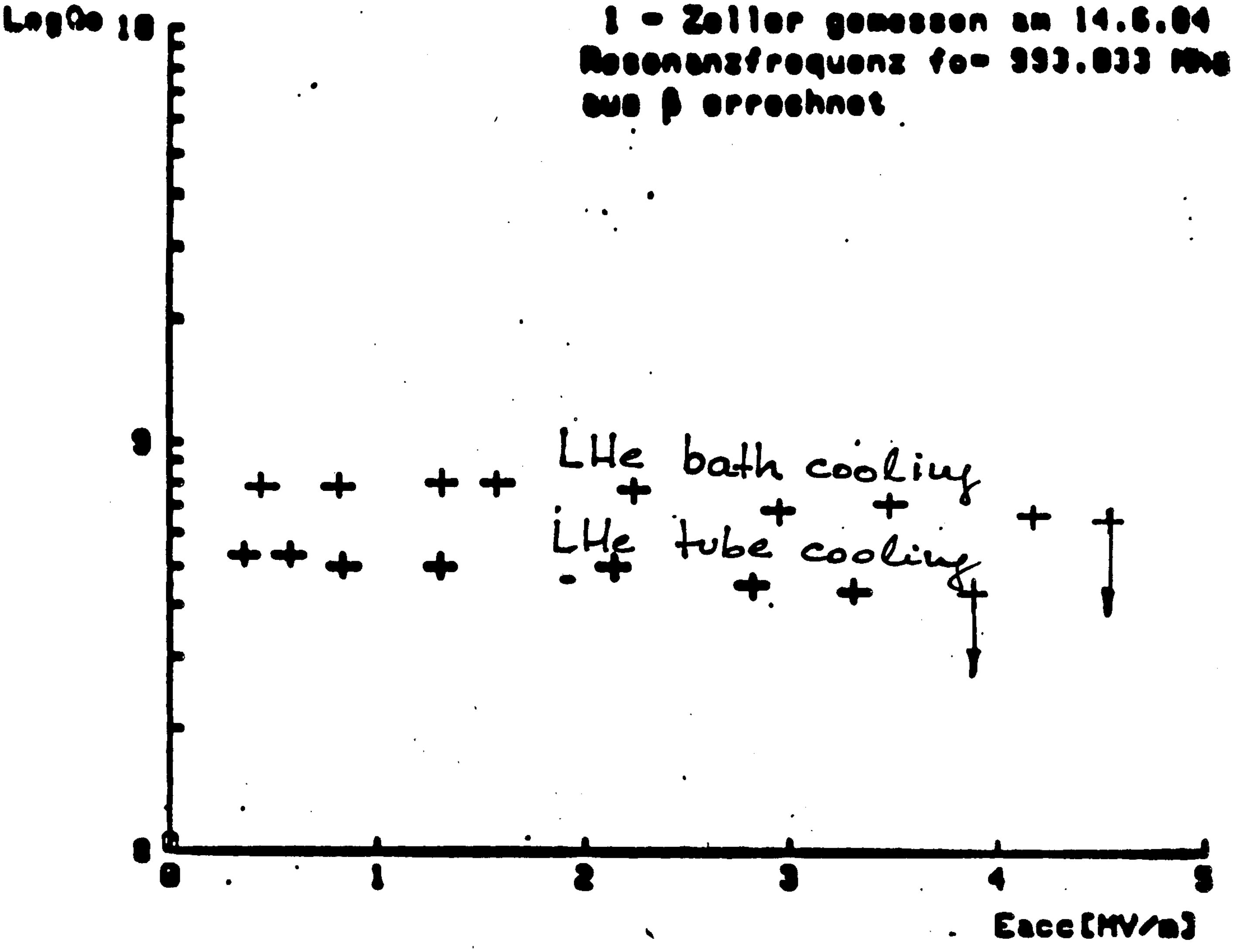


Fig 6

1-Cell 1 GHz, Ag-coated Nb-cavity test in LHe-bath, and in vacuum with cooling pipes.