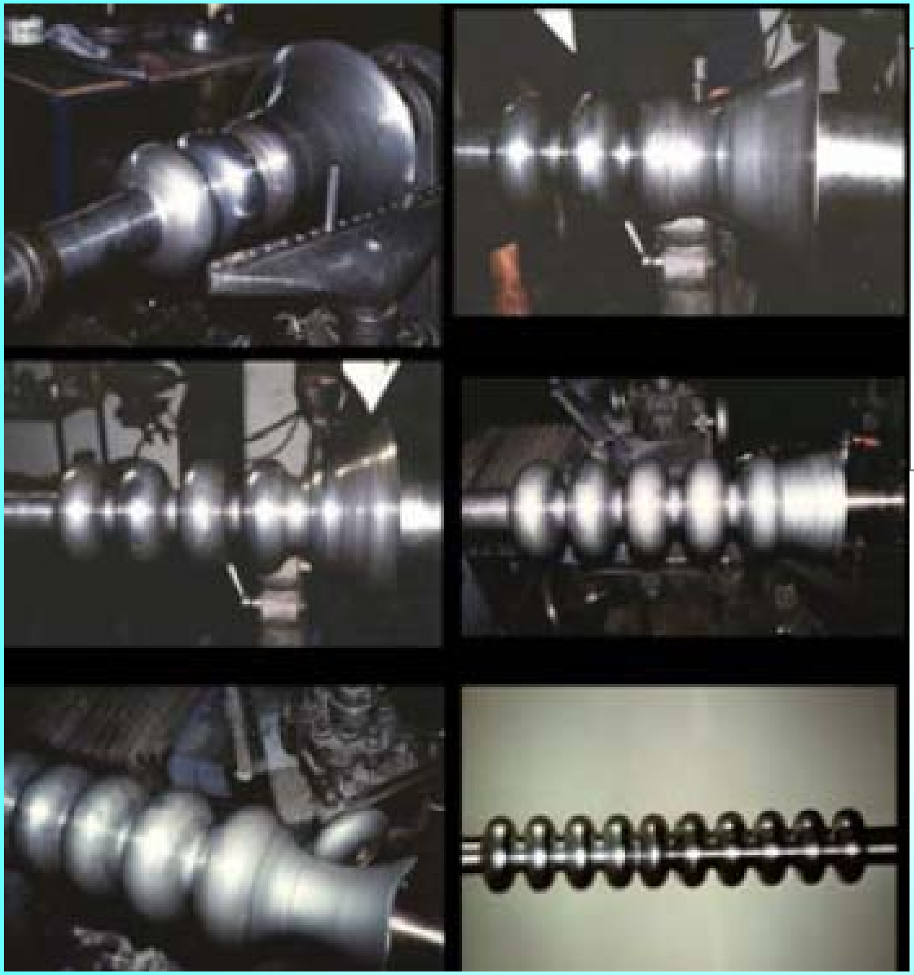
Seamless RF Cavities

Activities of DESY, KEK, INFN, JLab

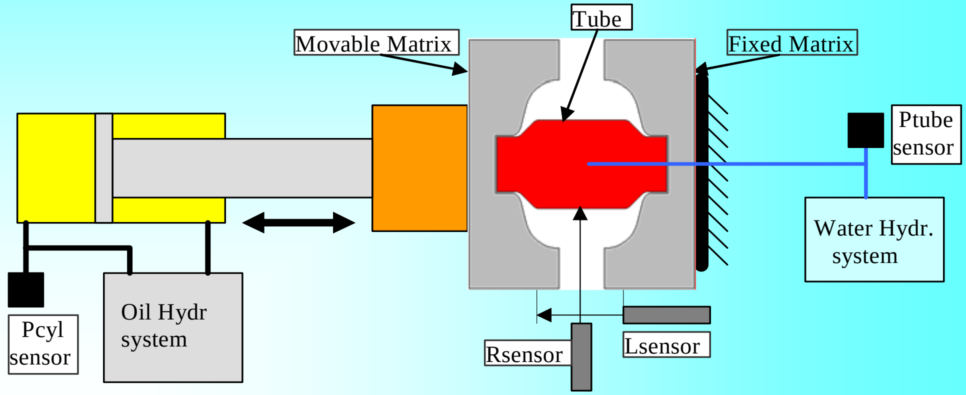
Presented by W. Singer

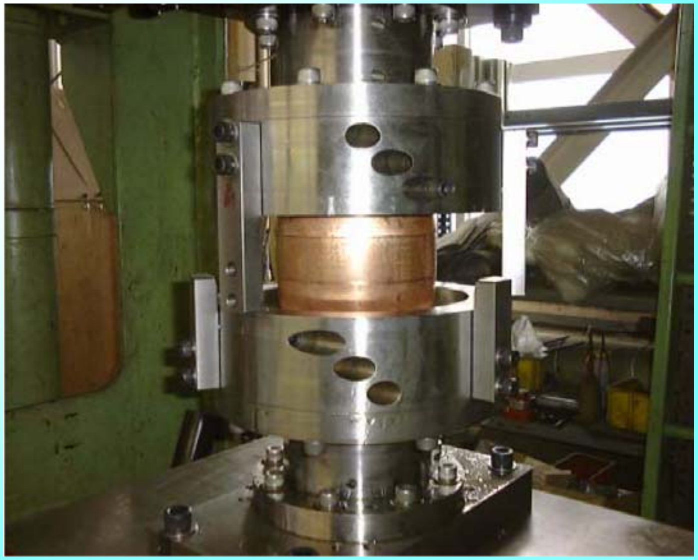
- Introduction
- Fabrication technique
- NbCu clad cavities
- Conclusion

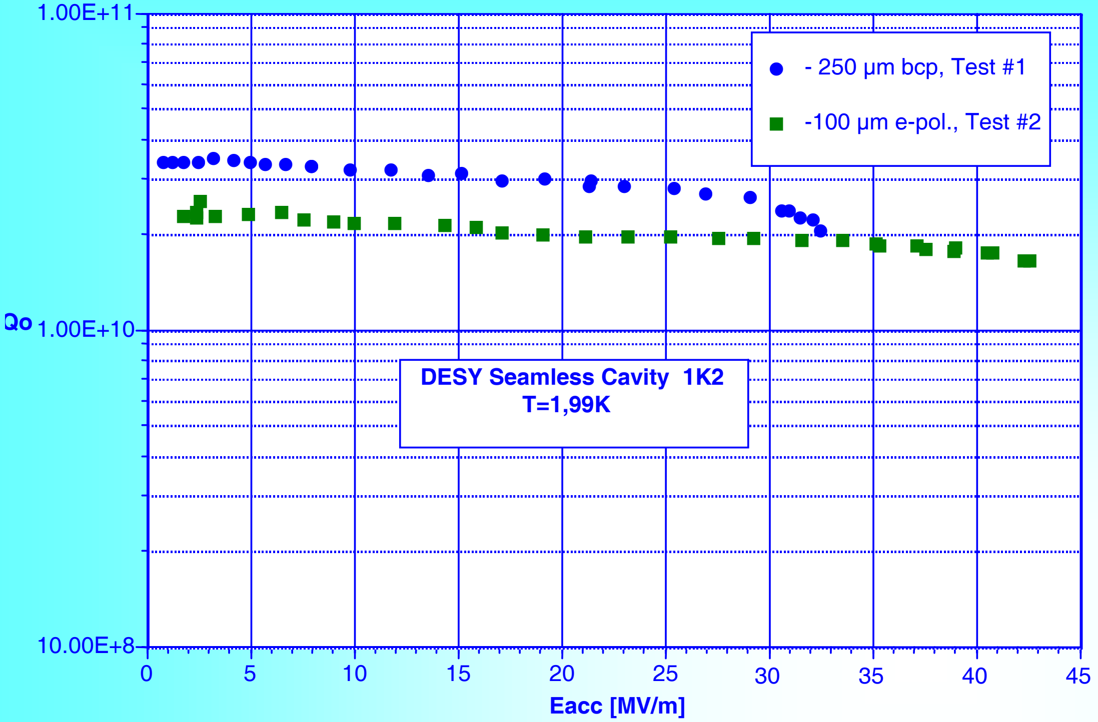
Spinning (V.Palmieri,INFN Legnaro)



Hydroforming, DESY, KEK

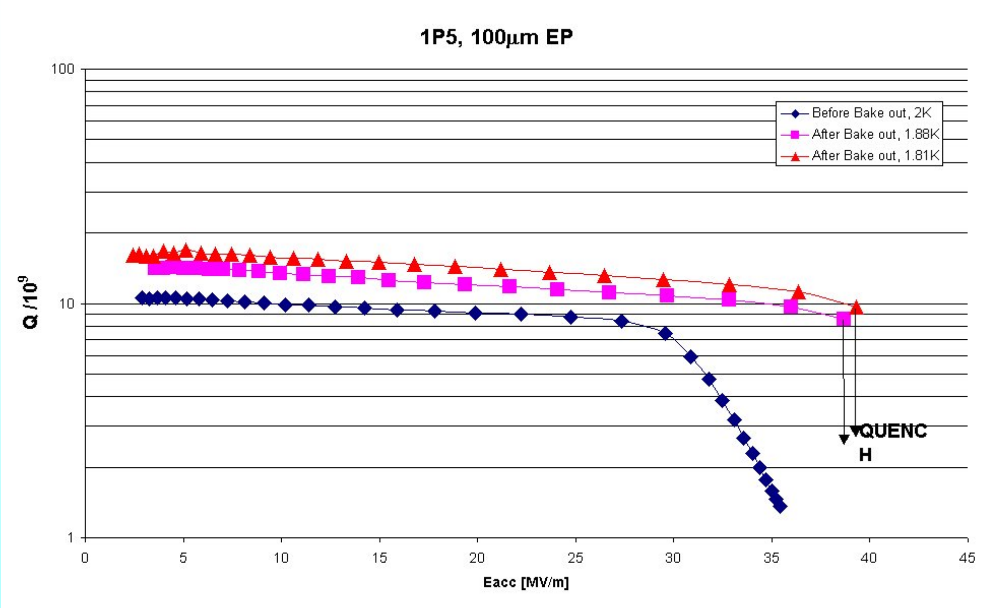






The best Q(Eacc) result of by hydroforming produced single cell cavity

The best Q(Eacc) result of by spinning produced single cell cavity



Fabrication technique

Significant progress was achieved in last years in development of seamless cavities.

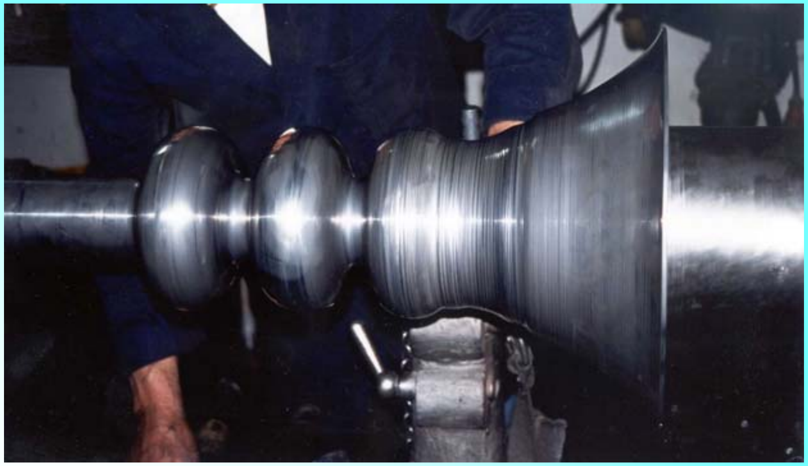
It was shown that the high accelerating gradient ca. 40 MV/m can be achieved in seamless cavities

The main technical problems of the fabrication of seamless single cell and multi cell (by spinning or hydroforming) are solved.

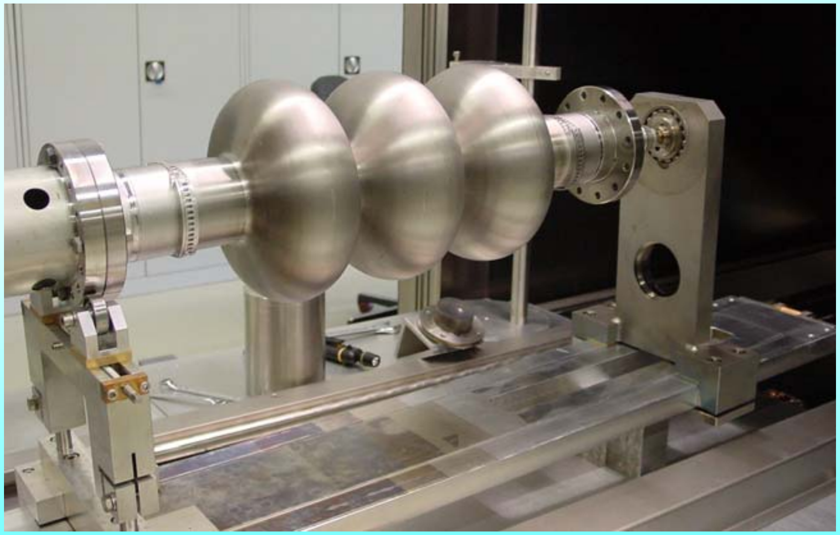
The main remaining task is improvement of the fabrication technique to the industrially applicable level.

Spinning (V. Palmieri, INFN)

Spinning from tube

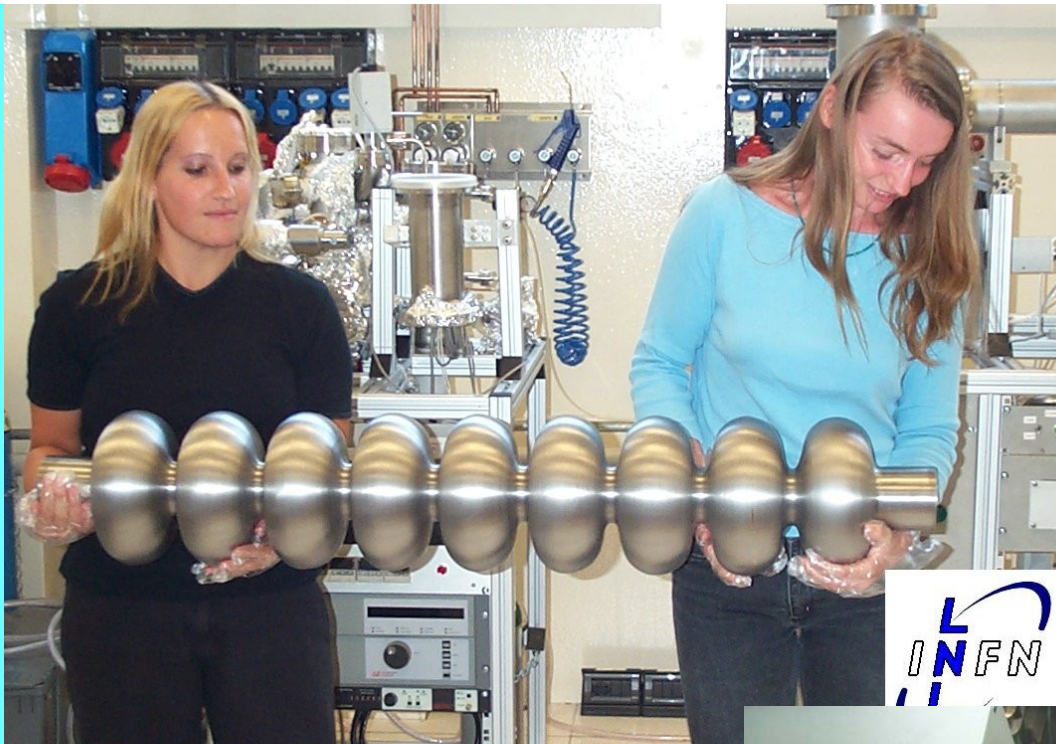


Spinning from disk



Spun 3-cell cavity

Spinning (V. Palmieri, INFN)



First spun 9-cell cavity

New spinning machine. The two spinning turrets (revolver heads) work one against each other. A 9-cell cavity can be spun in 4 hours.

Poster TuP68

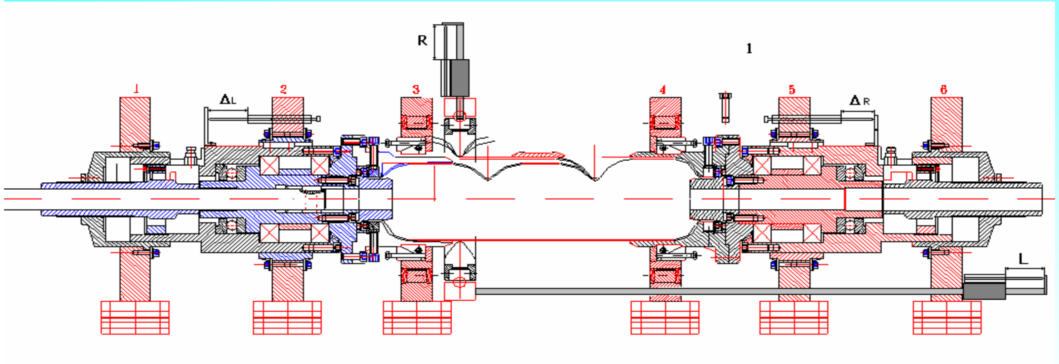
Two and three cell cavities hydroformed at DESY

Not uniform necking at the iris area done at company HTI (hole appeared during barrel polishing).

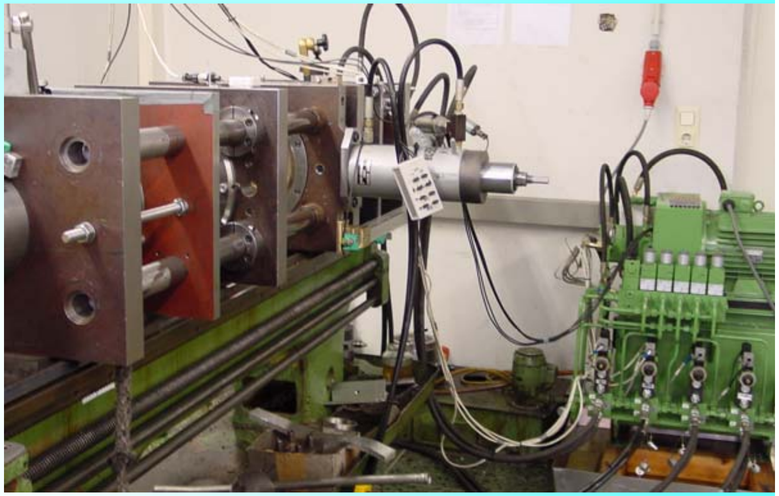
Improvement of the necking procedure was necessary

All steps of hydroforming optimized and checked on the Cu dummies

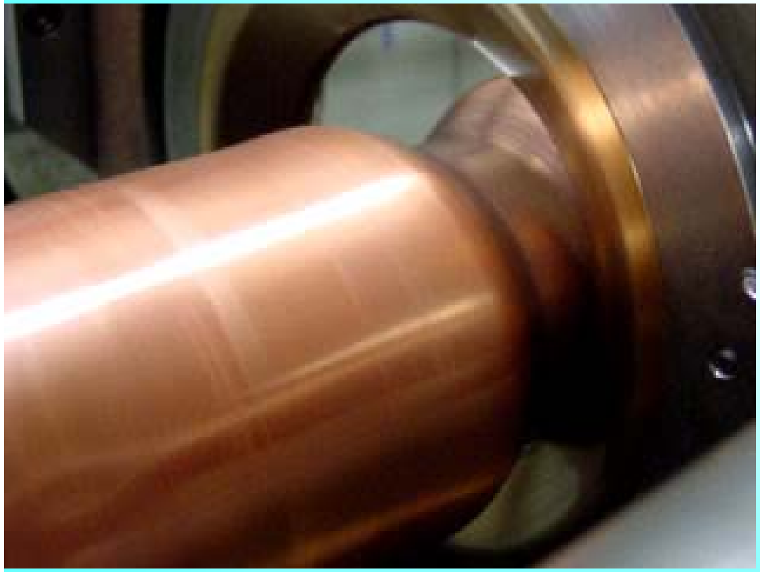
Seamless technique by hydroforming: step 1- necking



Principle of tube diameter reduction in the iris area



Reduction mechanism.

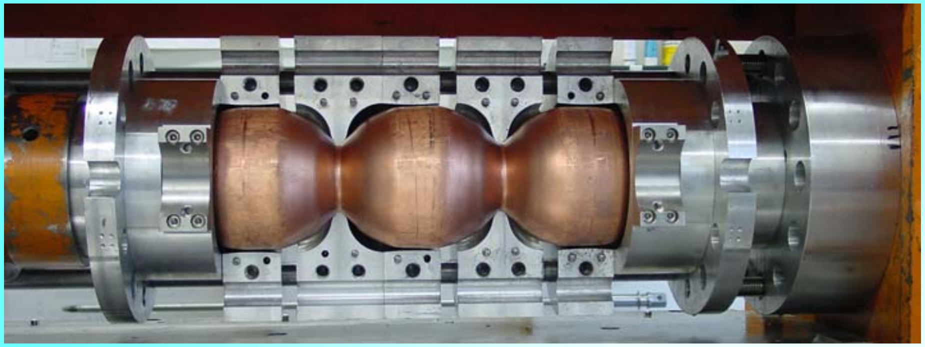


DESY Necking machine: new PC controlled necking procedure

Tubes after reduction in the iris areas

W. Singer SRF 2005

Seamless technique by hydroforming: step 2- expansion



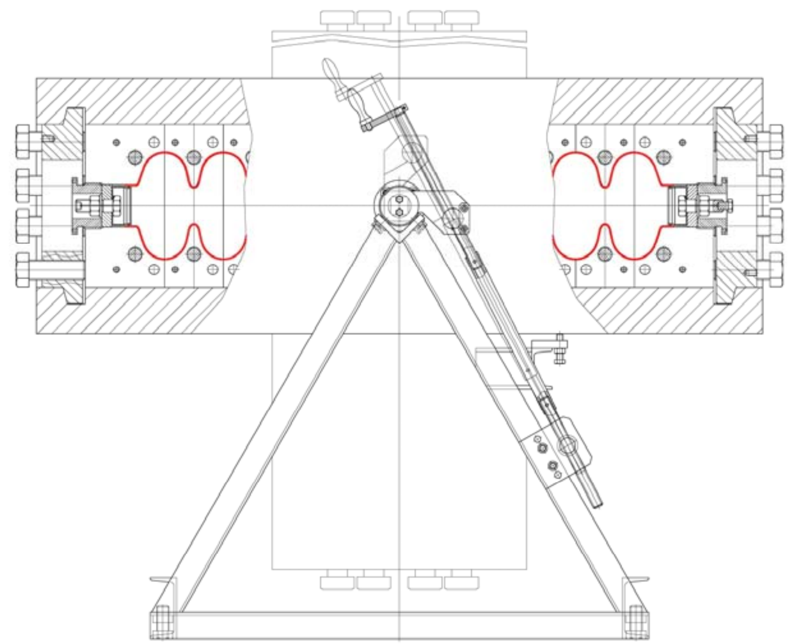
Principle of the tube expansion in the equator region

DESY hydroforming machine

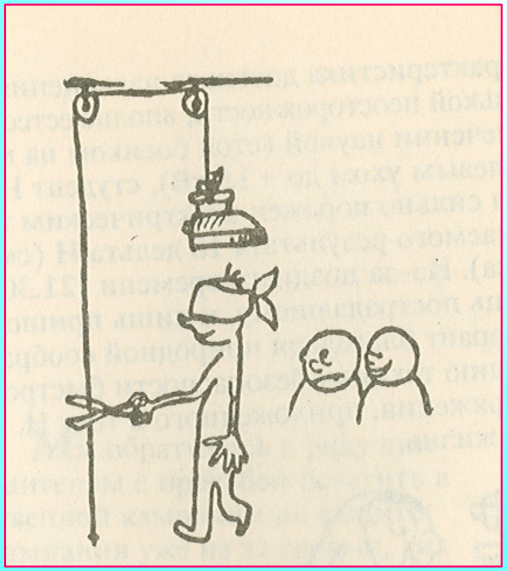
Example of hydroformed 3 cells

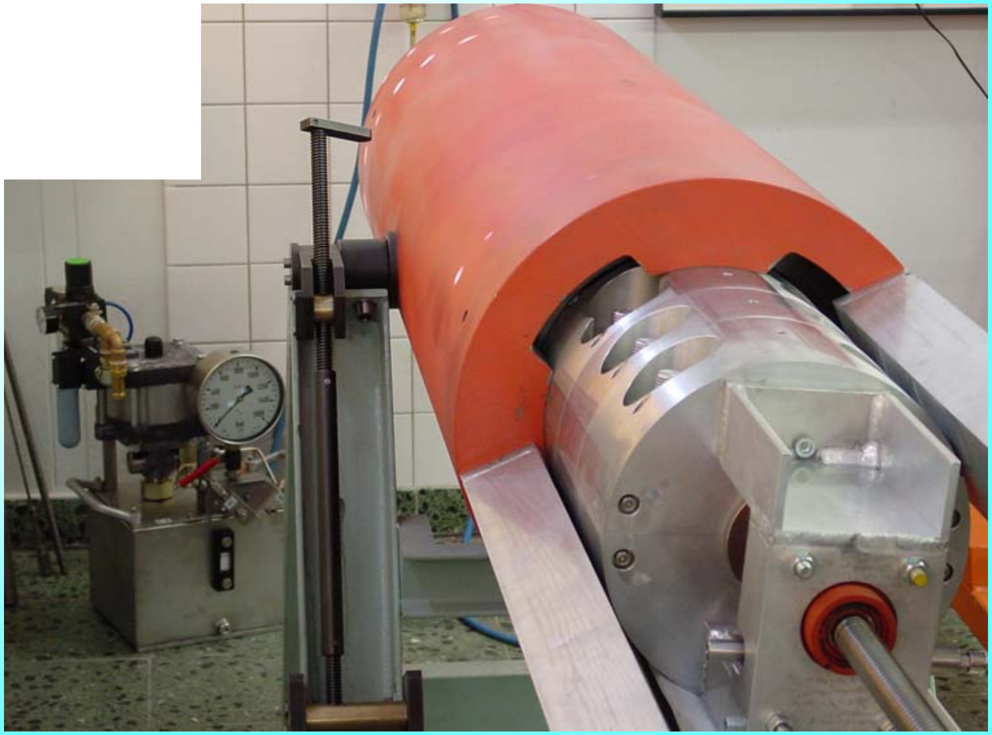
Rather uniform wall thickness distribution is achievable

Seamless technique by hydroforming: step 3- calibration

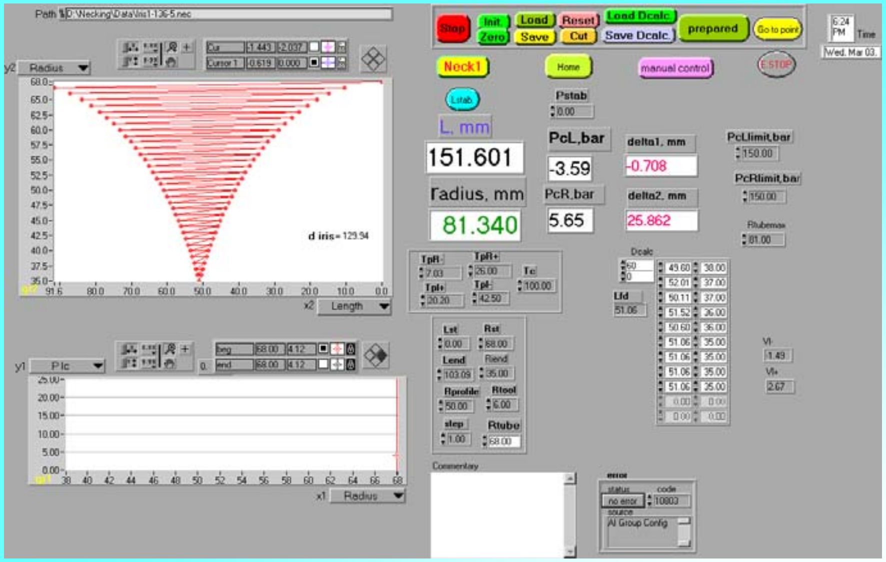


DESY high pressure device for cavity calibration. Pressure ca. 1 kbar

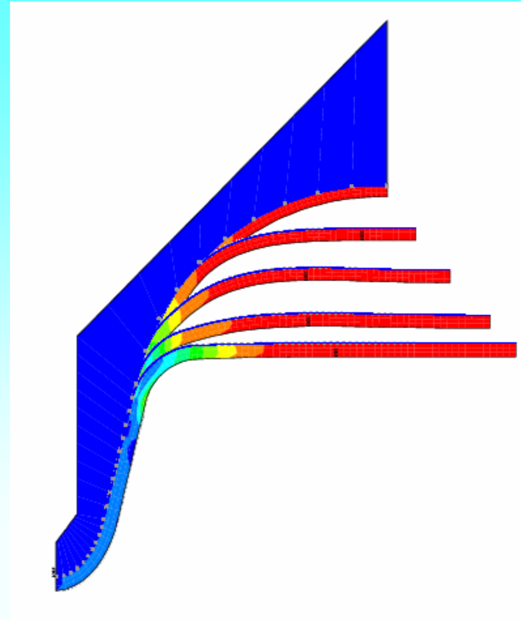




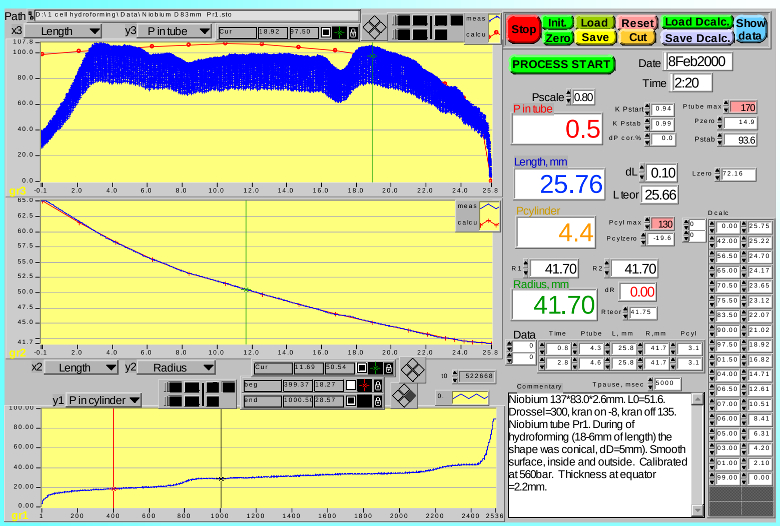
W. Singer SRF 2005



Front panel of the software for necking - machine



FEM simulations:
reasonable at the beginning

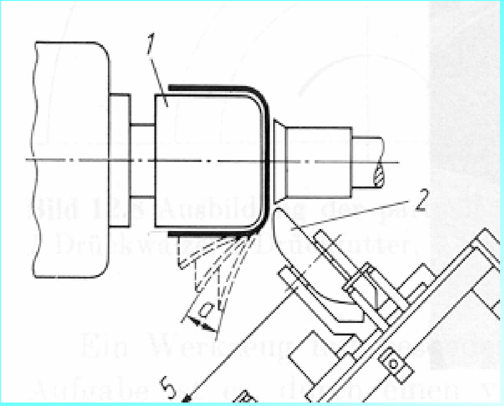


Front panel of the software for hydroforming - machine

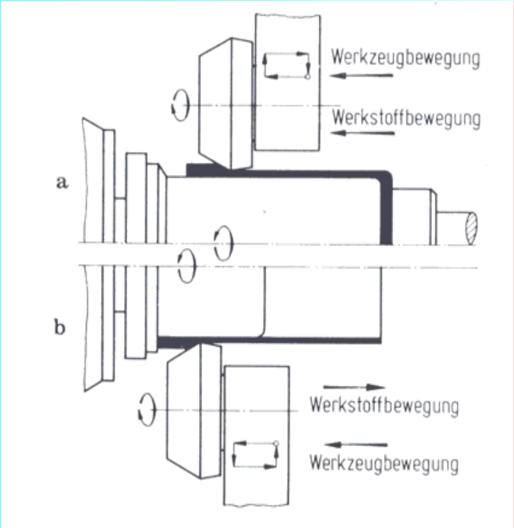
PC control allows reproducibly repeat the forming parameters

W. Singer SRF 2005

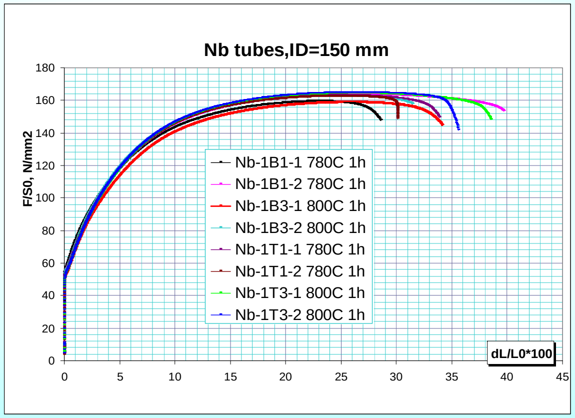
Fabrication technique: seamless Nb tubes

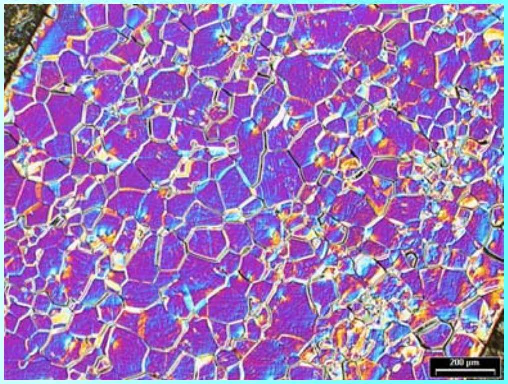


Pot with thick wall by spinning (or deep drawing)



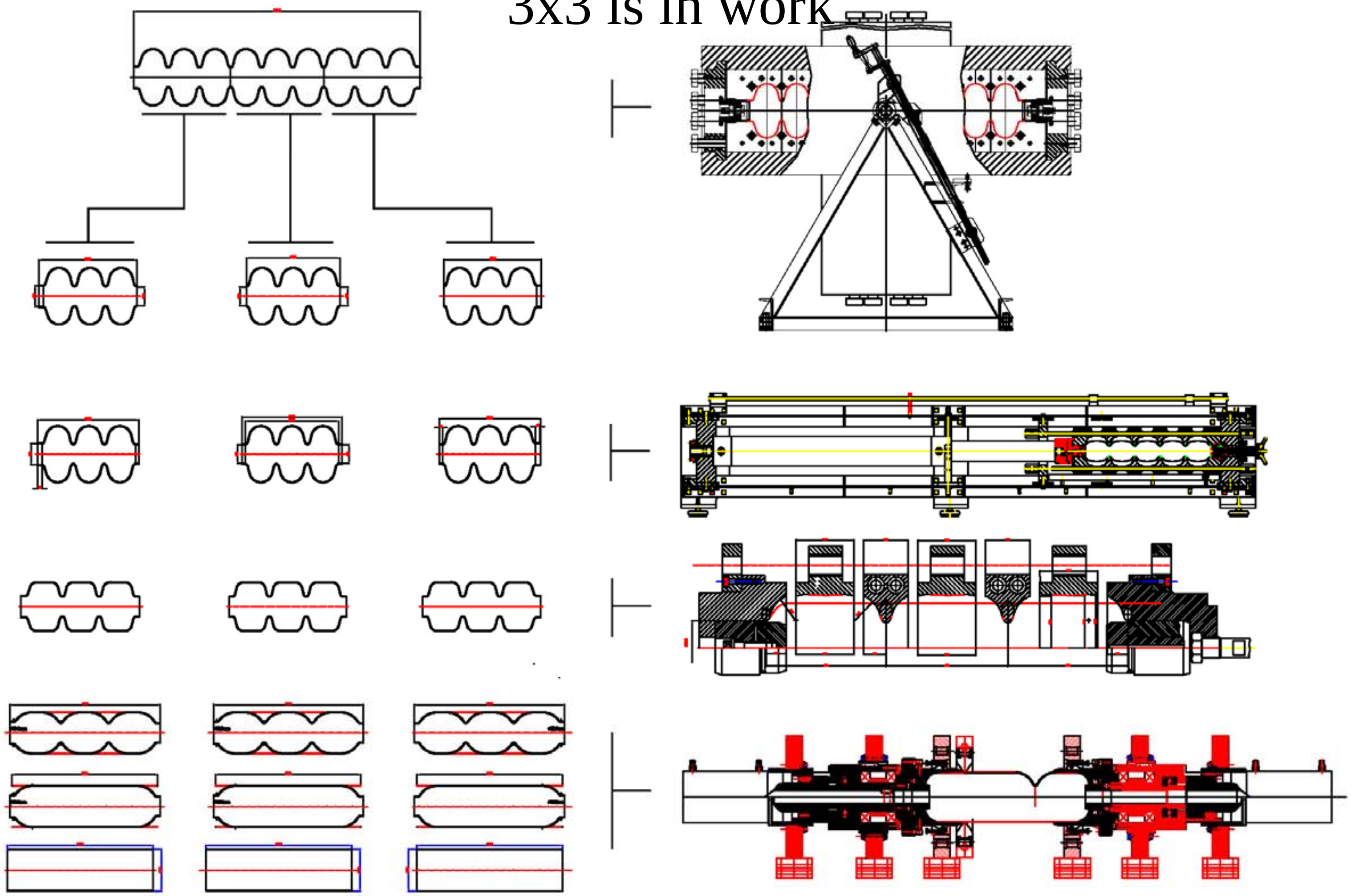
Flow forming





Appropriate microstructure and rather high strain before onset of necking. Tubes of 1,4 m long and ID ca. 200 mm for spinning have been build by V. Palmieri

Fabrication steps of 9 cell cavity by hydroforming as option 3x3 is in work



Barrel polishing, 800°C annealing, EP (KEK recipe) seams to be a most appropriate treatment for seamless cavities

Hydroforming of cells can be done or as three cells simultaneously or cell by cell

Hydroforming of 9 cell cavity from one piece tube can be done on the same way (three cells simultaneously in three steps)

NbCu clad cavities

Fabrication of cavity from bimetallic bonded NbCu tube by seamless technique (spinning or hydroforming).

Combination of the seamless technique with NbCu bonding gives to bimetallic option new opportunity.

Advantages

- cost effective: allows saving a lot of Nb (ca. 4 mm cavity wall has only ca. 1 mm of Nb and 3 mm Cu). Especially significant for large projects like ILC

- bulk Nb microstructure and properties (the competing sputtering technique does not have such advantages)

- the treatment of the bulk Nb BCP, EP, annealing at 800°C, bake out at 150°C, HPR, HPP can be applied (excluding only post purification at 1400°C).

- high thermal conductivity of Cu helps for thermal stabilization

- stiffening against Lorentz - force detuning and microphonics can be easily done by increasing of the thickness of Cu layer.

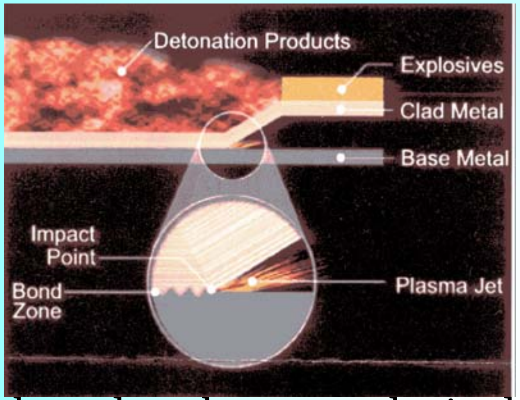
- fabrication by seamless technique allows elimination of the critical for the performance welds especially on equator

Fabrication of bimetallic NbCu tubes. Two options considered.

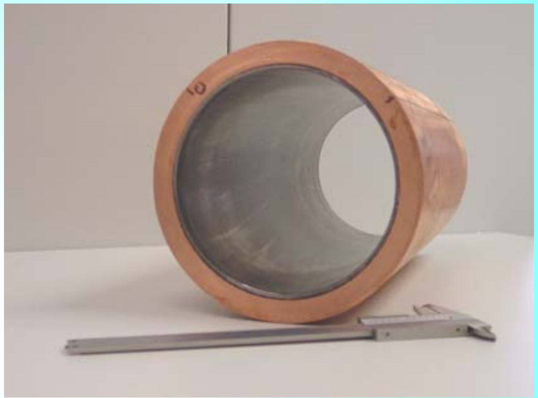
Explosively bonded NbCu tubes:

-Explosive bonding of seamless Nb tube ca. 4 mm wall thickness (RRR=250) with Cu tube of wall thickness 12 mm

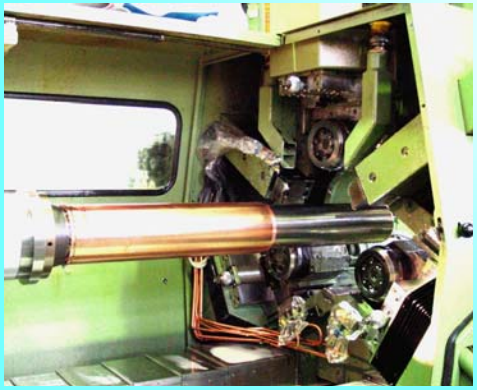
- Flow forming into NbCu tube, wall thickness ca. 1mm Nb, 3 mm Cu



The bonding takes place by an explosively driven, high-velocity angular impact of two metal surfaces.

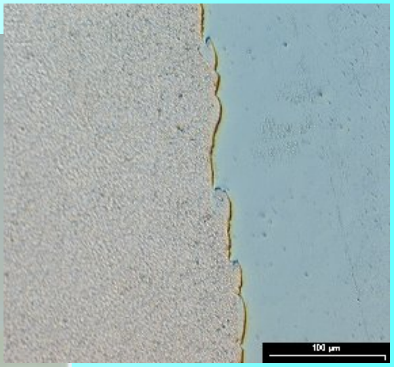


Explosively bonded NbCu tube

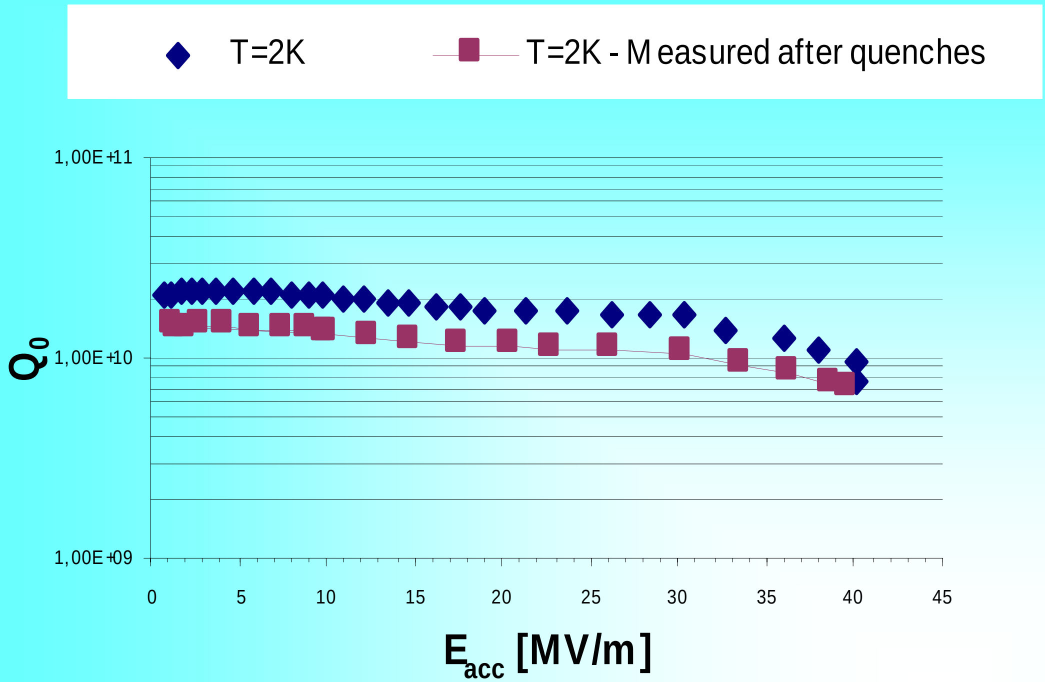


Flow forming of NbCu tube

After flow forming



Structure of Nb/Cu interface



NbCu cavities hydroformed from explosively bonded tubes at DESY.

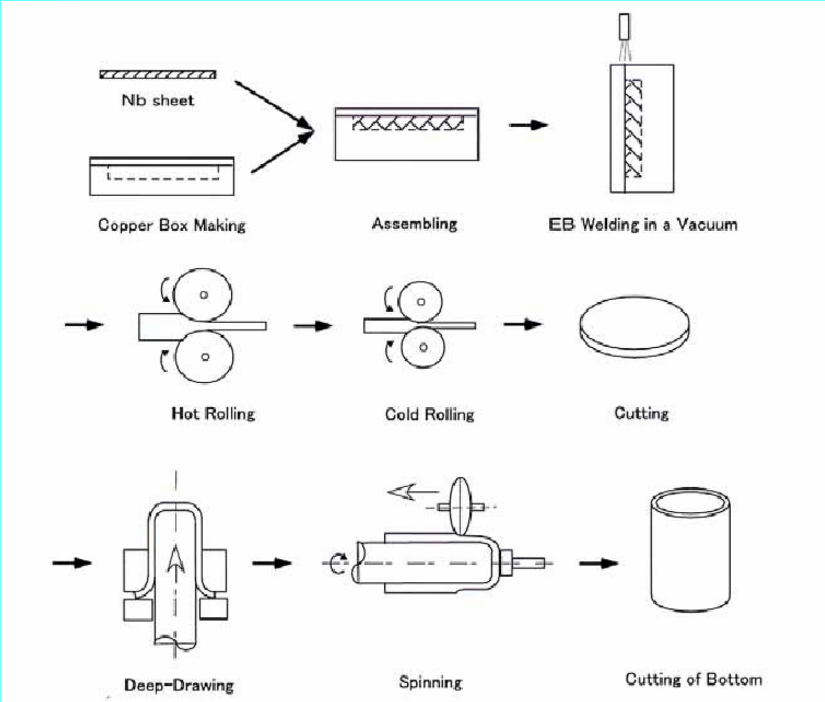
NbCu single cell cavity 1NC2 produced at DESY by hydroforming from explosively bonded tube. Preparation and HF tests at Jeff. Lab: 180 µm BCP, annealing at 800°C, baking at 140°C for 30 hours, HPR (P. Kneisel).

Difficult to get reproducibly high bonding quality. Hot bonding fabrication procedure of NbCu tubes seems to be more promising

40 MV/m without EP

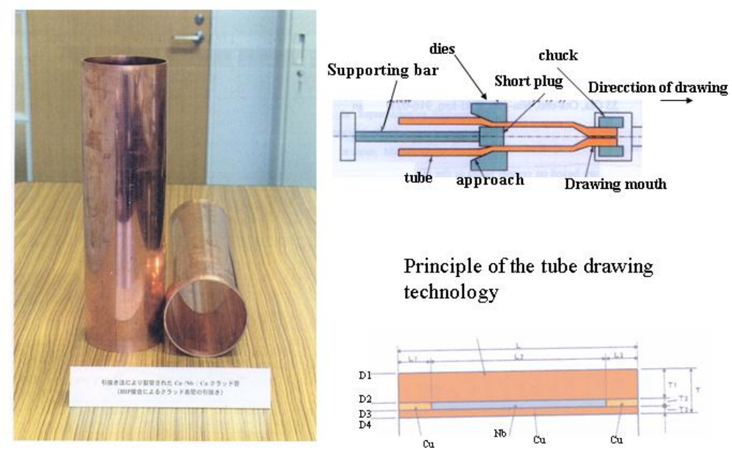
W. Singer SRF 2005

- Hot bonded NbCu tubes



Fabrication principle of sandwiched hot rolled Cu-Nb-Cu tube (KEK and Nippon Steel Co.)

Hot roll bonded Cu-Nb-Cu tube produced at Nippon Steel Co.



Cu-Nb-Cu Sandwiched Tubes (KEK)

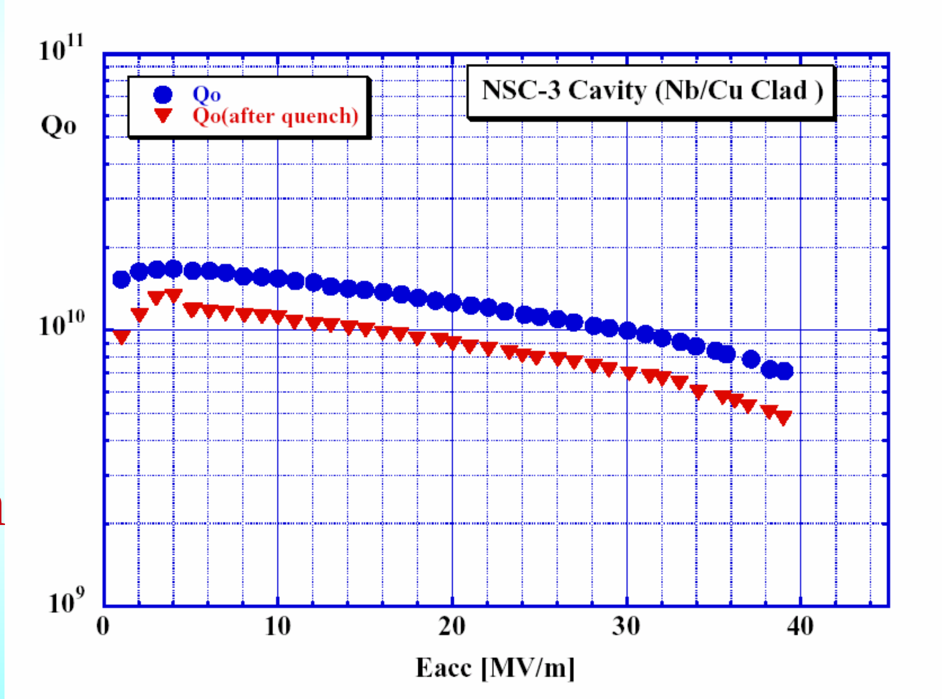
Fabrication principle of sandwiched coextruded Cu-Nb-Cu tube (KEK)

Single cell NbCu cavities produced at DESY by hydroforming from KEK sandwiched tube.

Not enough statistic for comparison of explosive bonding and hot bonding. Quality of hot bonding is more reliable; better statistic is to expect

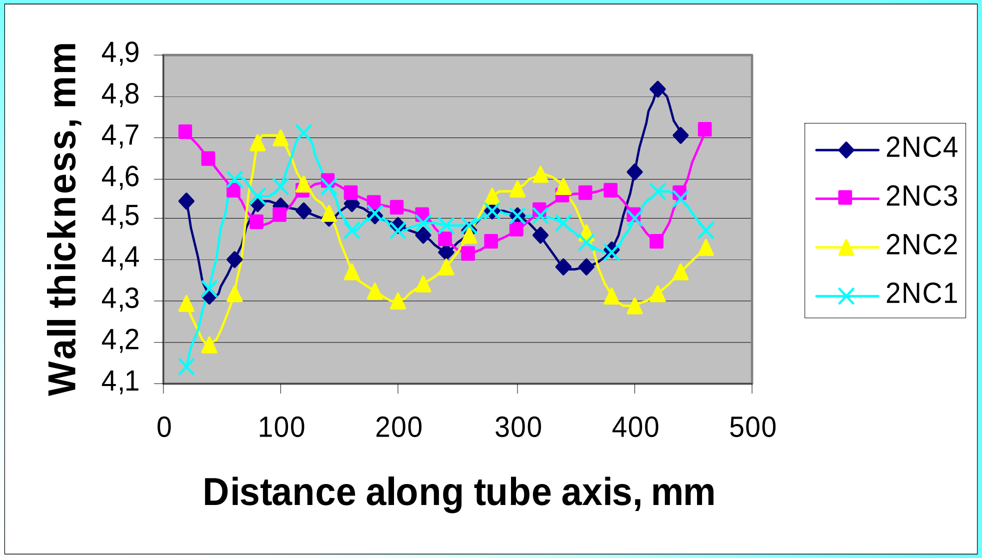
One NbCu sandwiched cavity was tested NSC-3.

Hot roll bonded tube fabrication at Nippon Steel Co., hydroforming at DESY, Preparation and RF tests at KEK



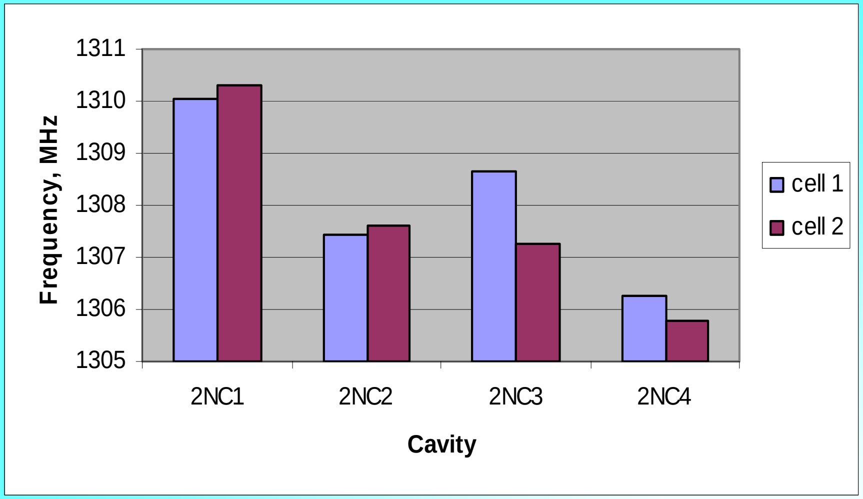
NSC-3: Barrel polishing, CP(10 mμ), Annealing 750°C x 3h, EP(70 μm)
K.Saito

Multicell NbCu clad cavities (Poster TuP59)

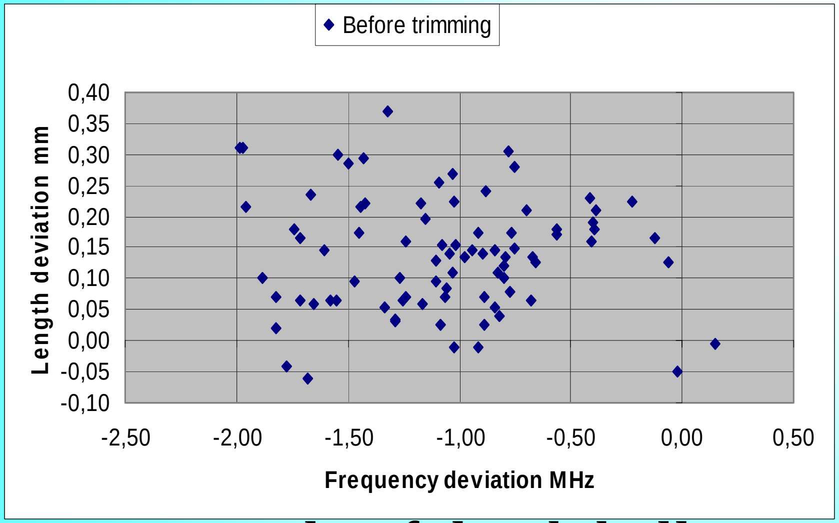


Wall thickness distribution

Four 2 cell NbCu clad cavities recently produced at DESY from KEK tubes (no cracks on the inside surface)



Frequency distribution in cells



Example of dumb bells frequency for standard cavity fabrication

Frequency measurement (G. Kreps)

Small frequency deviation between the cells can be achieved. Warm tuning seems to be unavoidable

Cost comparison of Nb and NbCu clad cavity of TESLA shape (pessimistic estimation)

9 cell Nb cavity cost = (disc weight • Nb disc cost per kg • 18) + (costs of not cell parts like flanges, end tubes etc.)+ (standard cavity fabrication costs)

9 cell NbCu clad cavity cost = (tube weight for 9 cells • 0.25•8.4/8.96• Nb cost in tube per kg) + (tube weight for 9 cells • 0.75•8.96/8.4• Cu cost in tube per kg) + (costs of not cell parts like flanges, end tubes etc.)+ (cavity fabrication costs by hydroforming)

Assumed:

• Cavity fabrication costs by hydroforming and standard fabrication roughly the same (industrial studies)

• Fabrication costs for bimetallic NbCu clad tubes are by factor of two higher as for Nb discs.

• Costs of not cell parts like flanges, end tubes etc. the same for Nb and NbCu clad cavities (prices based on TTF experiences)

• Contribution for Nb disc fabrication is 20 % of total Nb cost

NbCu clad cavity cost /Nb cavity cost = 70.5 %

Difficulties in NbCu technology

1. Dangerous of cracks appearance in iris area during fabrication (because of big difference in recrystallization temperature of Nb and Cu)

Microstructure of Cu and Nb after annealing at 560°C for 2 hours. Nb is not recrystallysed (hard).

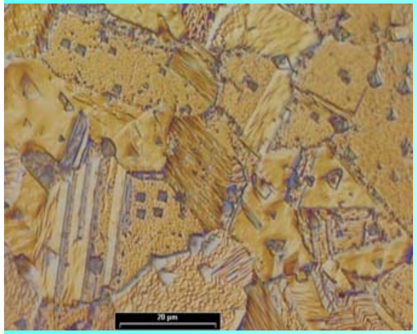
Two ways to defeat the cracks*

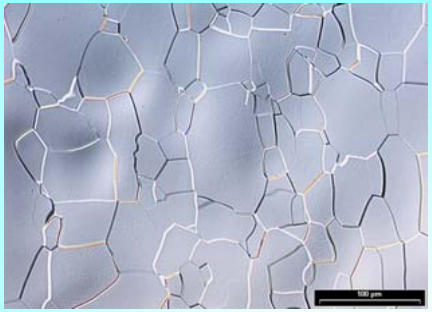
a) Sandwiched tube (Nb is between two Cu layers. Cu layer on both sides prevent creating of cracks in Nb); removing of inside Cu layer on the cavity after forming (K.Saito). The option was checked, it works

* Improvement of the necking technique allows reducing the cracks dange

Possible solutions

b) Cu only outside: Cu0.15%Zr special Cu with high recrystallization temperature

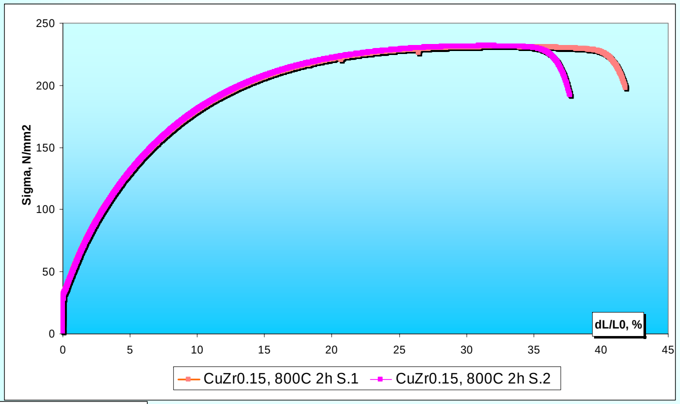


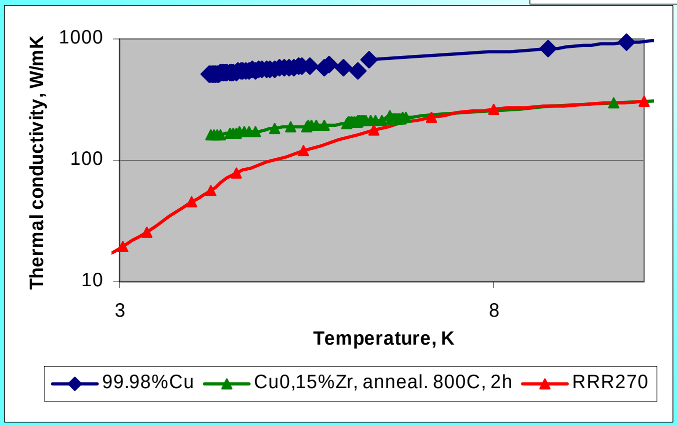


Microstructure of Cu0.15%Zr and Nb after annealing at 800°C for 2 hours.

The Cu0.15%Zr shows a high elongation after annealing at 800°C, small and rather uniform grain and can be a good candidate for replacing of pure Cu in NbCu clad tubes

Stress –strain behavior and thermal conductivity of Cu0,15%Zr after annealing at 800°C for 2 hours compared with Cu and Nb.





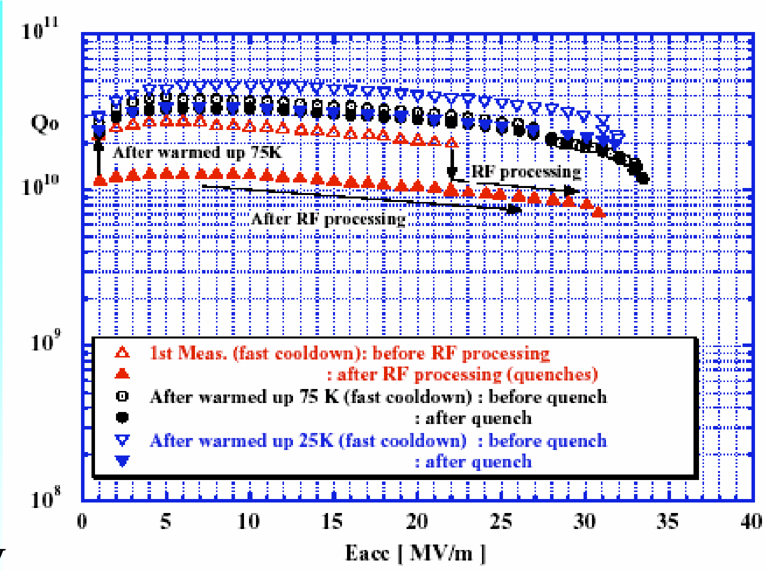
W. Singer SRF 2005

Thermal conductivity can be recovered by aging at ca. 400°C/one hour. Zr leaved the solid solution and creates precipitates Cu_5Zr finely distributed in Cu matrix

NbCu0.15%Zr tube

2. Q degradation during fast cool down, RF processing or quench (trapping of magnetic flax caused by thermo - coupling effect).

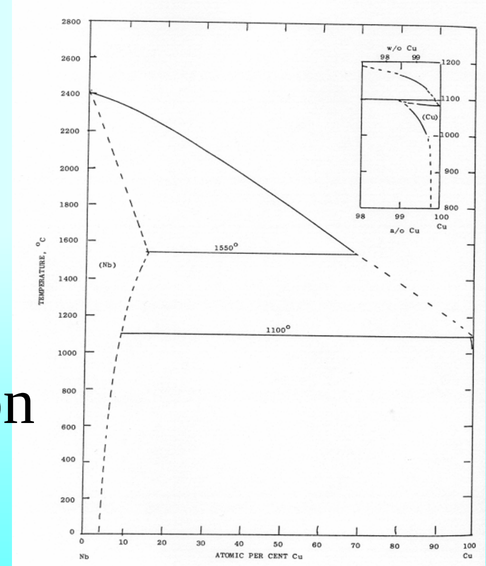
• Is not completely understood, more work is necessary. Similar effect was observed on Nb_3Sn cavities (M.Peiniger). Similar effect is to expect in sputtered NbCu cavities.



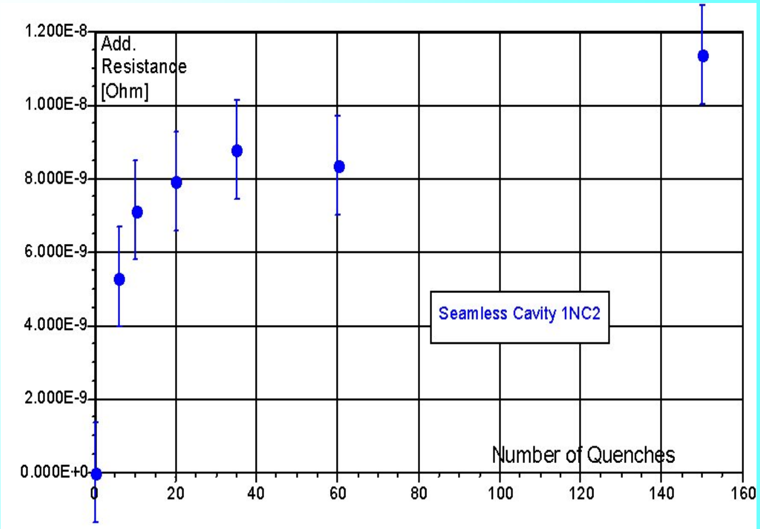
Q degradation in a seam less single cell cavity from NbCu explosively bonded tube (K.Saito)

• The Q degradation is relatively moderate especially for rather thick Nb layers of ca. 1 mm thickness (less than one order of magnitude). Can be cured by warm up over Tc and slow cool down.

• It seems that annealing and hot bonding (due to diffusion) should contribute to reduction of the thermal coupling effect



NbCu phase diagram



Additional surface resistance after quenches at ca 40 MV/m (P.Kneisel)

Conclusion

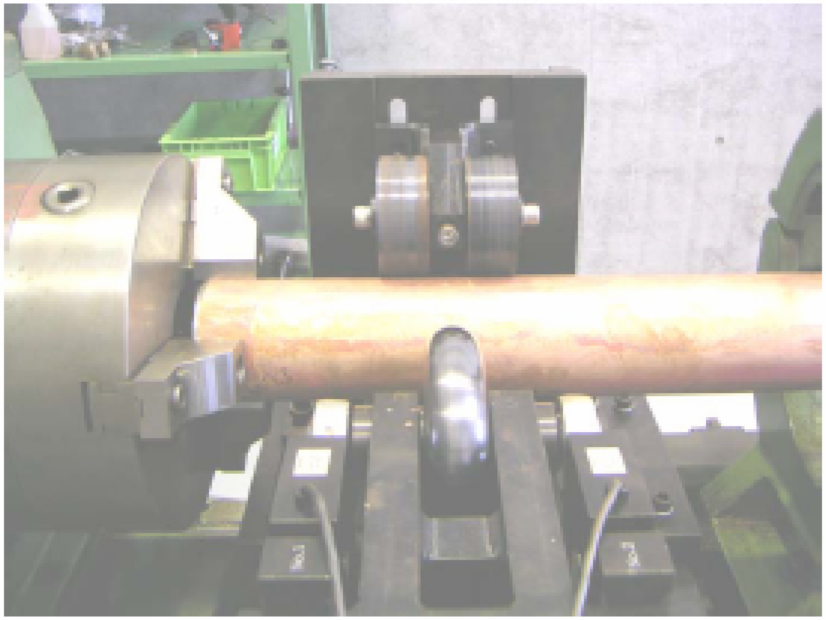
On laboratory level the most work is done.

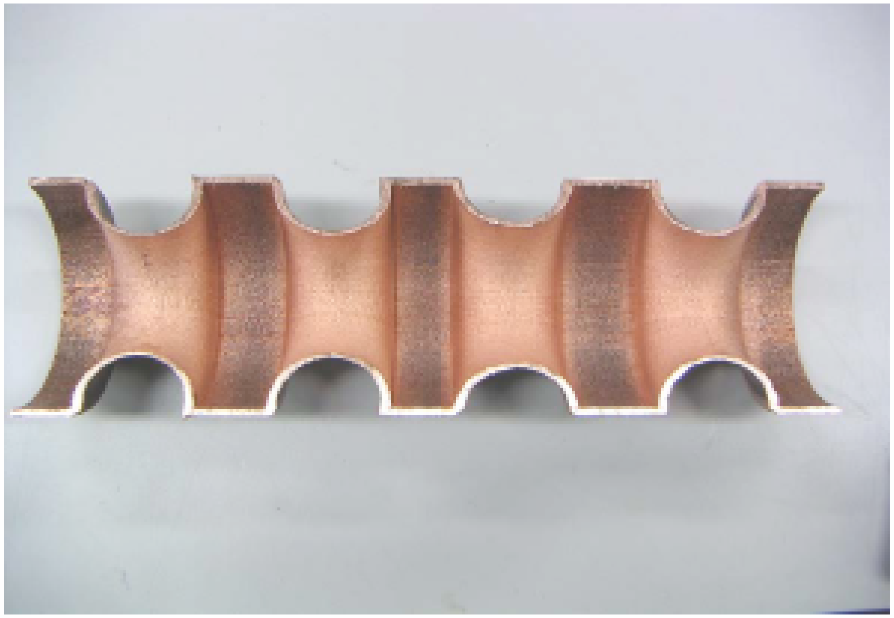
Industrialization of seamless technique is the main remaining task

KEK present activity towards the industrialization is very worthwhile

Successful necking test on June 20-24th in Shimizu Co.

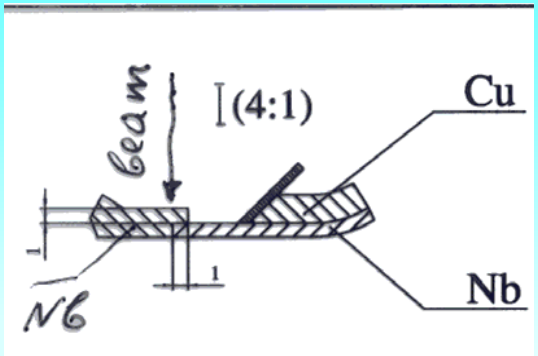
Poster TuP59





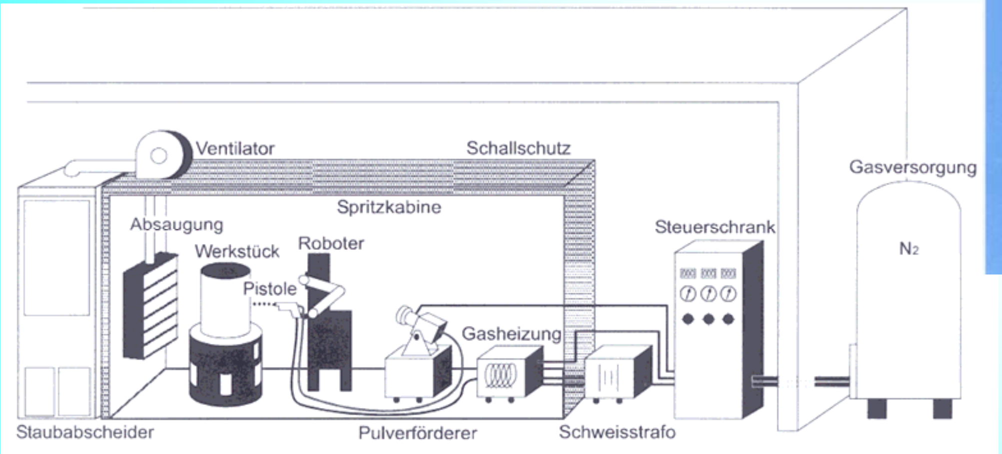
Necking 100phai, 3mm thick copper tube to 50phai

Connection of end tubes to NbCu cells

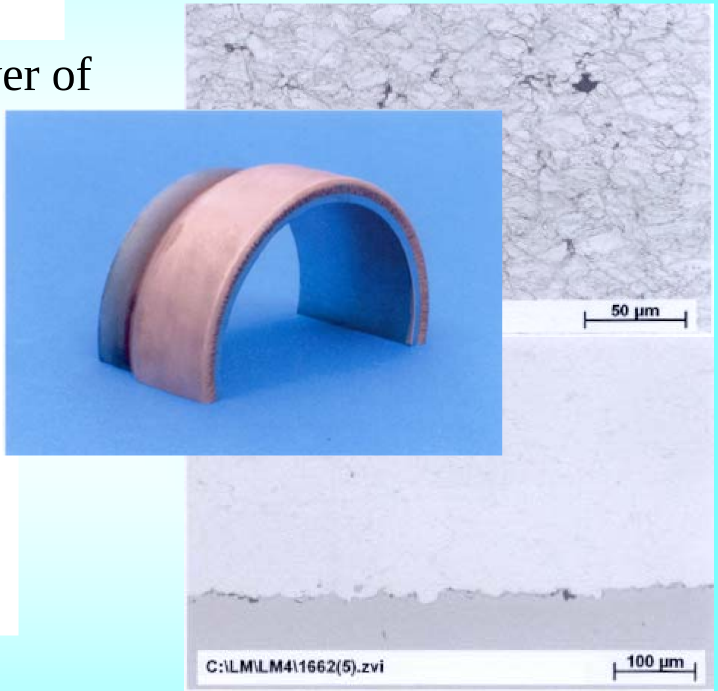


Cu layer on Nb tube. Small purity degradation of Nb during spraying: from RRR=300 to RRR=250

Principle of the welding of 0,7-1 mm thick Nb layer of the cavity with 2 mm thick wall of Nb end tube.



New Cold Gas Dynamic Spray System. Warms up the particles by only ca. 300°C and accelerate to velocities of 600-1500m/s (H.Kreye, University of the Federal Armed Forces in Hamburg)



Microstructure of CGDS Cu coating on Nb, small porosity ca. 1%, small oxidation. electr. conduct. ca.80% of bulk Cu (top: spraying by Nitrogen, bottom- by Helium)

W. Singer SRF 2005