DESY Experiences in Hydroforming of RF Cavities

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DESY

- Introduction
- Hydroforming technique (necking, expansion)
- Nb tubes for hydroforming
- Examples of RF performance
- Cost issue

Introduction

Advantages of seamless cavity fabrication

• no RRR degradation in the welding seam, in the heat affected zone HAZ and in the weld overlapping

• no risk of equator weld contamination due to not sufficiently clean preparation for critical welding

• no problem with pits in the HAZ, that are intensively in discussion last time

• lower cost of fabrication can be expected, especially for large series.

• less scattering in performance statistic of seamless cavity compare to welded cavities is to expect .

Hydroforming technique

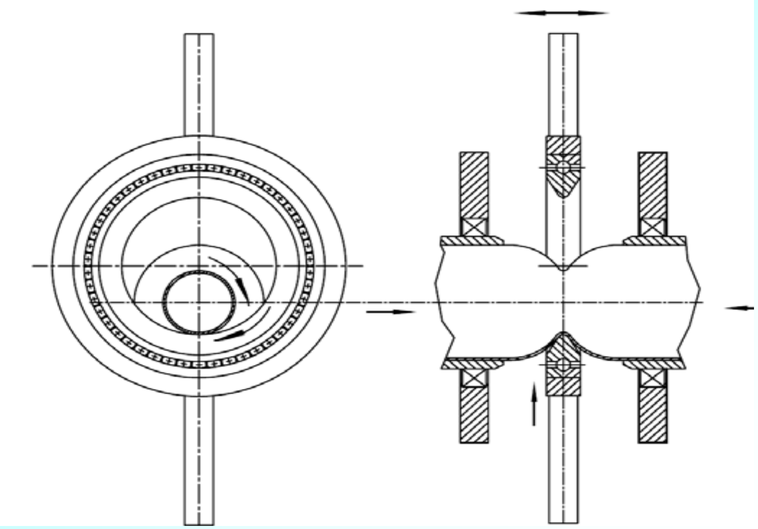
Hydroforming consists of two steps:

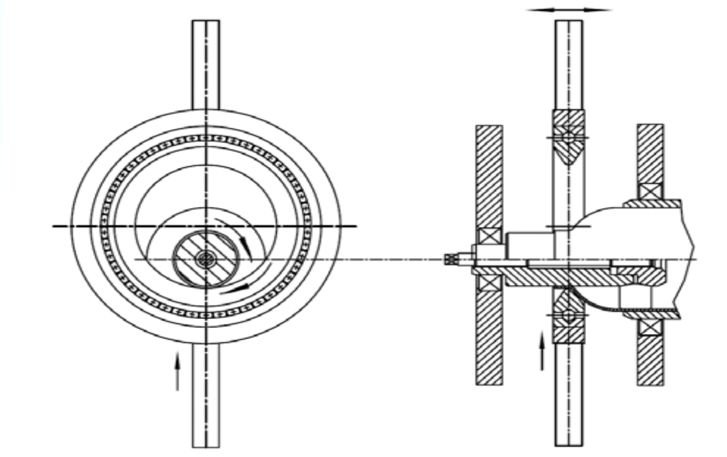
a) reduction of diameters at ends of tubes and iris areas (necking)

b) tube expansion at the equator

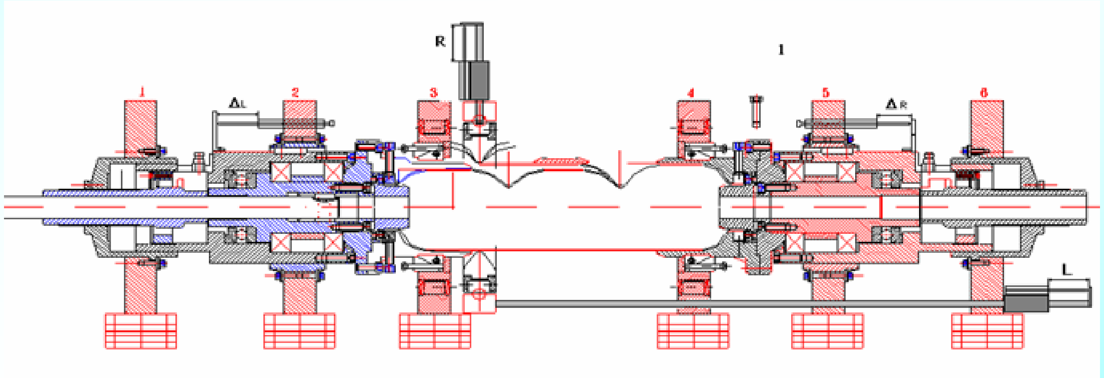
Step 1: Necking (by profile ring)

Development of DESY necking equipment and necking procedure provided the success (combination of radial and axial movement)

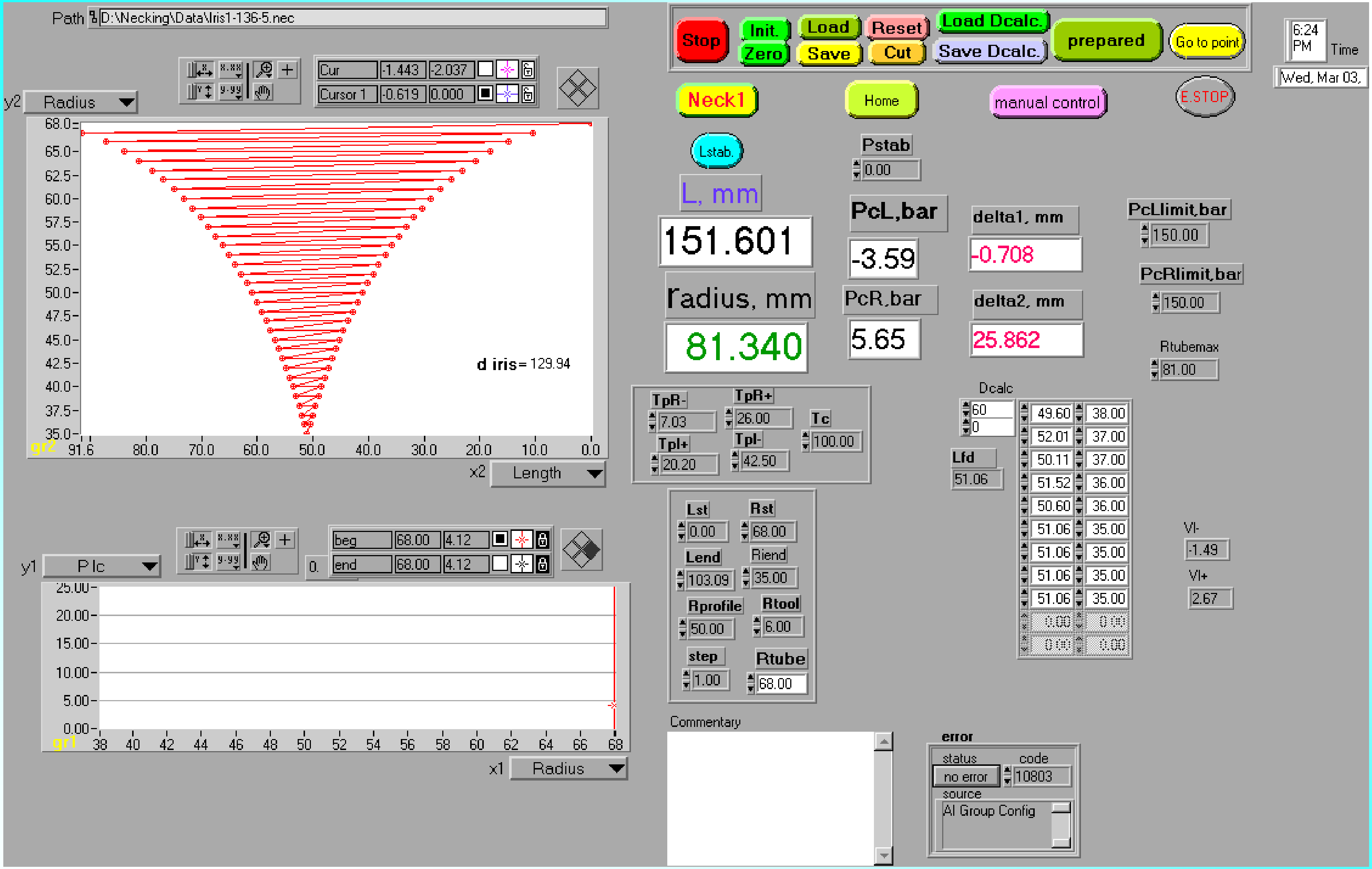




Principle of diameter reduction in the tube end and iris area



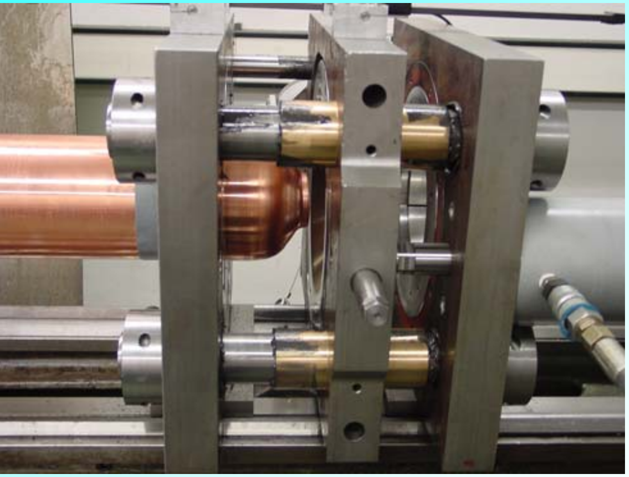
Principle of DESY necking equipment



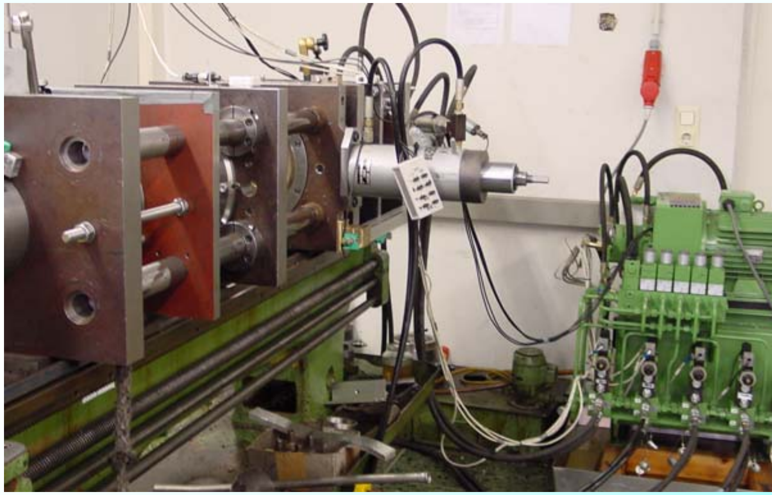
Front panel of the software for necking - machine

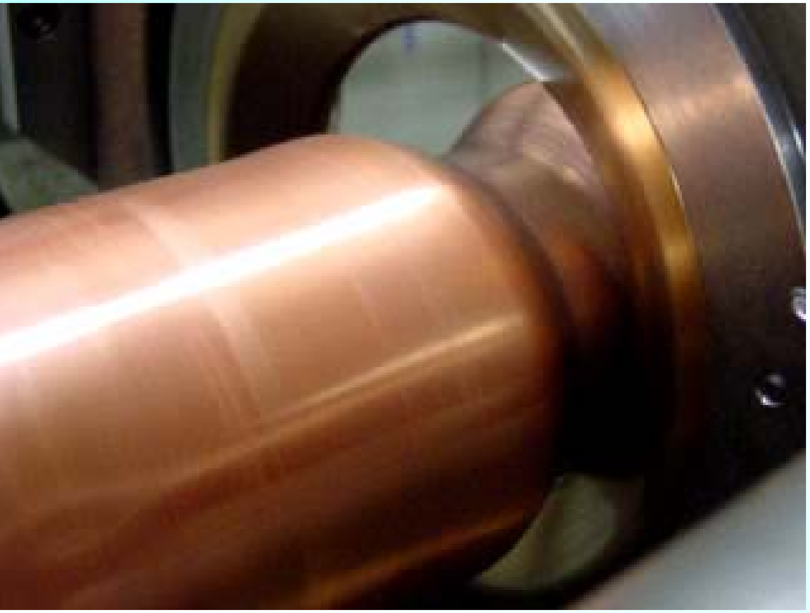
All steps of hydroforming optimized and checked on the Cu dummies

Seamless technique by hydroforming: step 1- necking



DESY necking equipment : PC controlled necking procedure



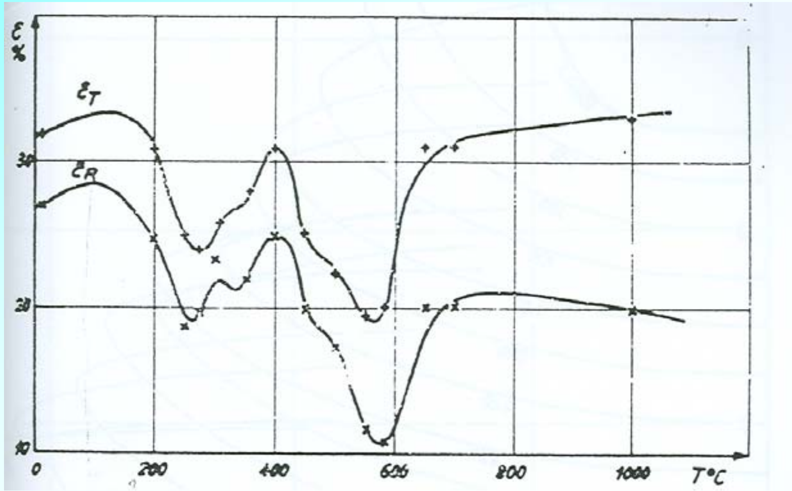


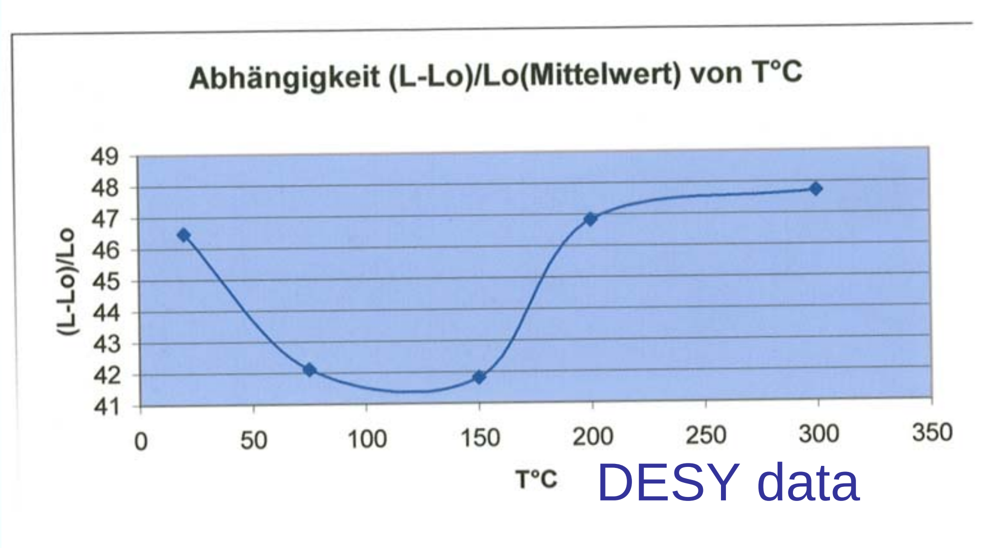
Tubes after reduction in the iris areas

Step 2: Expansion (Hydroforming)

First question. Hydroforming conditions, parameters?

Is the room temperature appropriate for hydroforming? Yes



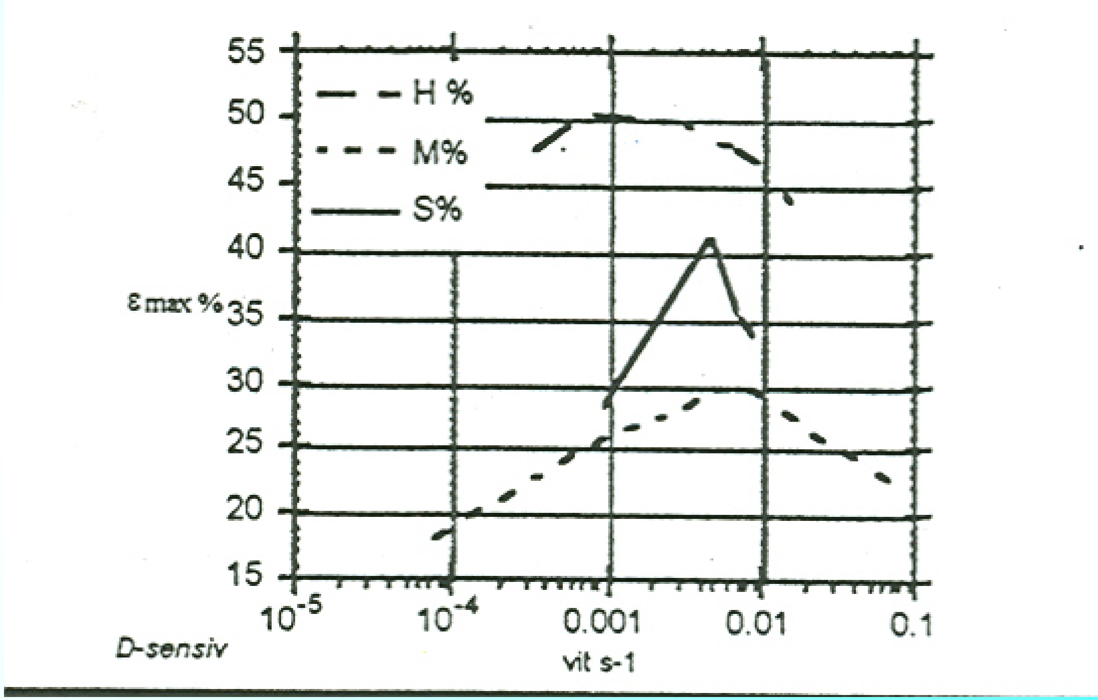


Dependence of the elongation on temperature. It makes sense to perform hydroforming of niobium at room temperatures

How fast to perform the deformation (hydroforming)?

Strain rate $\dot{\varepsilon} = \frac{\partial \varepsilon}{\partial t}, \sec^{-1}$

Dependence of maximum elongation of niobium versus strain rate (H, M, S different literature data).

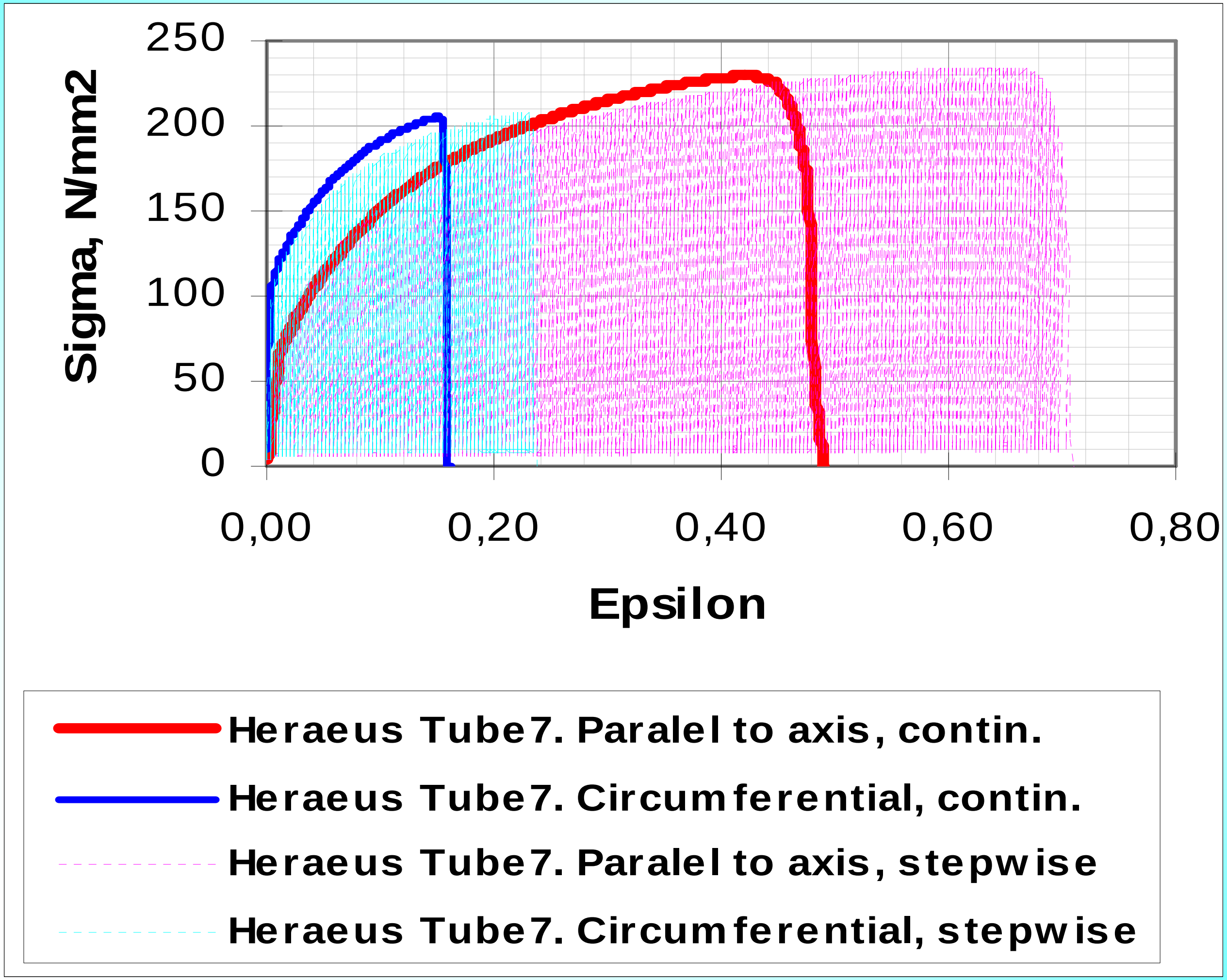


Correct strain rate should be chosen for hydroforming

Chosen strain rate is between 0.01 sec-1 and 0.001 sec-1

Compilations of C. Antoine

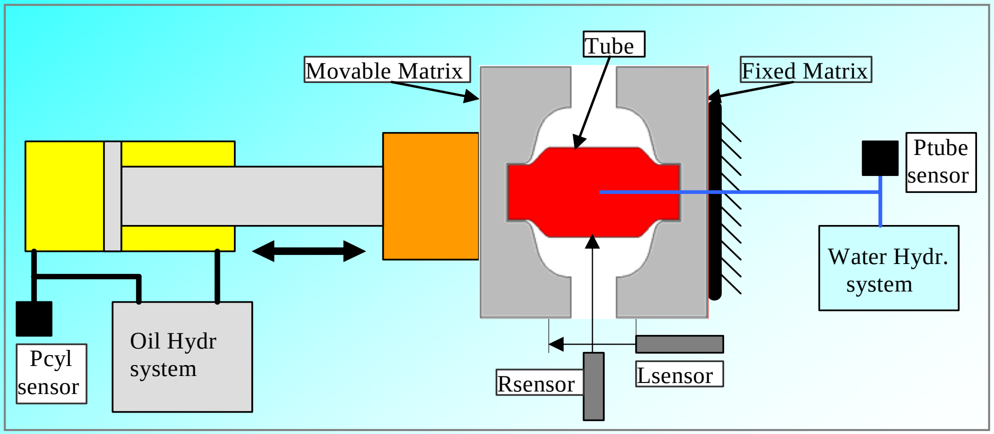
Pulsing of the pressure during hydroforming helps



Comparison of the tensile test in continues and pulse regime

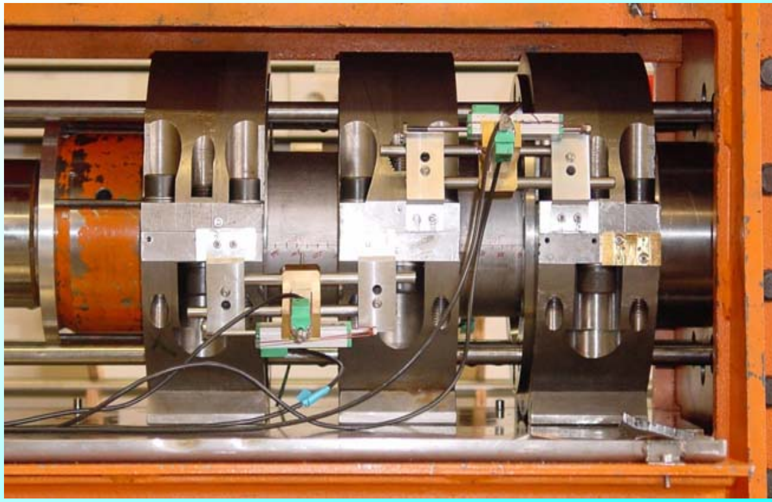
The strain before necking can be increased by using a periodic stress fluctuation (pulse regime). Probably the pull-release regime of the deformation artificially increases the work-hardening of Nb in low-yield strength regions and therefore shift the break to higher elongations.

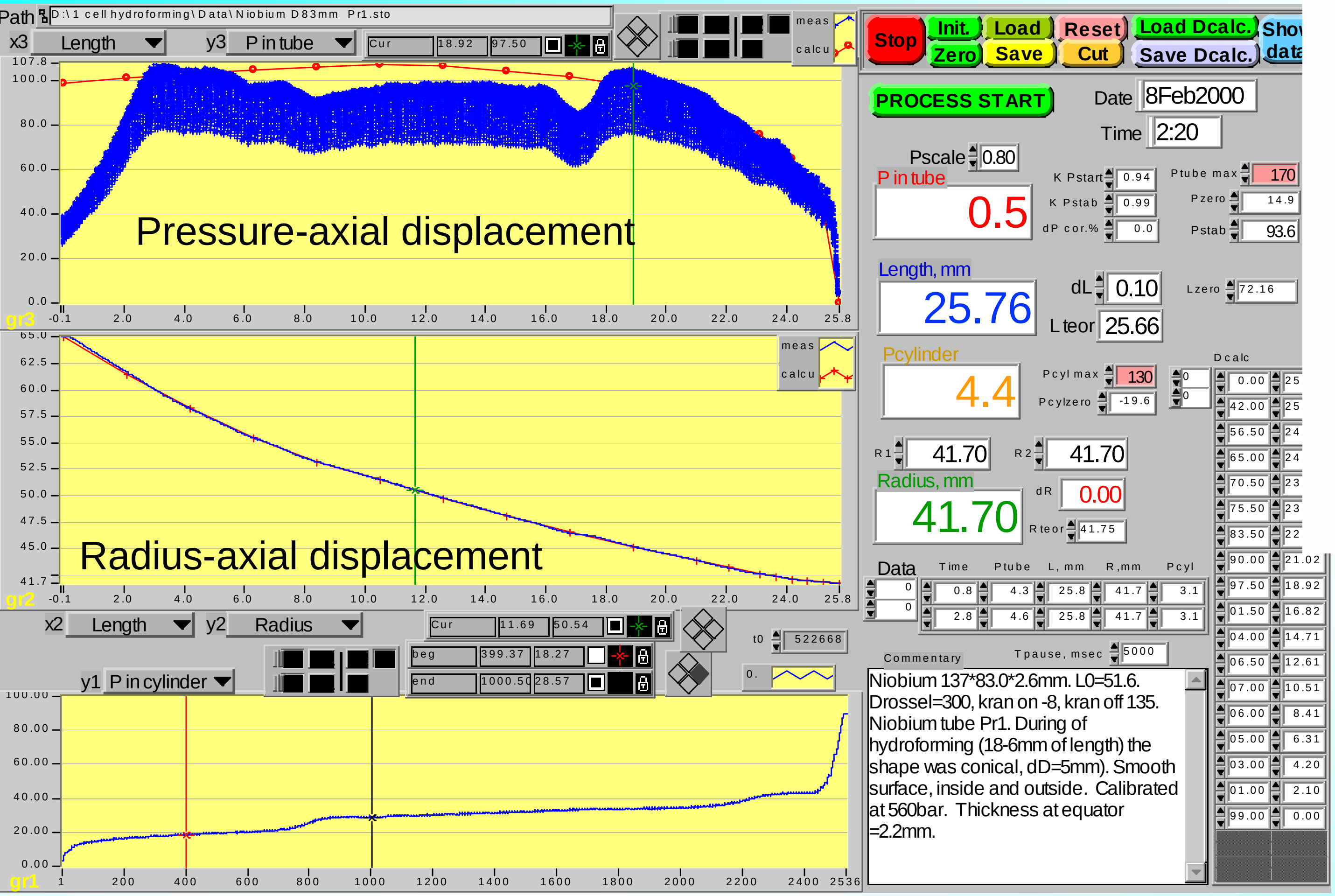
Principle of hydroforming

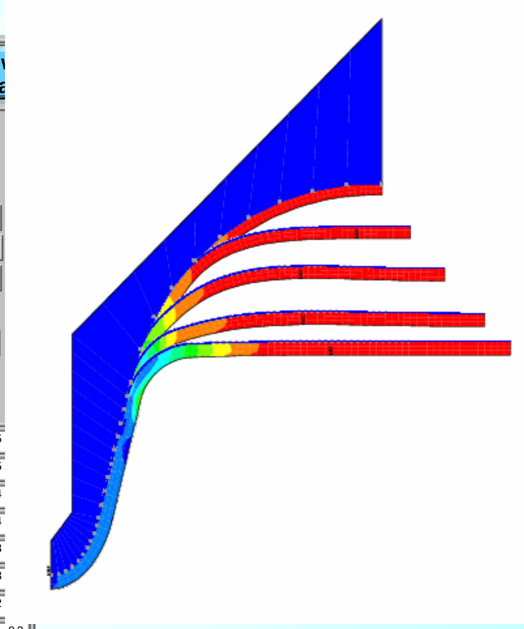


DESY hydroforming machine

- Designed and build in Russia (INR, Troitsk)
- Equipped with hydraulic systems and software at DESY
- From dimension is in position to produce only units of 3 cells







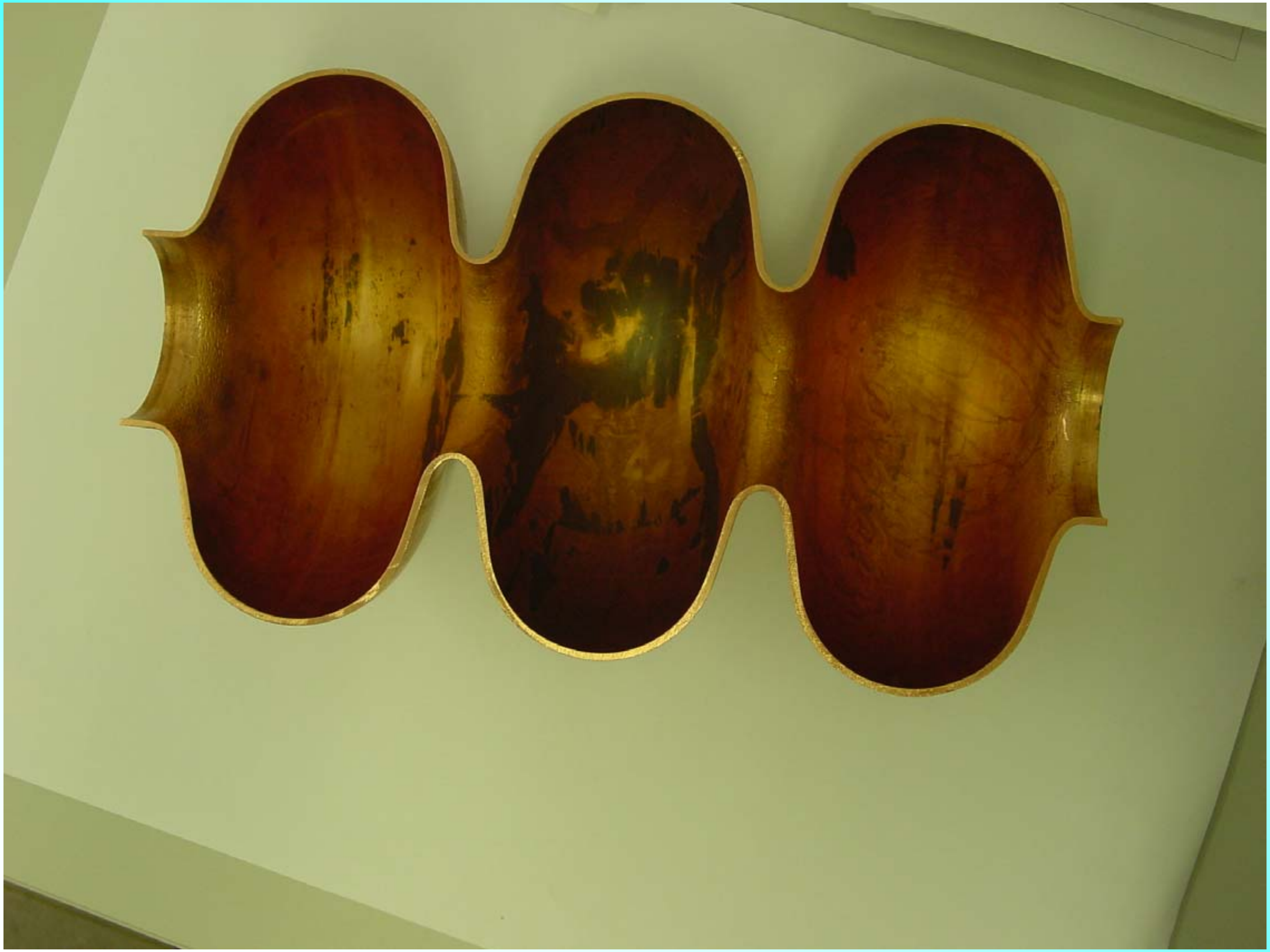
FEM Simulation of the hydroforming

Front panel of the software for hydroforming - machine

PC control allows reproducibly repeat the forming parameters

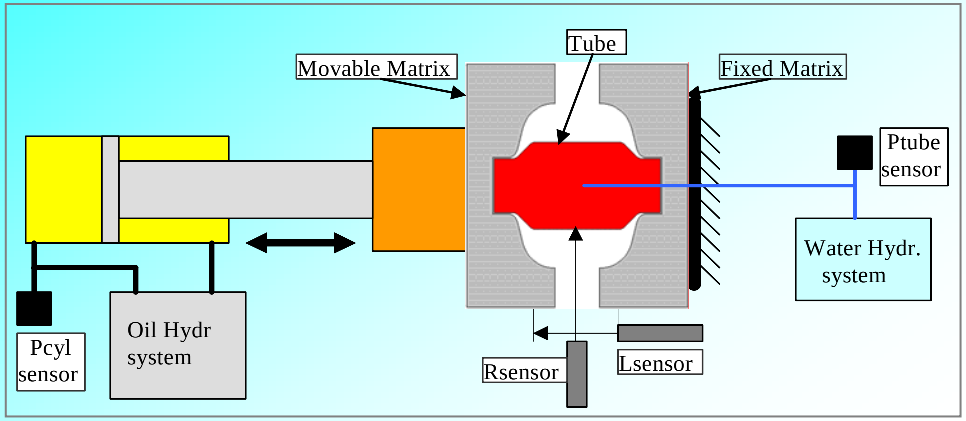
All steps of hydroforming optimized and checked on the Cu dummies

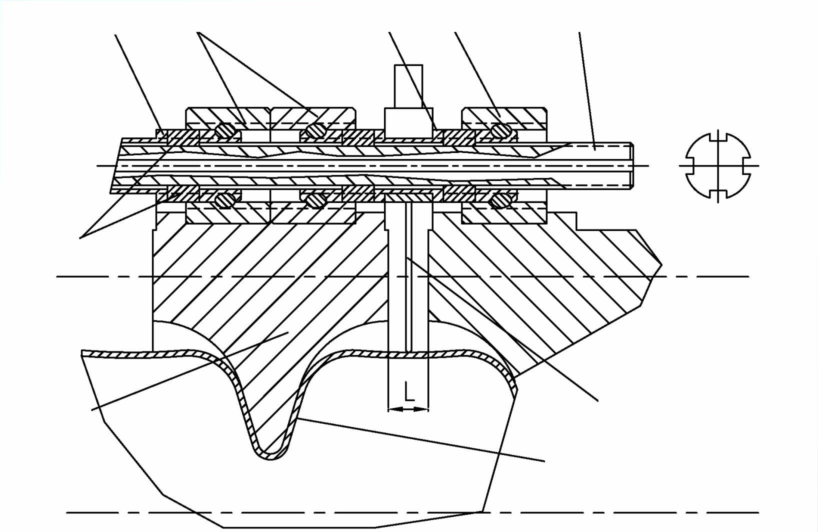
Hydroforming of cells can be done by three cells simultaneously as well as cell by cell (hydroforming of the 9-cells from one tube piece can be done on the same way)



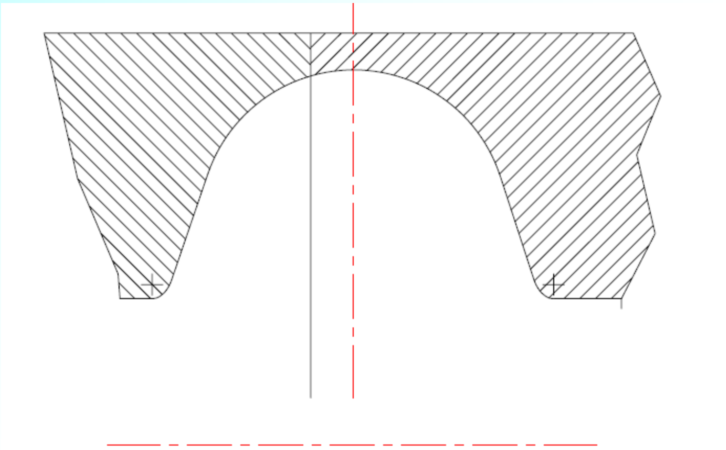
Rather uniform wall thickness distribution is achievable

Some ideas contributed to hydroforming success





Synchronization mechanism for multi cell fabrication by hydroforming

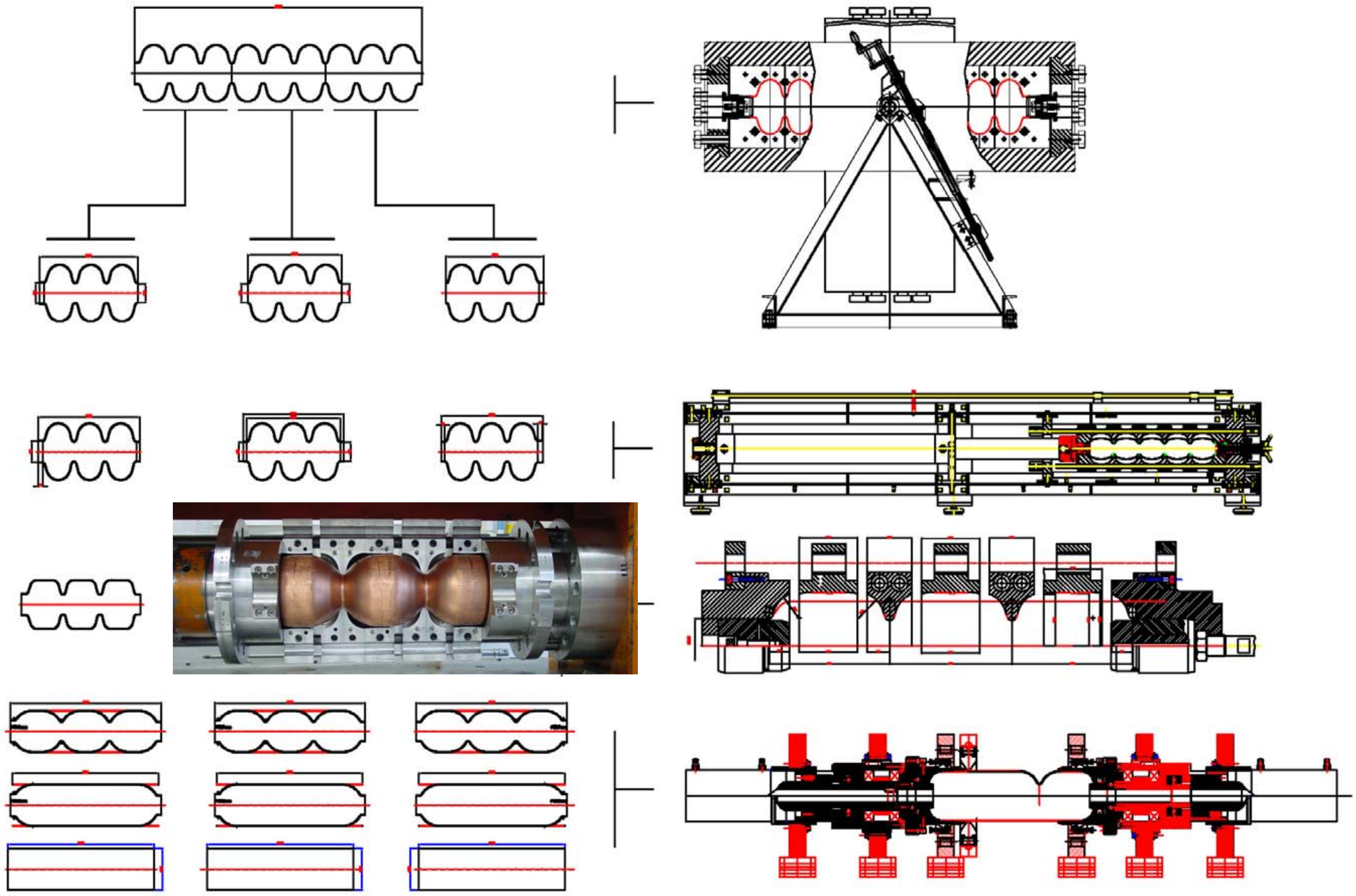


Nonsymmetrical mould for hydroforming

Developed ideas summarized in the patent.

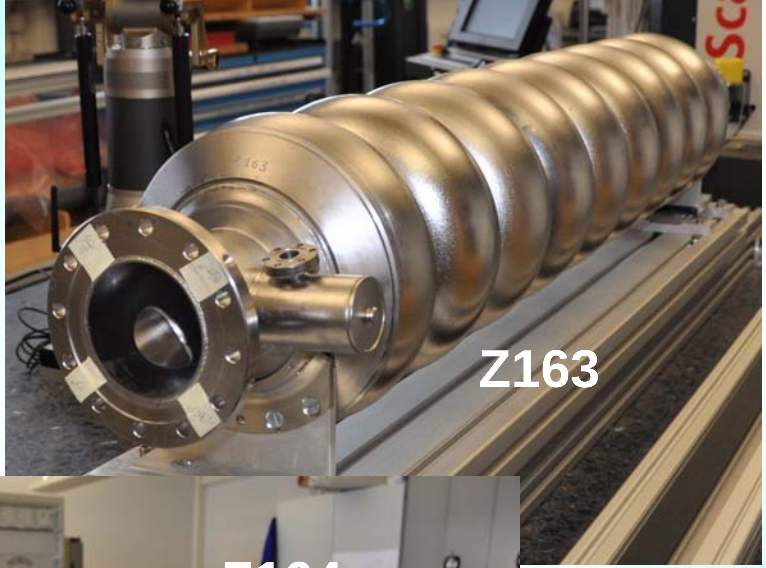
W.Singer, I.Jelezov; No. 10 2007 037 835 ; 18 September 2008

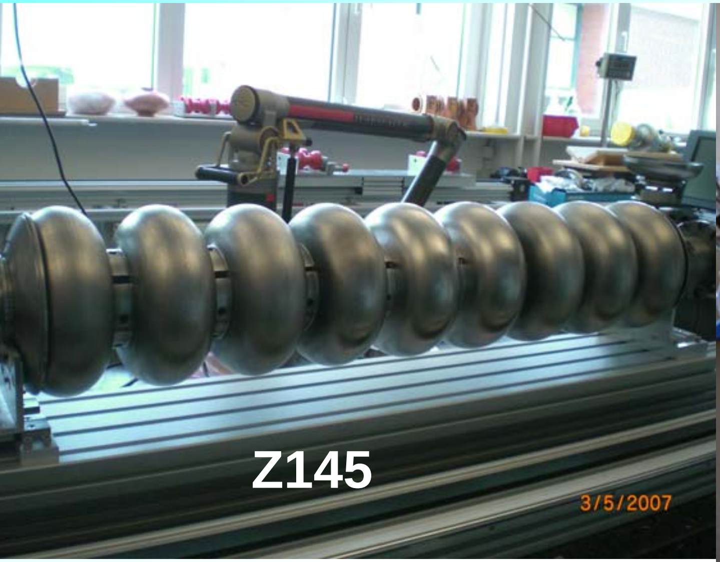
Fabrication steps of 9 cell cavity by hydroforming as option 3x3

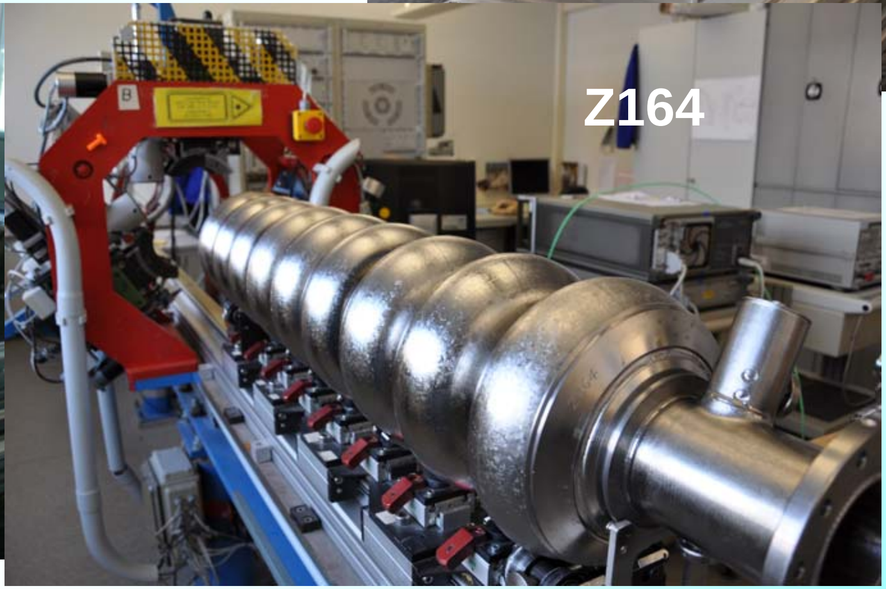


Three 9-cell cavities from hydroformed at DESY units completed at E.ZANON (Z145 reached Eacc~30 MV/m, Z163 and Z164 in work)

One 9-cell cavity from hydroformed at DESY units is completed at JLAB







Completed at JLab 9-cell cavity

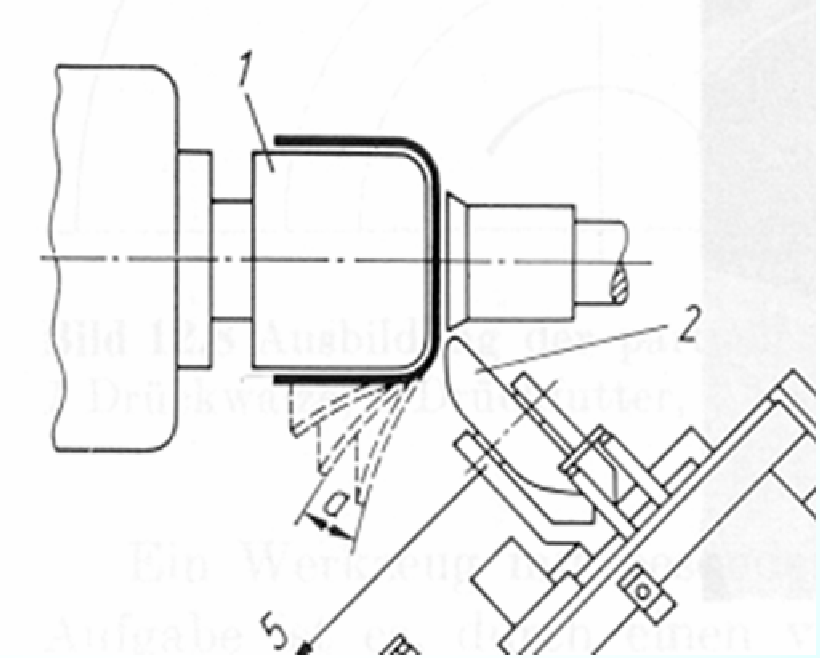
Bulk Nb tube fabrication.

Fabrication of seamless tubes required special development. Several techniques of the tube fabrication have been taken into consideration at DESY

- Tube production by back extrusion from the ingot part:
- Tube production by spinning
- Tube production by deep drawing
- Tube processing by flow forming
- Welded Nb tubes.
- Seamless Nb tubes produced on powder metallurgical way

• Spinning:

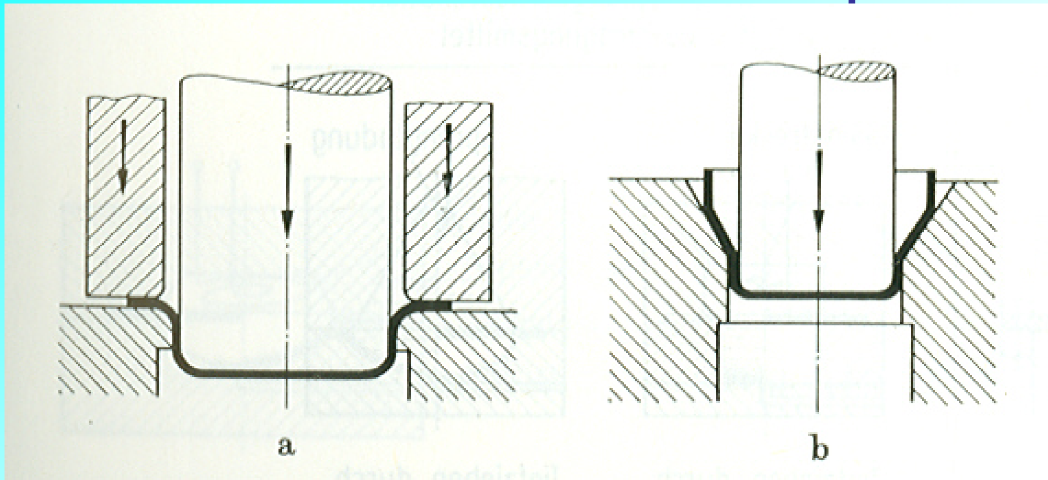
OK for single cells



Cavities hydroformed from spun tubes (reached up to 42 MV/m)

Fabrication of the seamless pot from Nb plate by spinning is possible without intermediate annealing

• Deep drawing



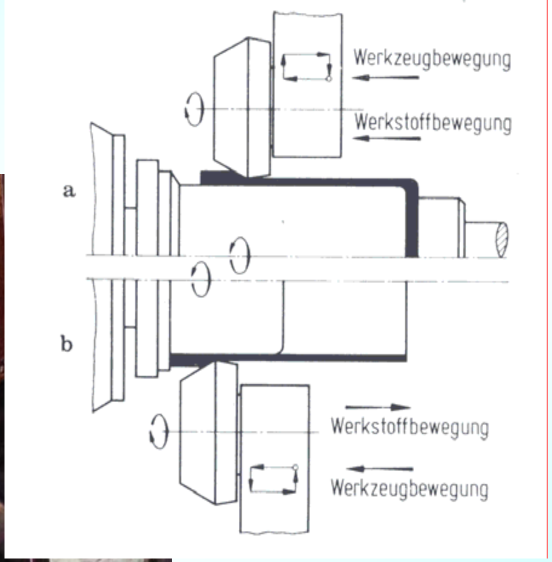
Principle of deep drawing; a-first step, b-second and further steps

Successful long tube fabrication by collaboration of Fa. Bravo and INFN Legnaro

Single cell cavity fabricated at Fa. Butting (Germany) in collaboration with DESY from deep drawn tube produced at the company B.J. Enterprise (USA) (reached 39 MV/m

In some cases bad inside surface of tubes (cracks, removed by machining)

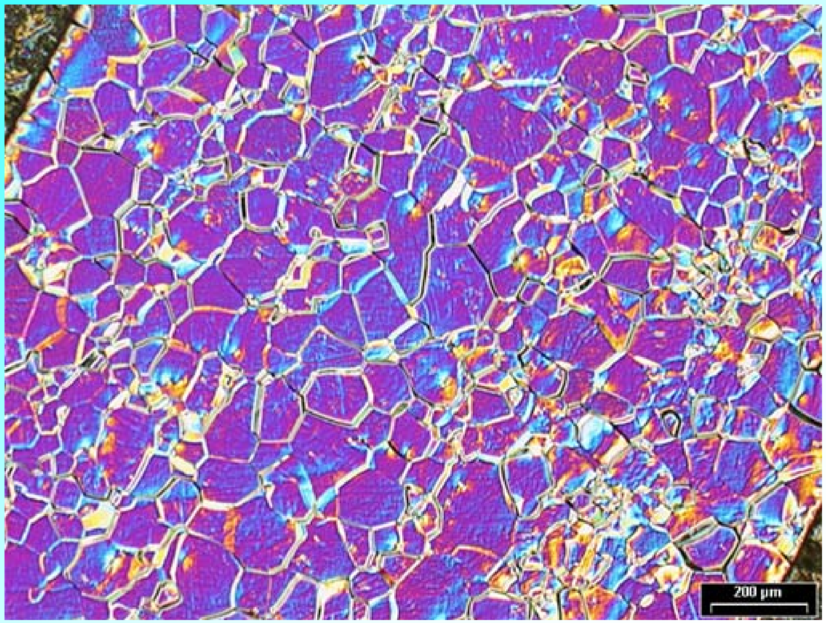
• **Flow forming**

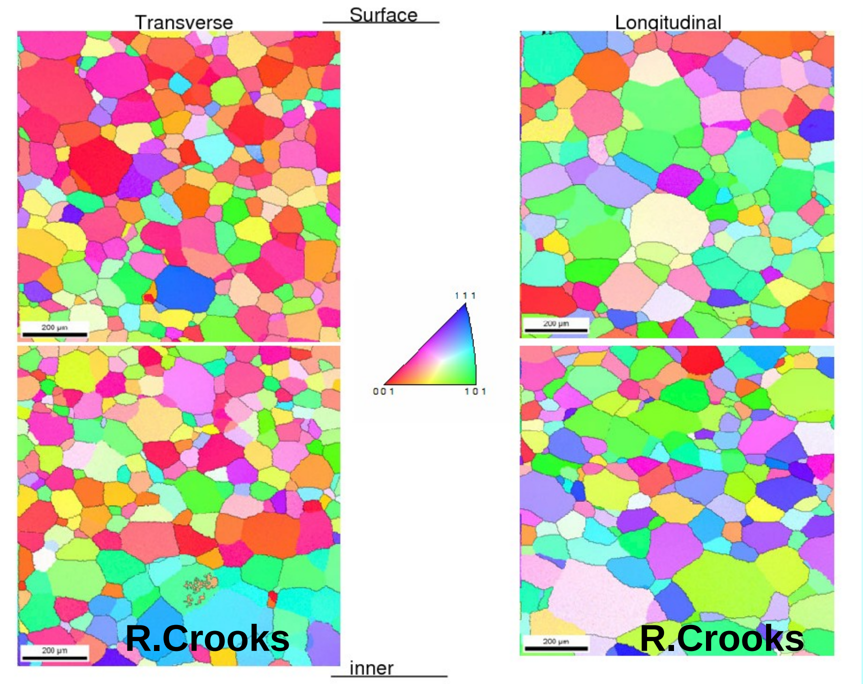


Flow forming of niobium spun tubes at MSR (Germany). Precise wall thickness after flow forming. Tolerances within of +/- 0,1 mm

Best result was achieved by combination of spinning (or deep drawing) with flow forming

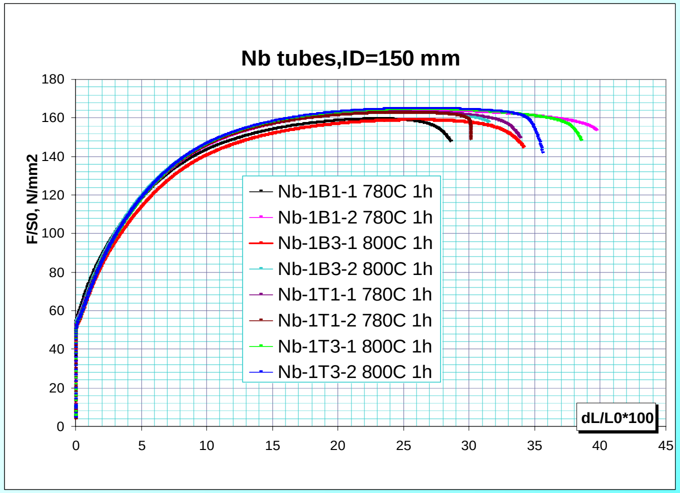
Best result was achieved by combination of spinning (or deep drawing) with flow forming: appropriate microstructure and mechanical properties





Microstructure and texture of Nb tubes produced by combination of spinning and flow forming

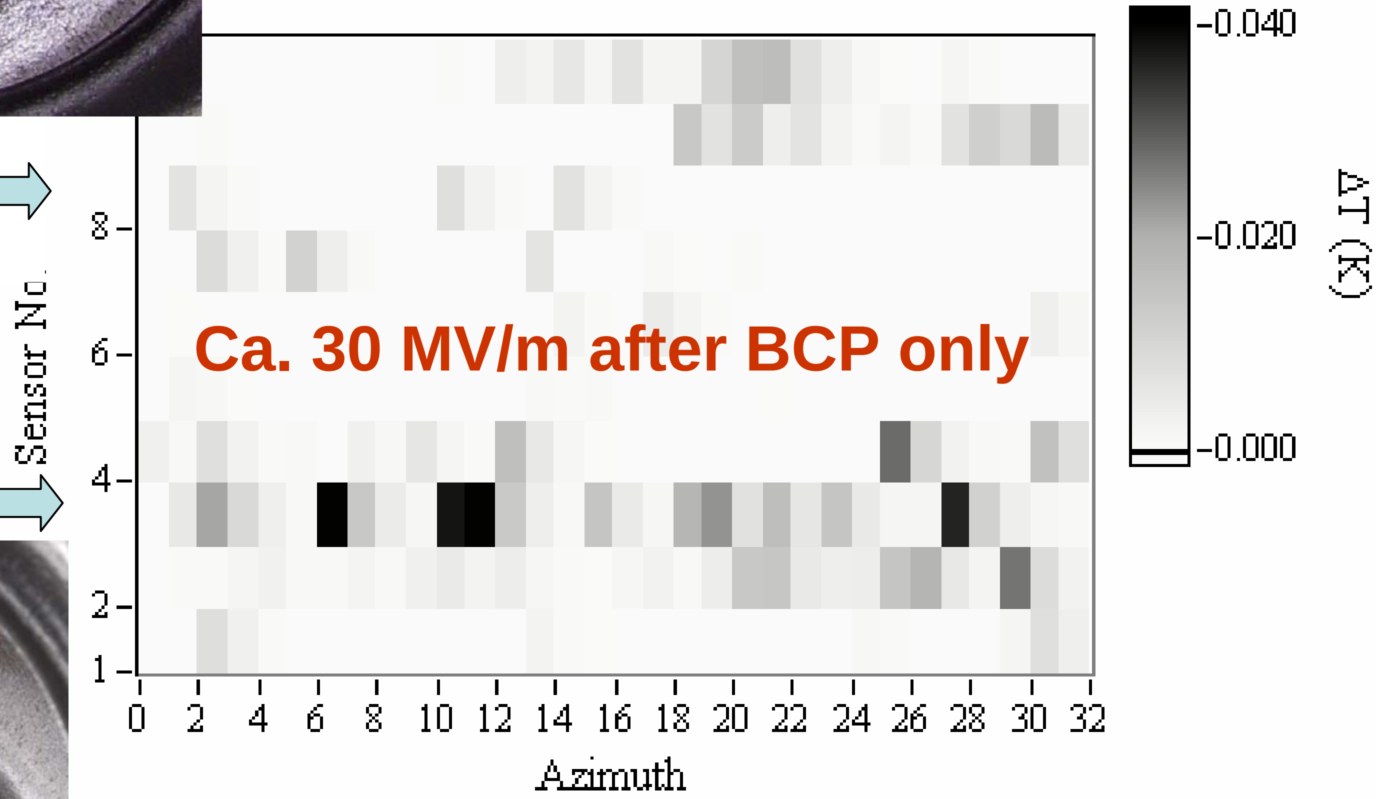
Stress-strain curves and microstructure of Nb tubes produced by combination of spinning and flow forming. Tensile tests done in circumferential direction



Such tubes used for fabrication of multi cell cavities

Relation of Eacc to the tube fabrication method

(Tube bottom)
Bottom cell



Top cell
(tube top)

Cavity top inside surface

T-map on 3-cell hydroformed cavities from spun+ flow formed tubes at E_{acc} = 27 MV/m, (**JLab**) indicating several hot-spots in the equator area, mostly on the top cell.

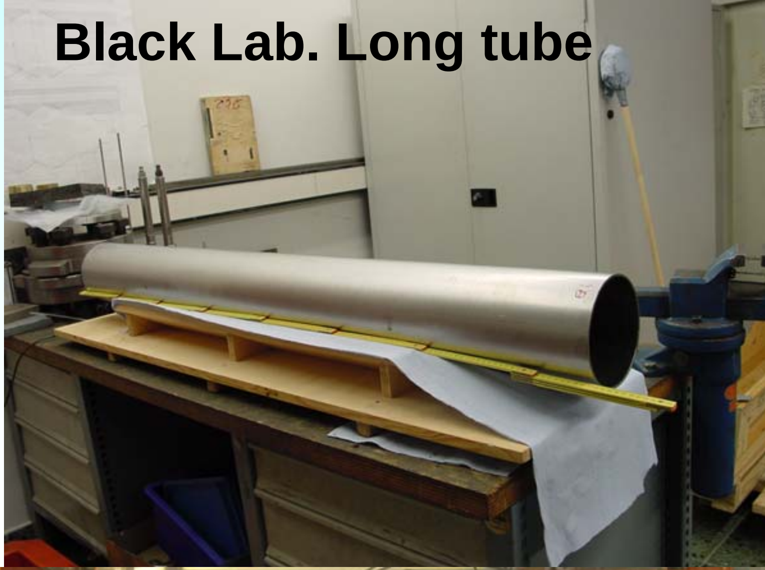
Good Eacc results, nevertheless the tubes can be made better

Tube after spinning

Last development:Tubes of Black Lab + WahChang.

Heavily deformed billet, processed for fine grain structure

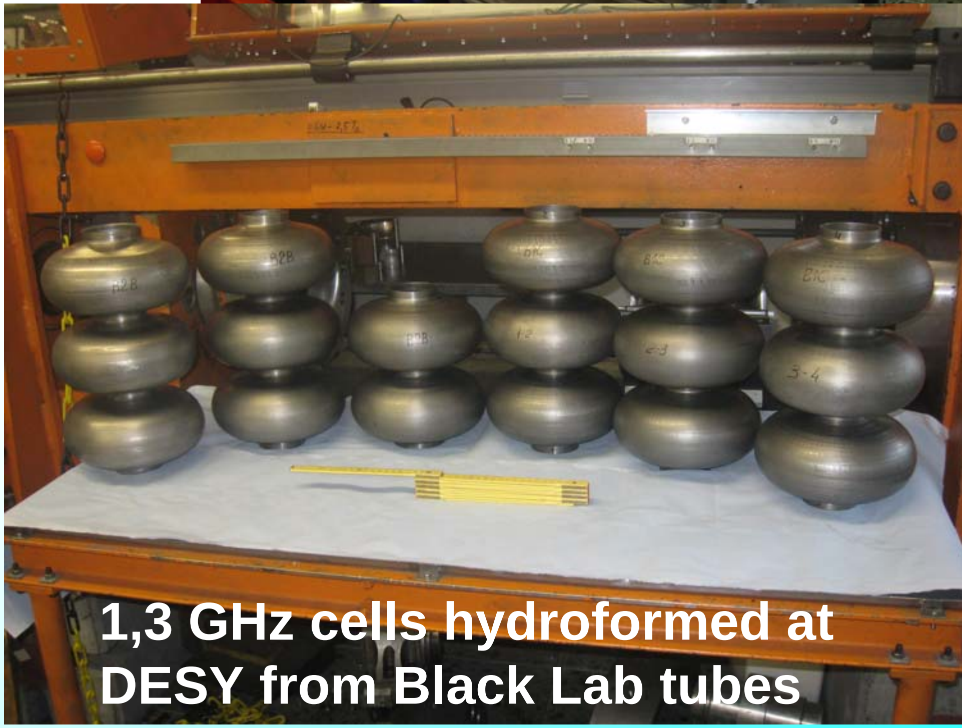
Shaped by forward extrusion and flow-forming



Black Lab. Long tube

Necking

First stage of hydroforming

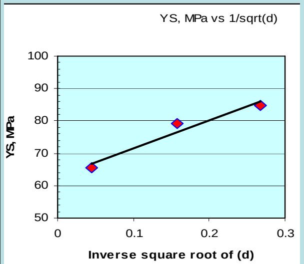


1,3 GHz cells hydroformed at DESY from Black Lab tubes

BLACK LABORATORIES L.L.C.

Processing improvement studies needed

Grain Size & Texture



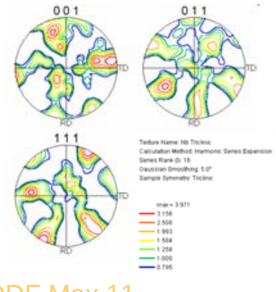
Low T final anneal

Texture radial sections

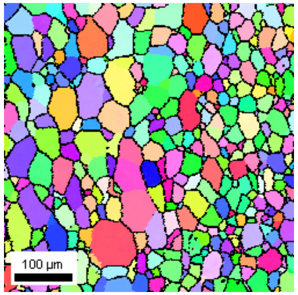
850°C

Radial

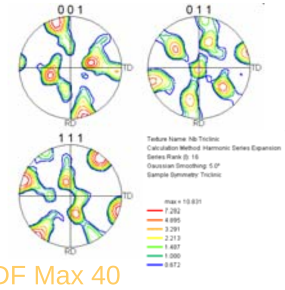
Axial (TD)



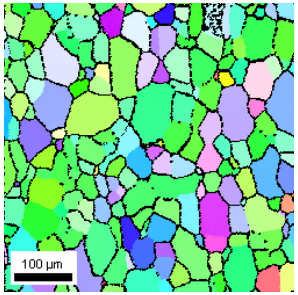
ODF Max 11



B1B



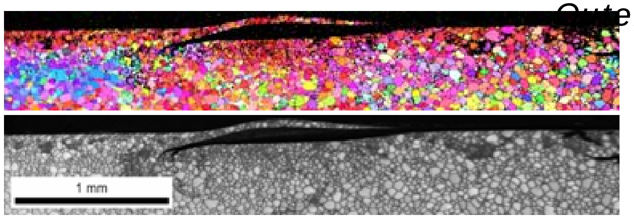
ODF Max 40



B1A

Tube Surfaces

Surface lapping cracks

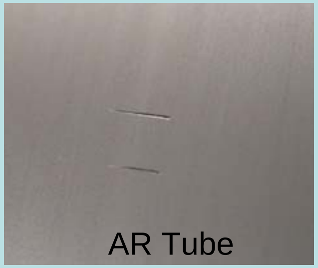


Outer surface

B1B

Surface cracks of unknown origin

B2B



B1C

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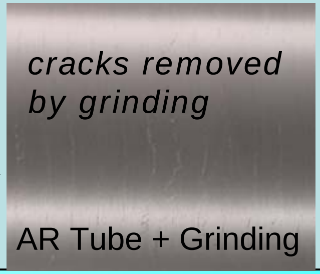
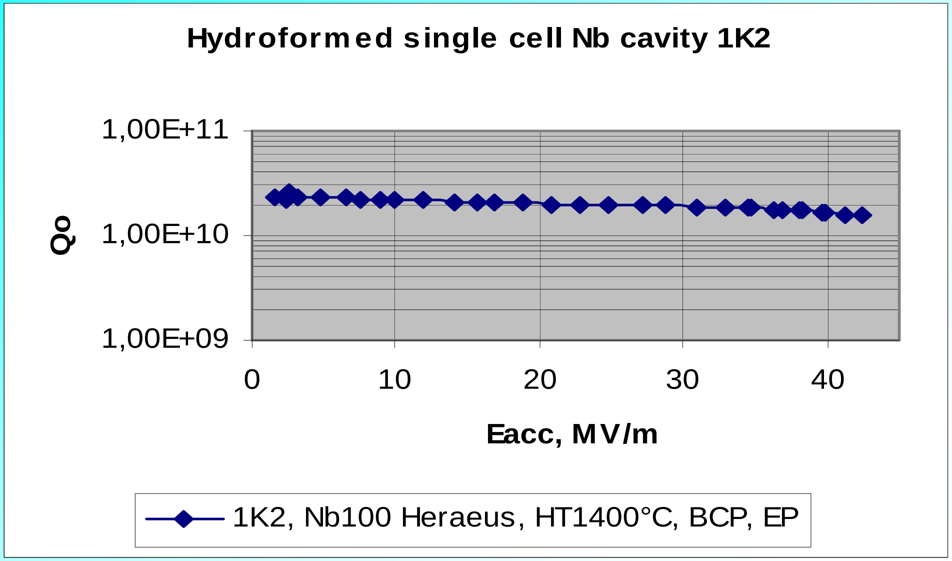
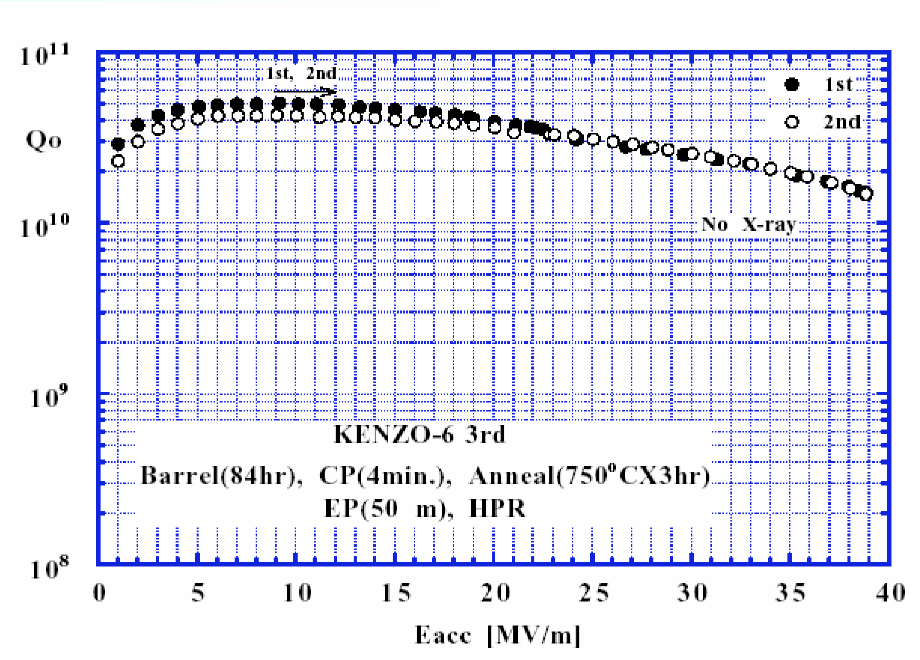
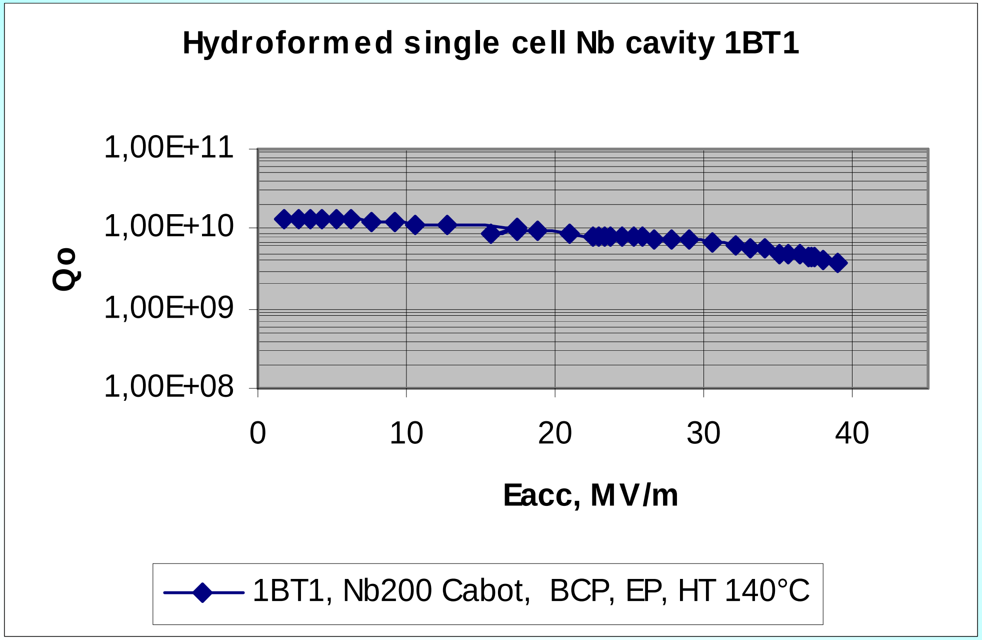


Examples of RF performance: single cells

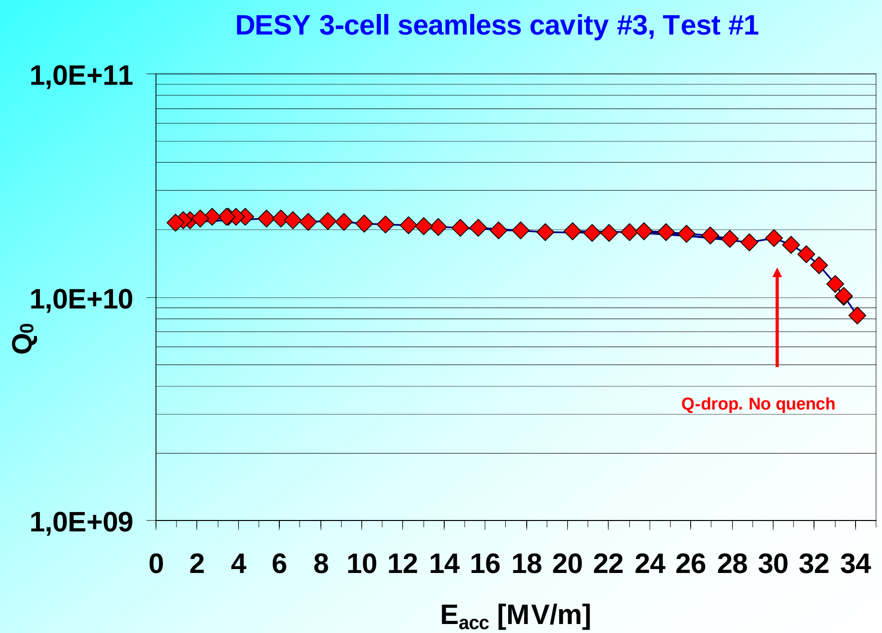


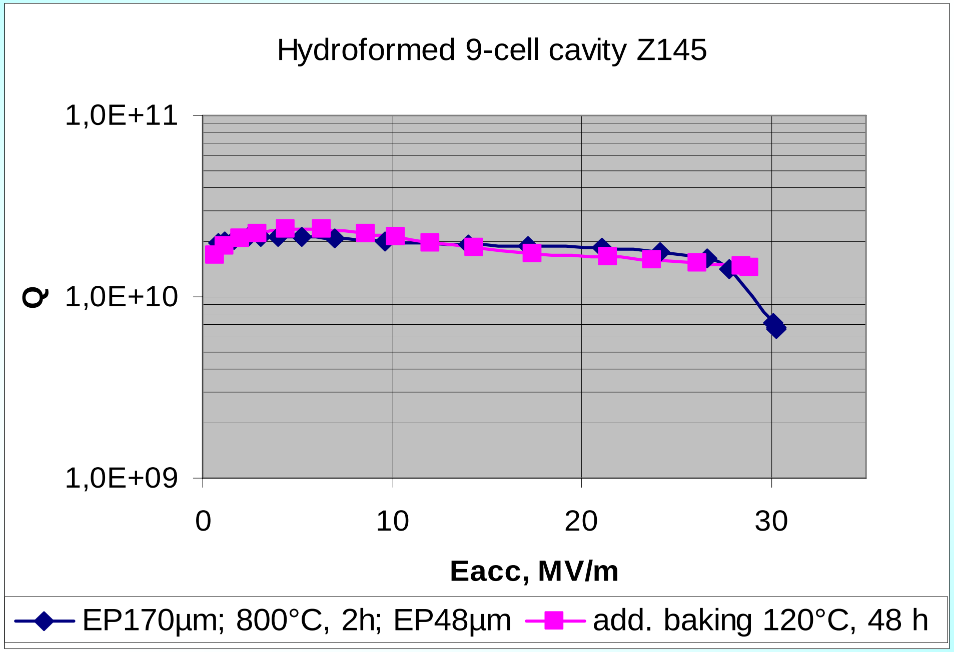




Some best seamless single cell cavities. Preparation and RF tests: K.Saito, P.Kneisel

Examples of RF performance: Multi-cell cavity





9-Cell cavity Z145

3 -cell hydroformed cavity

After BCP and post-purification at 1200°C for 3 hrs with titanium and subsequent BCP. The total material removal is ca. 250 µm.

Surface treatment at DESY: 40 mm BCP, 800 °C heat treatment, tuning; 170 mm electropolishing (EP), ethanol rinsing, 800 °C heat treatment; 48 mm EP, HPR and additional baking at 120°C for 48 h

Individual cells have performance between 30 MV/m and 39 MV/m

Cavity Fabrication Cost Issue:
Comparison of costs for hydroformed and welded 20.000 CVs

Mech. Fabrication of Welded CVs: Study, NOELL, 2000 (Based on experiences of another companies).

Mech. Fabrication of Hydroformed CVs: Study BUTTING, 1999 (Based on owns experiences of hydroforming of 1-cell cavity)

Fabrication by hydroforming was ca. 10-15% more expensive as conventionally welded cavities

The comparison of costs for welded and hydroformed cavities has to be reinvestigated

Conclusions

• High accelerating gradient up to 40 MV/m can be achieved in hydroformed cavities of TESLA shape

• Fabrication of the 9-cell cavities (3x3 units) of TESLA like shape is proven.

• Hydroformig of 9-cell cavity from one tube-piece is feasible. Fabrication of long tubes for 9-cell cavities from one piece is proven

• The main technical problems of the fabrication of seamless single cells and multi cells by hydroforming are solved.

• The main remaining task is industrialization of the fabrication technique.

• The comparison of costs for welded and hydroformed cavities has to be reinvestigated

ACKNOWLEDGMENTS

Many thanks to my colleagues at DESY who works with me these years and significantly contributed to the development of hydroforming technology:
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Significant contribution to the success of hydroforming development was done by P. Kneisel (JLab) and K. Saito (KEK) due to state of the art preparation and RF tests of the hydroformed cavities.

The work was done in collaboration with INR (Russia).