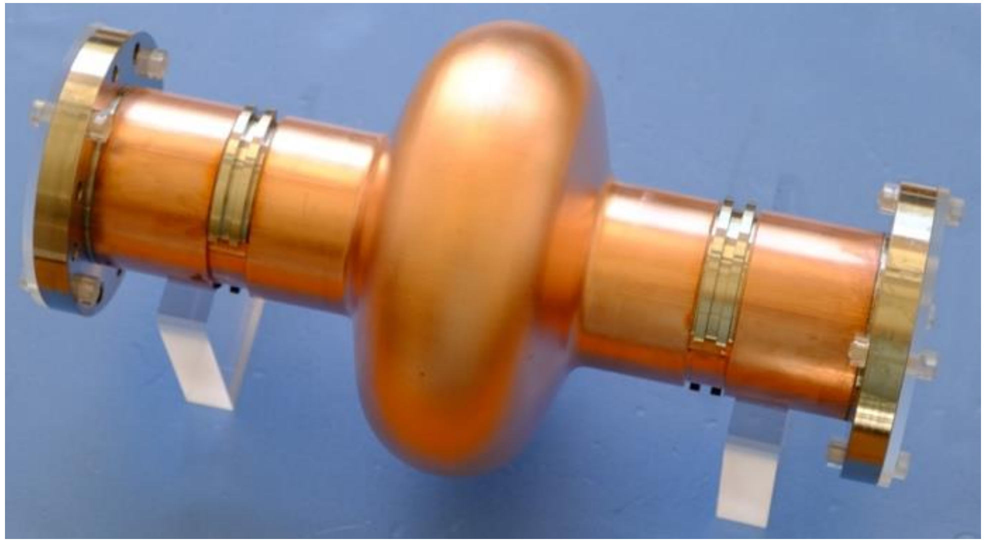
11th International Workshop on Thin Films and New Ideas for Pushing the Limits of RF Superconductivity
TFSRF2024 16–20 Sept. 2024 Université Paris-Saclay, France

Copper full-seamless substrate cavity manufactured by hydroforming



KEK
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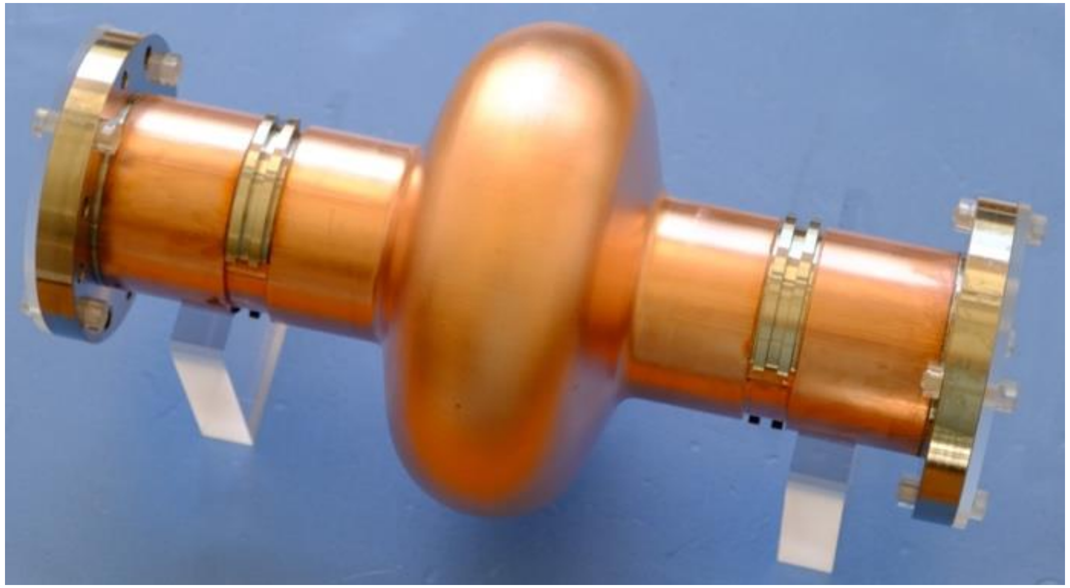
CERN

Contents

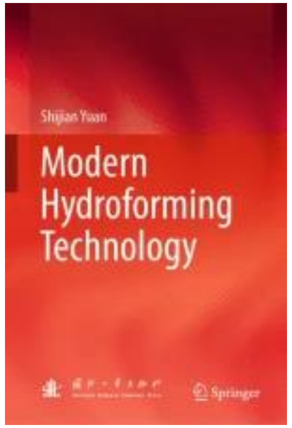
- Fabrication of full seamless cavity
- Niobium coating
- RF test



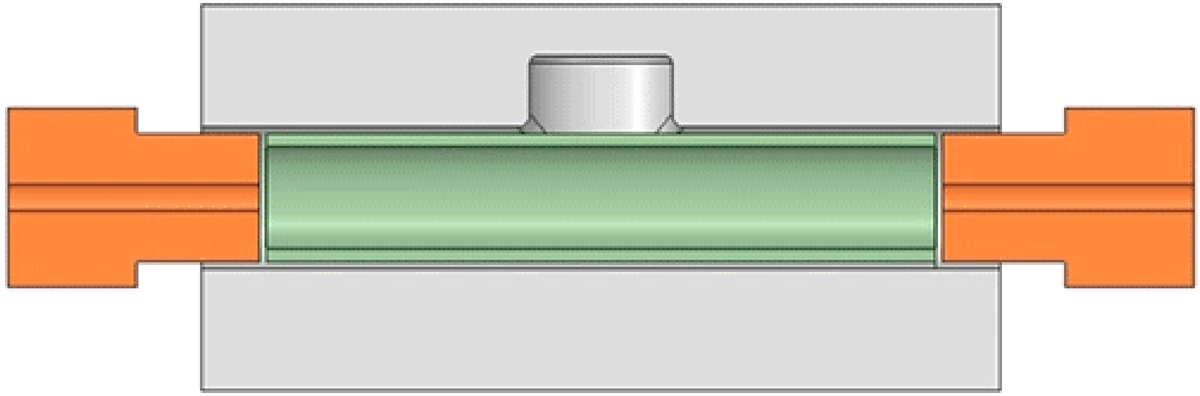
1.3 GHz one-cell full-seamless copper substrate cavity

Tube hydroforming

Well-known plastic forming technique



Shijian Yuan, Springer



Principle of hydroforming

https://www.tube-forming.co.jp/bulge.html

Bellows

Automobile parts
Hydraulic joints

Flexible tubes

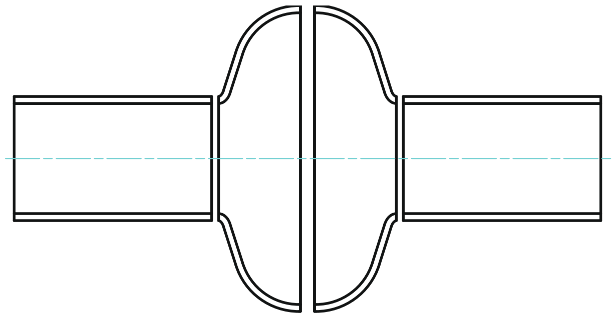
Hollow flame parts

https://sango.jp/pipe.html

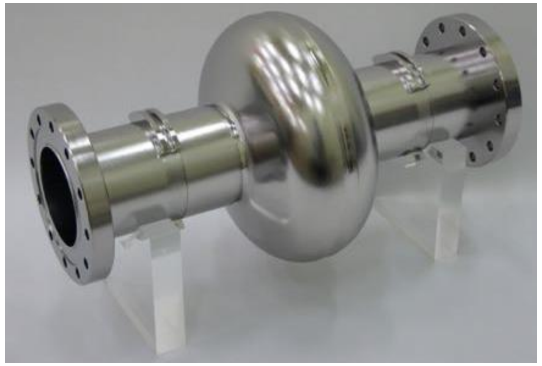
Industrial applications

Full-seamless cavity concept

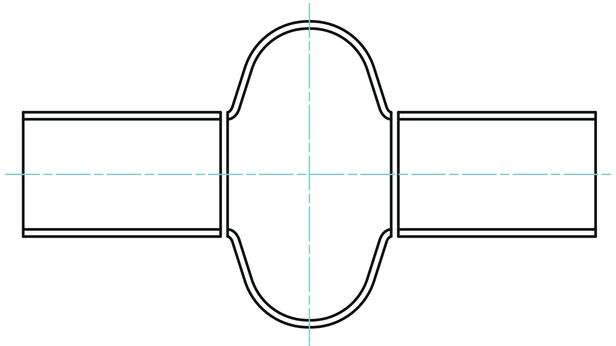
Conventional (4 pieces)



Cell part is manufactured by press-forming and EB welded with beam tubes

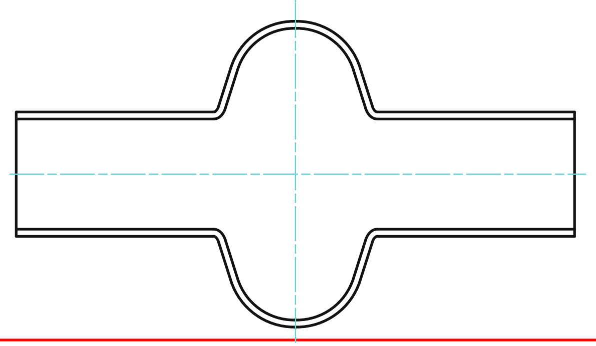


Seamless (3 pieces)

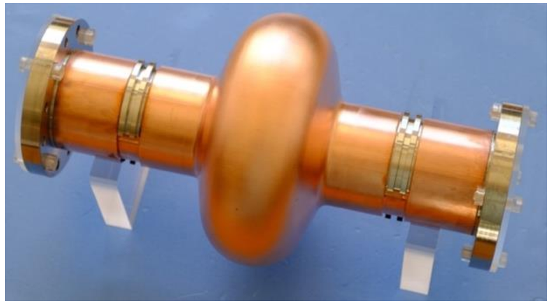


Cell part is manufactured by hydroforming from a seamless tube, then EB welded with beam tubes
KEK succeeded 3-cell bulk niobium cavity in this method.

Full seamless (1 piece)

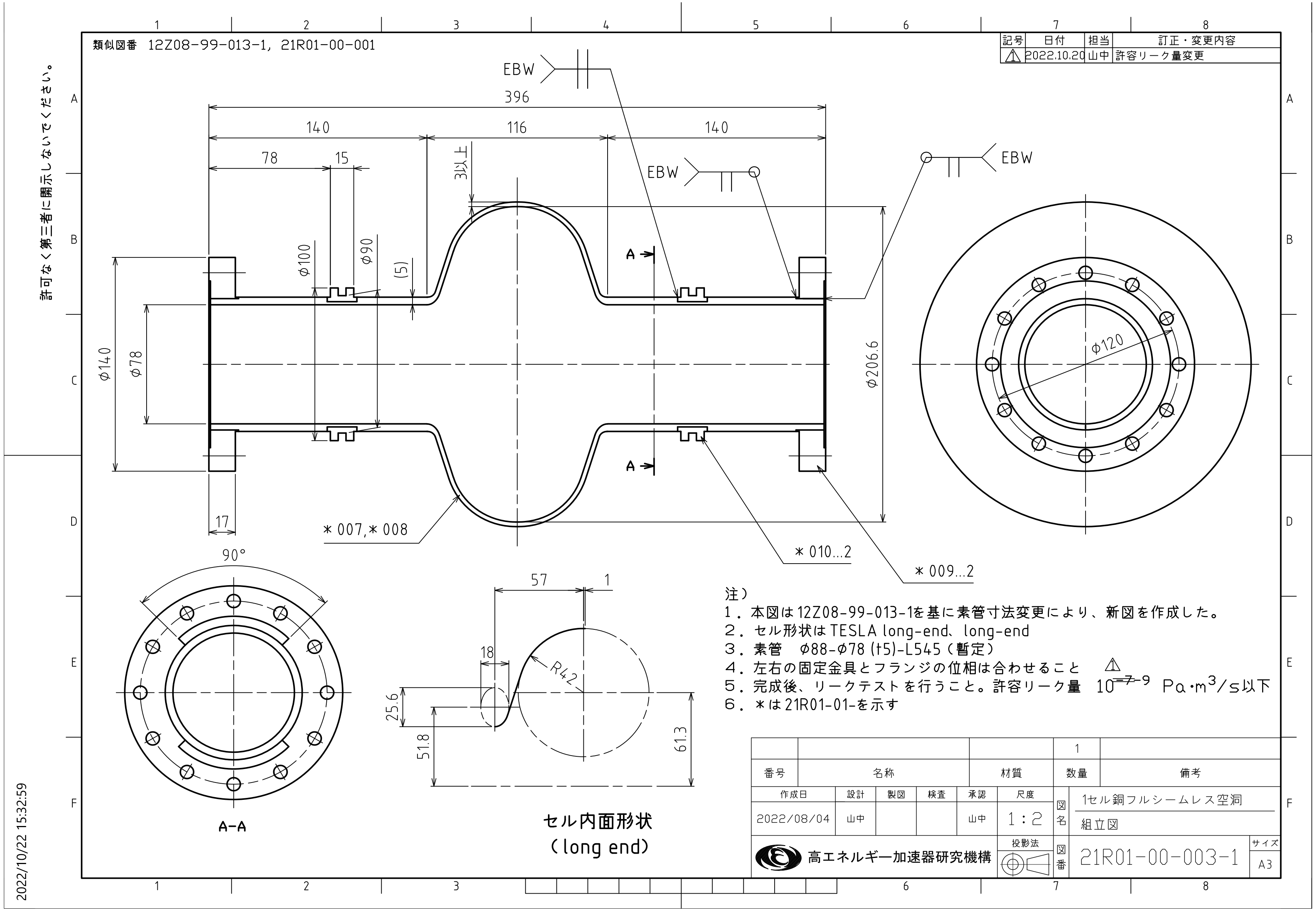


Whole cavity is manufactures by hydroforming from one seamless tube.
There is no welding part (no bead).



- This time, we try an **OFE copper** substrate cavity for niobium coating.
- There is no welding bead on equator and iris parts so that inner surface is so smooth. It has a big merit for niobium coating.

1.3 GHz one-cell full-seamless copper cavity



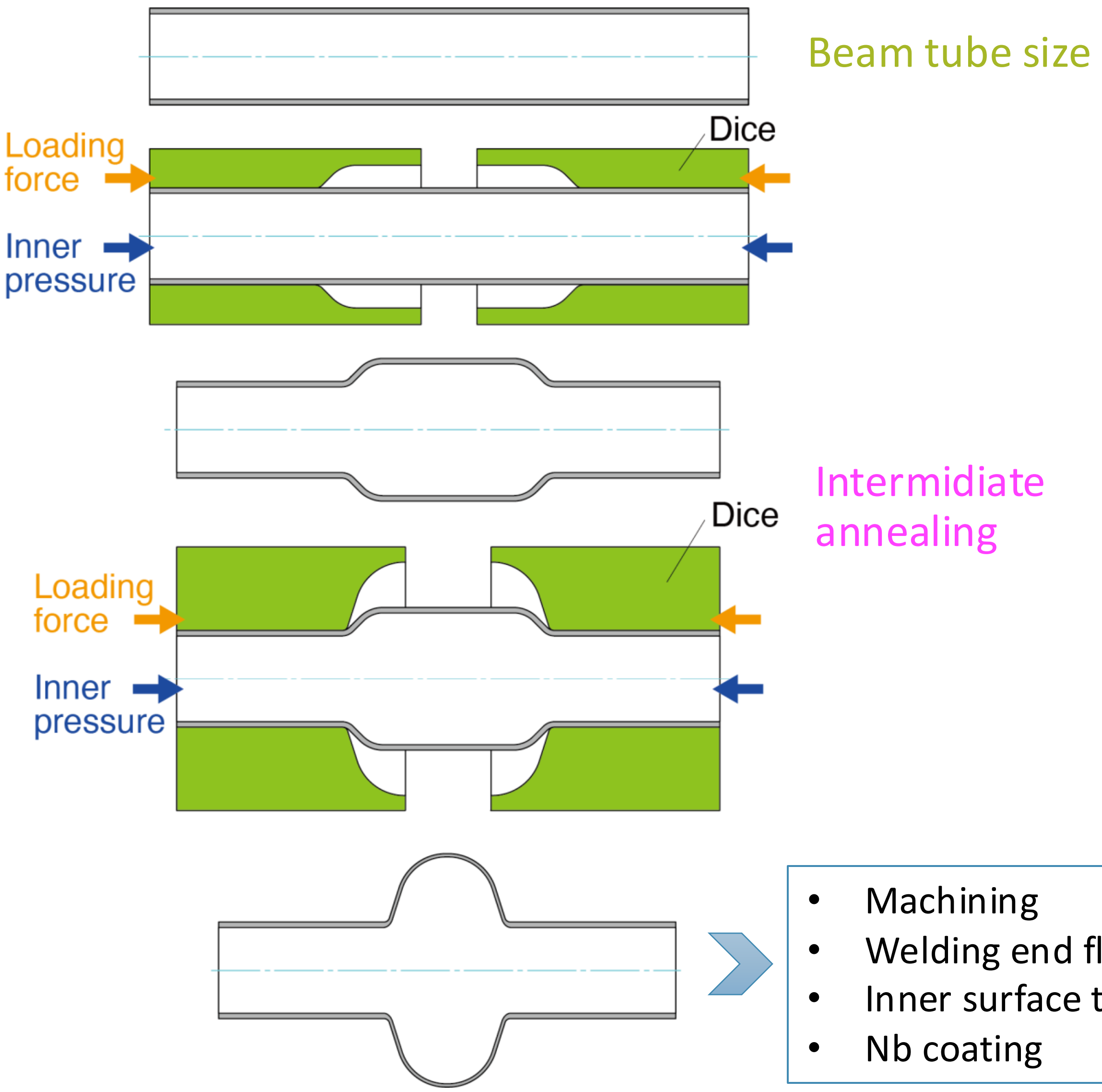
Optimized manufacturing process

Initial tube

Hydroforming 1
(HF1)

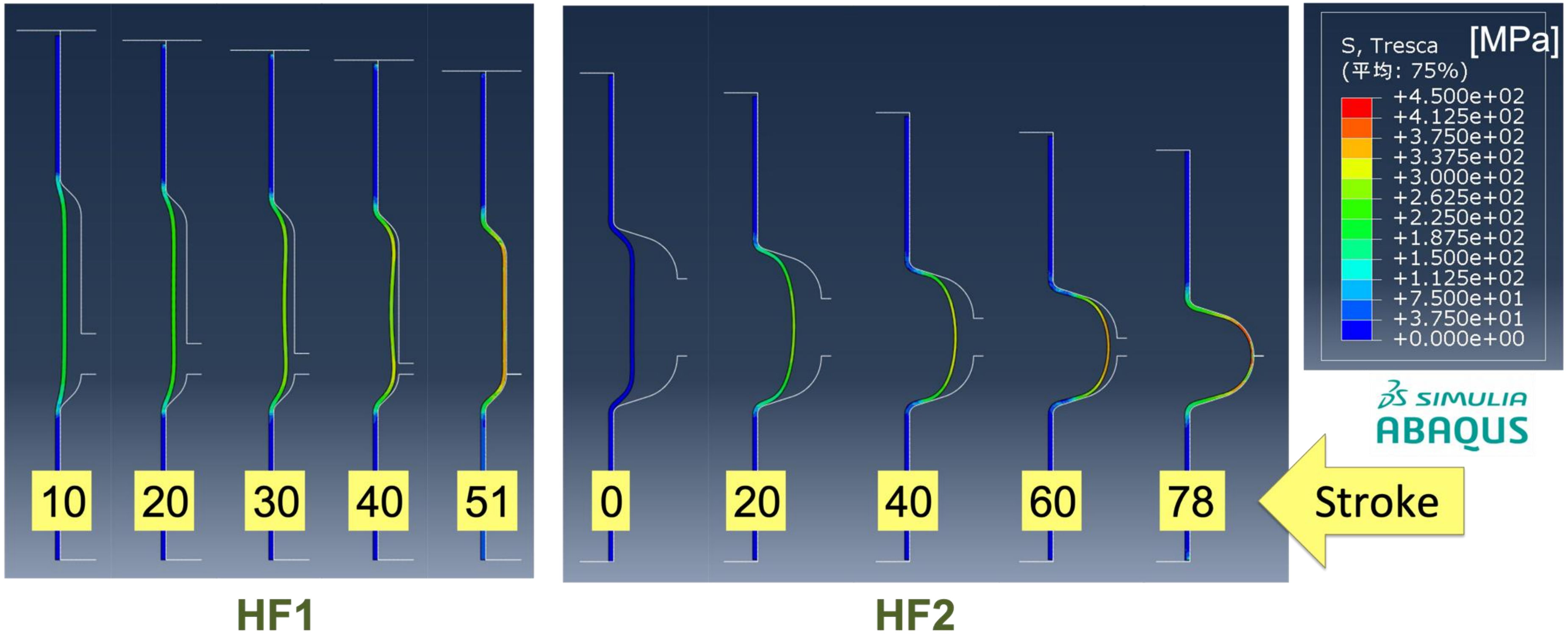
Hydroforming 2
(HF2)

Finish



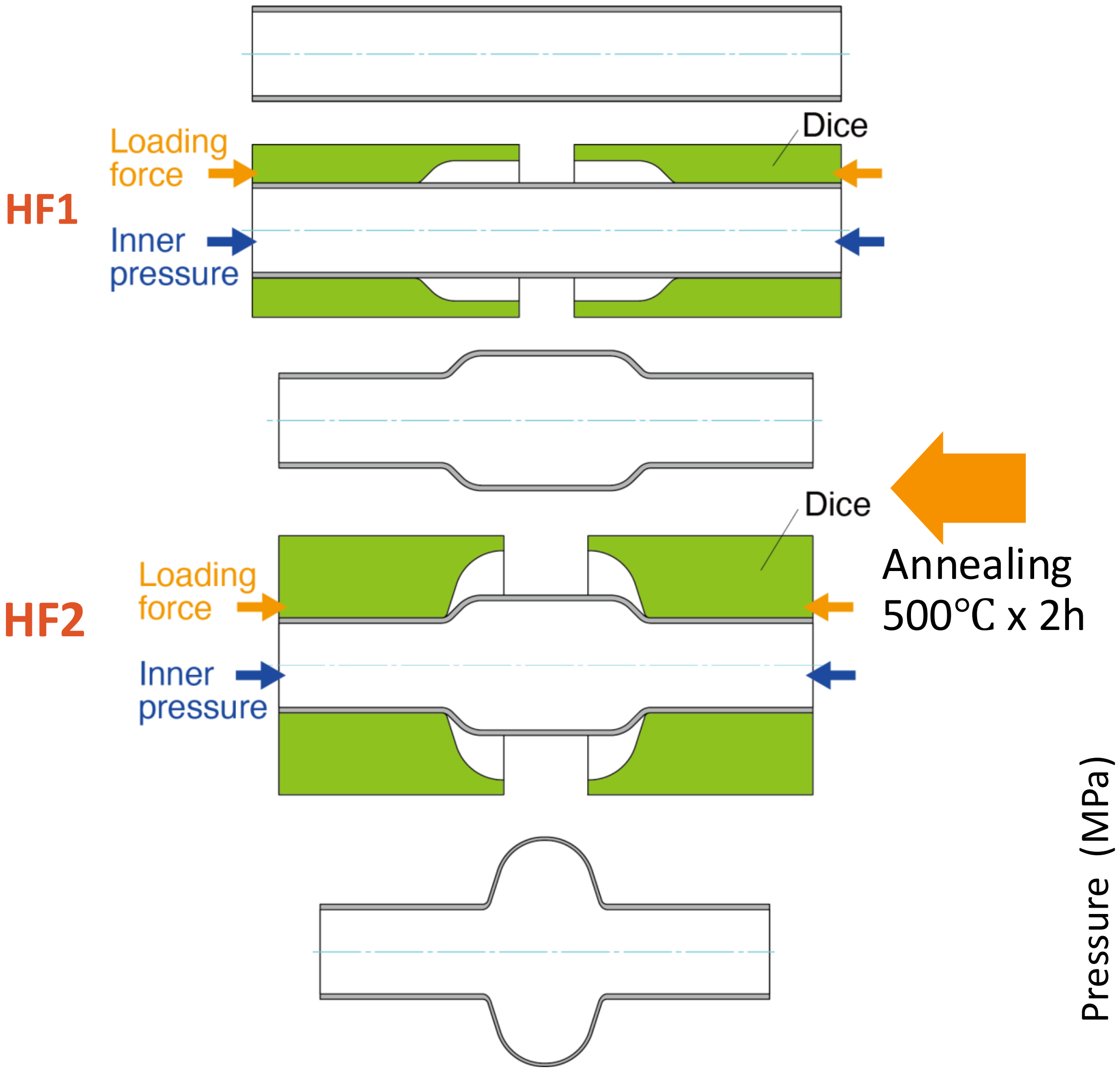
- Machining
- Welding end flanges
- Inner surface treatment
- Nb coating

Simulation



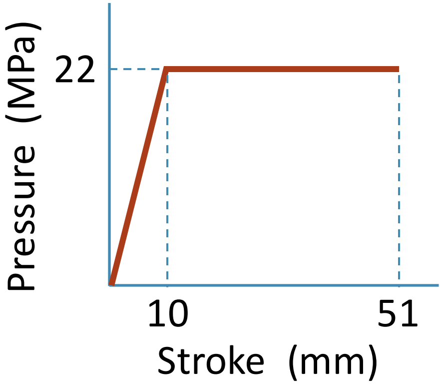
Tresca stress distribution according to stroke
MAX. stresses are 381.5 and 424.1 MPa at HF1 and HF2, respectively
Hydroforming is held in vertical. Lower die is fixed, and upper die moves to the downward direction (see pic. next page).

Successful hydroforming

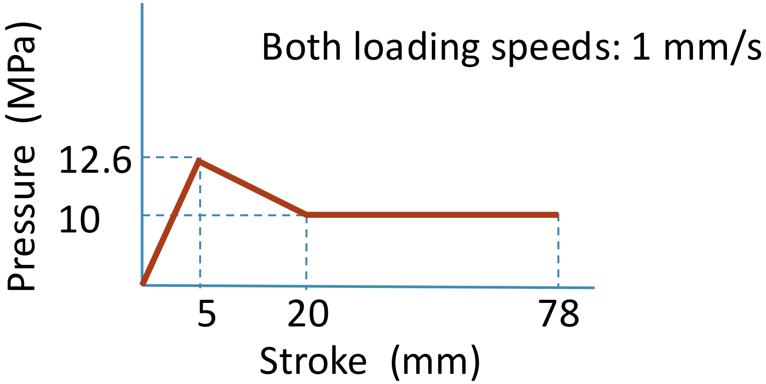


Hydroformed copper tubes

Hydroforming machine

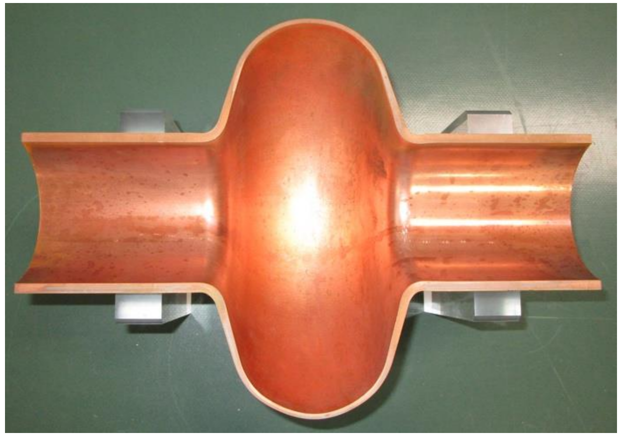


HF1 (1 pass)



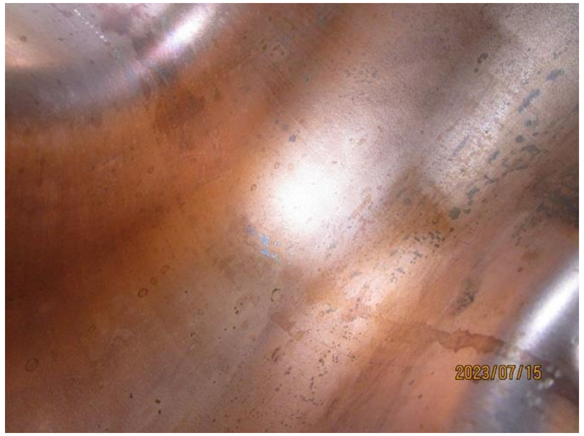
HF2 (1 pass)

Measurement of roughness

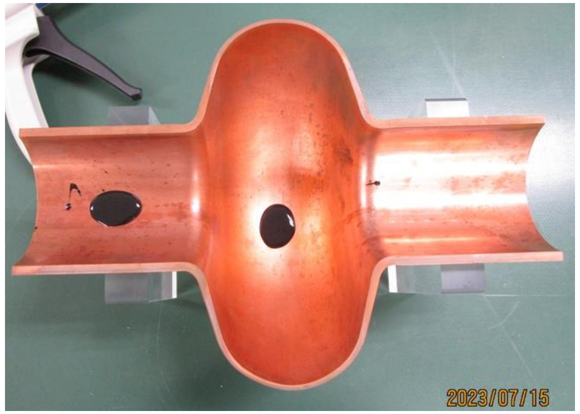


Cut piece of cavity

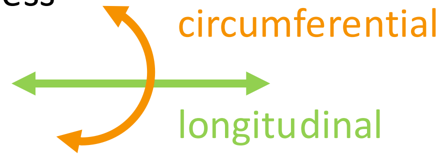
Close up at beam tube



Close up at equator



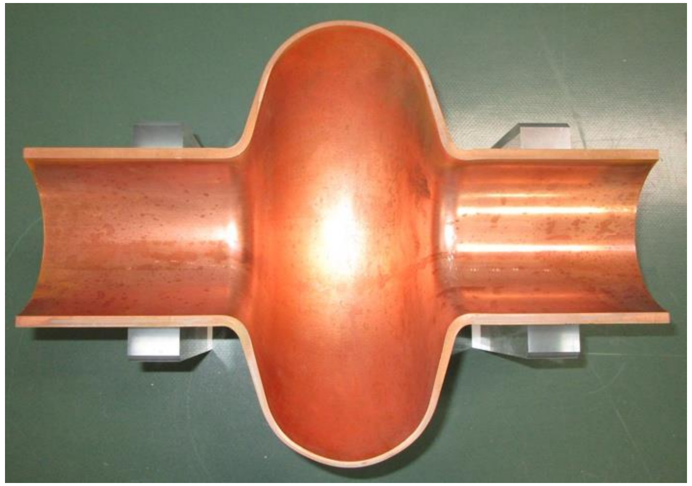
Plastic replica is used for roughness measurement



Measured roughness [µmRa]

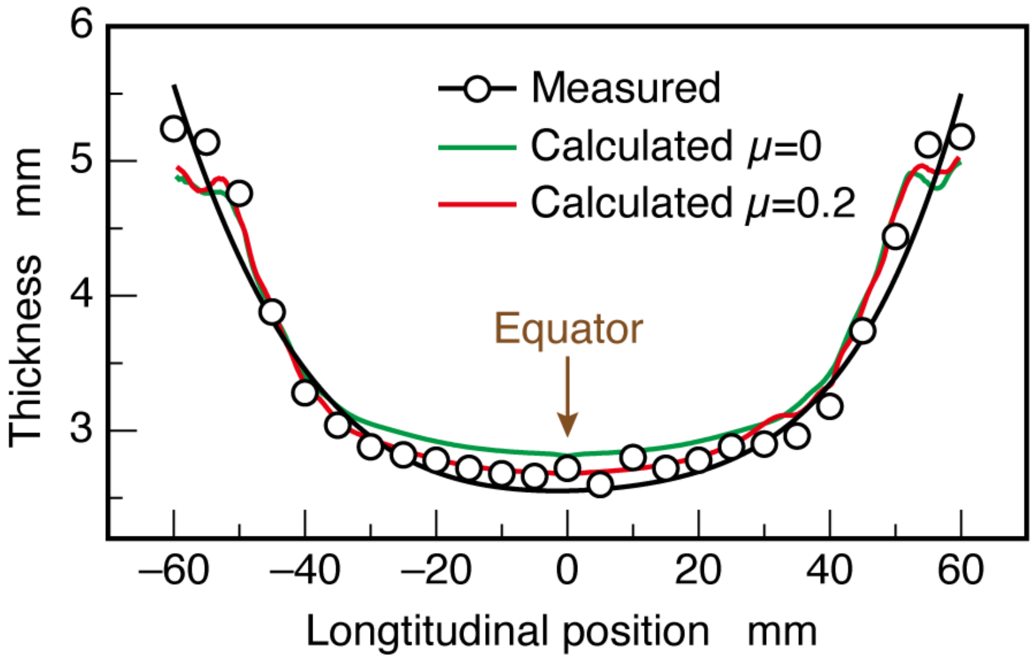
Direction	Beam tube	Equator
longitudinal	1.0	2.9
circumferential	0.8	2.6

Thickness distribution



The wall at equator becomes thick

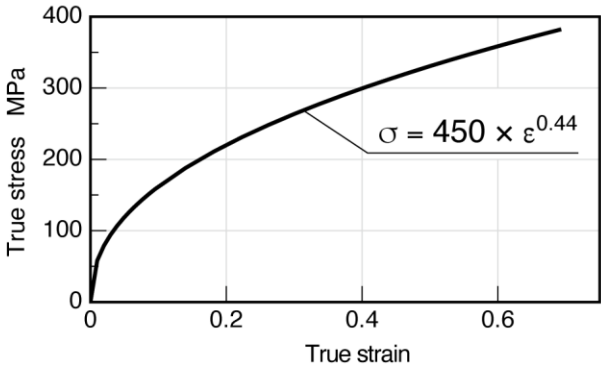
Thickness was measured by caliper



Comparison between measured and calculated thickness

In case of μ=0.2, measured and calculated results agreed well

We will apply to design of dice considering thickness distribution

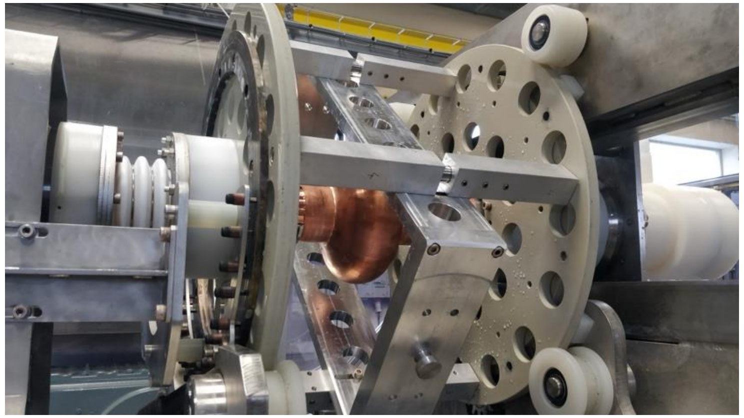


Tensile test was achieved using the specimen from actual copper tube

Nb thin film coating

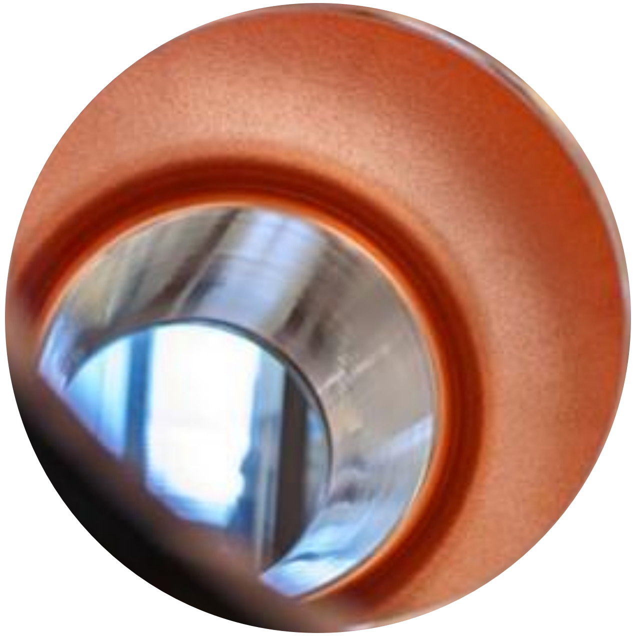
Process flow

1. Electropolishing
2. HPR (100bars)
3. ISO 5 Cleanroom assembly
4. Pump down
5. Bakeout
6. Coating
7. ISO Cleanroom disassembly
8. HPR (100 bars)
9. Shipping to KEK



Cavity on the EP bench

Cavity on the HPR setup



Cavity's cell surface during cleanroom assembly

Cavity on the coating bench

Nb thin film coating

Process parameters

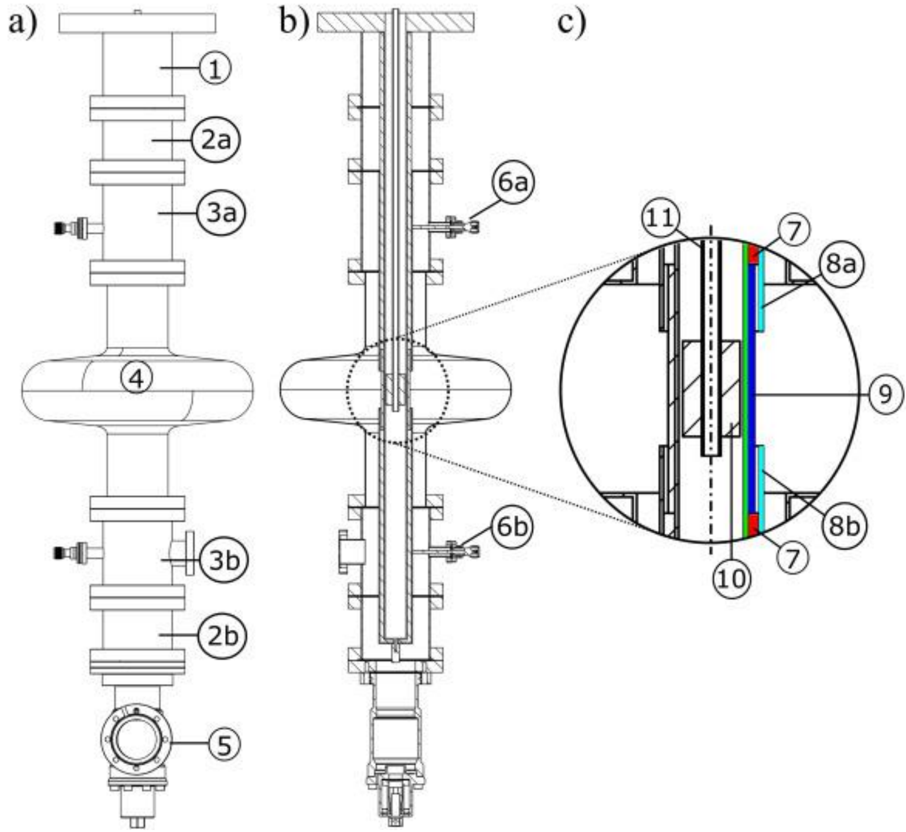
EP: 40 minutes, target 12 μm removed material.

HPR: 100 bars, 3 hours, cavity dried under vacuum at 50°C.

Bakeout: 48h, 200 °C, base pressure ~ 2.10^{-10} mbar

Coating: HiPIMS

- cut-offs: 350W, $2.5.10^{-2}$ mbar Kr, 6 positions/cut-off, 150 °C, unbiased.
- cell: 2 kW, $2.5.10^{-3}$ mbar Kr, 6 hours, 150 °C, -75V bias voltage
- Targeted thickness at the equator: 6 μm



Coating apparatus schematic

https://doi.org/10.1016/j.surfcoat.2022.128306

RF Measurement

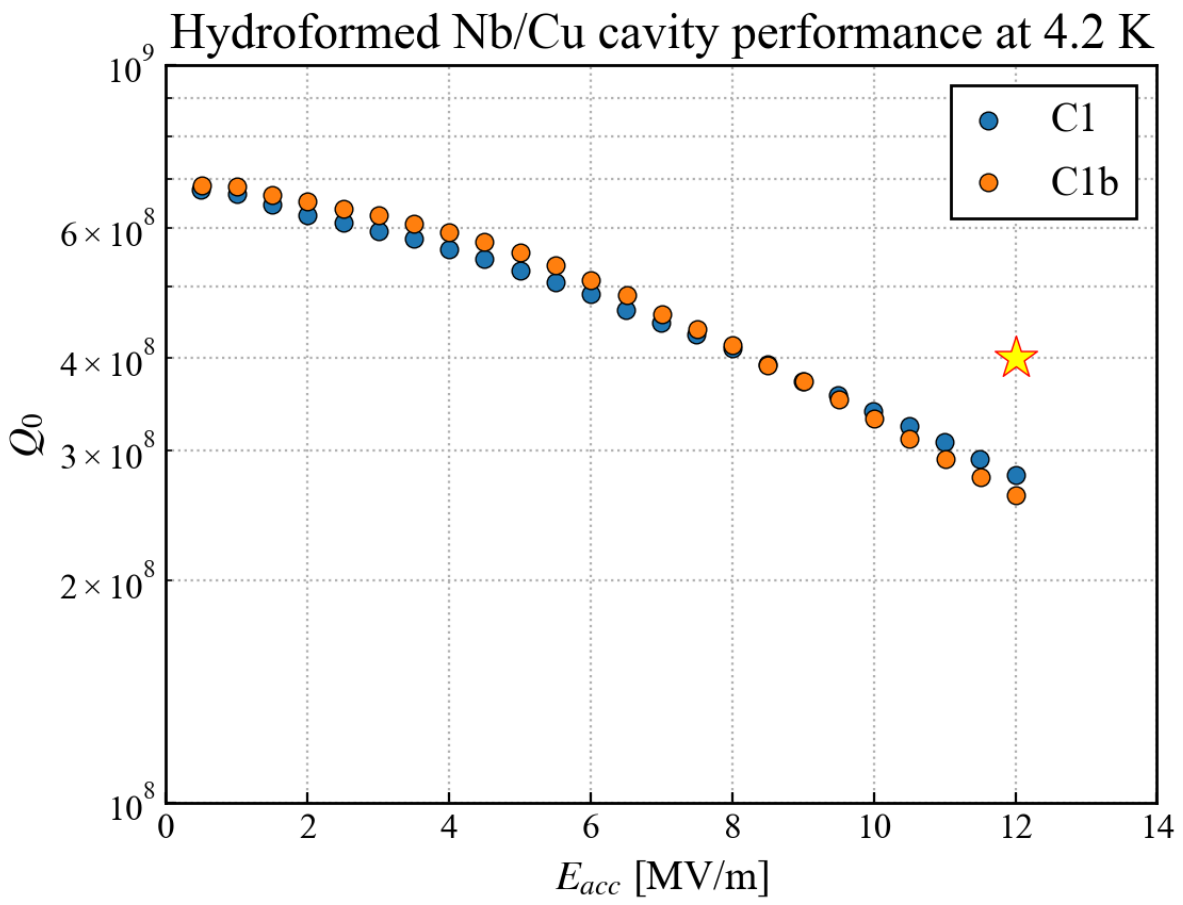
4.2 K Measurement

Target: Q > 4×10^{8} at 12 MV/m

Equivalent with Q > 3×10^{9} at 4.5 K, 400 MHz (FCC)

Result (at KEK, March 2024):

- Could not reach Q requirement
  - 2.6-2.8 ×10^{8} at 12 MV/m
- Stopped at 12 MV/m due to power limit
- No field emission
- No quench
- Good reproducibility between the two cavities

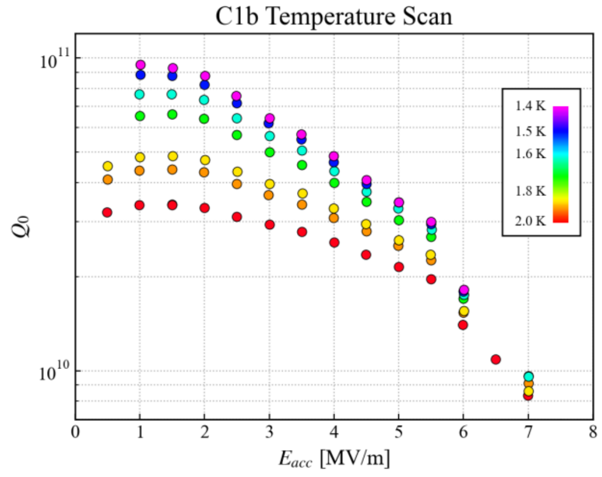


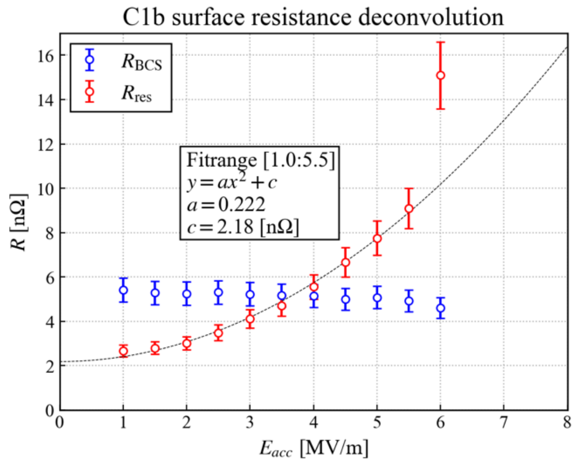
RF Measurement

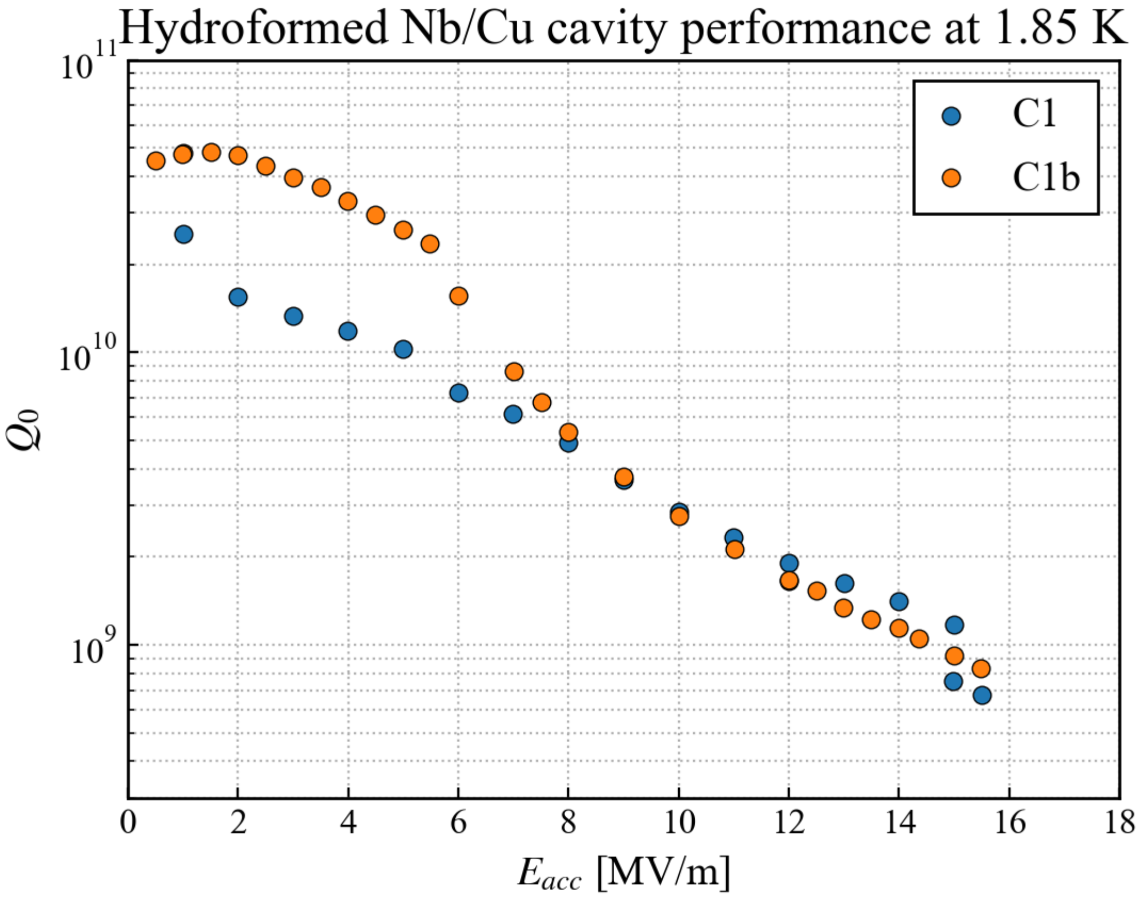
Below 2.0 K

- Max E_{acc}: 15.5/15.7 MV/m (C1/C1b, 1.85 K)
- Max Q: 9.5 ×10^{10} (C1b: 1.40 K, 1.0 MV/m)

- Quench field exceeded 12 MV/m without field emission
- High quality factor in low field
- Q slope was too steep in high field
  - There is still room for improvement in surface treatment.
- Minimizing temperature gradient on T_c is essential.







Summary

- An optimized manufacturing method has been achieved, for the cavity without seam by hydroforming
- We succeeded in manufacturing of a full seamless cavity by **hydroforming.** We thank the strong collaboration with NEURON (Japan) and CERN
- Niobium thin film was coated with HiPIMS at CERN
- RF performance was measured at KEK and confirmed to be close to FCC requirement

Acknowledgements

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NEURON

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