Hydroforming Elliptical SRF Cavities: Studies on 1.3 GHz and Beyond

On behalf of FCC SRF Cavity Fabrication WP

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Context

The Hydroforming process

Hydroforming @ CERN Workshop. Our Aim for the present and future:

- **Reclaim CERN know-how** on the process, for future applications
- Potential provider of **Cu substrates** for ongoing coating studies and beyond

An established acquaintance in the SRF world

- Established industry practice. No direct technology breakthroughs in the last years

Why this resurgence of interest?

- **Enhanced capabilities all around**: manufacturing control, characterization, and acquisition
- Embedding novel **numerical simulations** for process modelling
Content

• Introduction on Hydroforming for SRF Elliptical Cavities
  • Advantages and Challenges

• R&D Campaign (simulations, tests)
  • T- and X-Bulged Tube (KEK Collaboration)
  • Elliptical Monocell Cavities: 400 MHz to 1.3 GHz
Hydroforming for SRF Elliptical Cavities

Main advantages
• Reduce number of welds (equator)
• Low cost and lead time for series

Initial Tube → Necking → Anneal → Hydroform → Anneal
Hydroforming for SRF: Challenges

- Raw material: seamless tube availability, 
  reliability (dimensional tolerances, surface conditions)

- Reliability of process
Hydroforming for SRF: Challenges

- Raw material: seamless tube availability, reliability (dimensional tolerances, surface conditions)
- Reliable suppliers for seamless OFE Tubes
- Over-thickness + Turning

- Reliability of process
- Suppliers with state of art know-how on process and its control

Initial fixed costs. Containment through:
- Going to industry for main processes
- Numerical Simulations, to optimize overall fabrication strategy…. Minimize straining of material, less fabrication steps, less thermal treatments
Shaping Process Optimization: FEM

- F.E. simulations and numerical optimization tools
- Taking trials out of the workshop
- Reducing process cycles to final cavity

Sheet Metal Forming Simulations: Why? What?

**MODEL**
- Take the initial trials out of the workshop into simulations
- Model the tools without producing them
- Compare different manufacturing choices & steer strategy

**PREDICT**
- forming defects
- highly stressed regions
- final thickness distribution
- ...

**OPTIMIZE**
- Process parameters
- tool design
- Costs
- ...

LS-opt standalone design optimization and probabilistic analysis package with an interface to LS-DYNA

REF: J. Swieszek SRF Workshop @CERN 2019
Sims VS. Reality : T-Bulged Tube

A benchmark for our simulations (hydroforming, CU OFE,..)

1) Hydroform

2) Measure :
   • Deformed 3D Shape & surface mesh
   • Thickness, Roughness

3) Simulate & Compare

Collaboration with KEK
A. Yamamoto, M. Yamanaka

Effective Plastic Strain
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Highly Accurate Results

Comparing **thickness** at various notable positions

**Average error ~ 4%**

Azimuthal strain values: Allows easy comparison for ‘coincident’ mesh elements between test piece & simulation

**Average error ~ 3%**
Highly Accurate Results

Comparing thickness at various notable positions

Average error ~ 4%

What’s Next?

X-Bulge fabrication test
To be compared with further advanced simulations

Azimuthal strain values:
Allows easy comparison for ‘coincident’ mesh elements between test piece & simulation

Average error ~ 3%
SRF Hydroforming: a Failure Model

- **Simulation performance**
- **Material Model**

- **Failure Model**: maximum strain criteria (Distortion Energy, Forming Limit Diagram)

Many thanks to J-F Croteau (EASITrain)!
New simulation & experimental campaign @ CERN
Uniaxial & Plane stress tests → different criteria for max allowable strain
SRF Hydroforming: Experimental FLD

New simulation & experimental campaign @ CERN
Uniaxial & Plane stress tests → different criteria for max allowable strain

Why?
• Focusing on thicknesses nearer to hydroformed tubes
• Qualify new design for FLD-testing, compatible with CERN test infrastructure
• Other failure aspects…
Other failure aspects…SRF$^{2}$LD!

**Specific SRF Failure criteria** being checked:

- Onset of critical thinning
- Roughness and general surface degradation
- Presence of surface microcracks, shallow voids

Further failure modes to be checked

- Presence of surface pollutants (organic, metal)
- Hydrogen content, inclusions, sub-damaged layer

Many thanks to W. Venturini, G. Rosaz, L. Marques Antunes Ferreira
Content

- Introduction
  - Hydroforming for SRF Elliptical Cavities
  - Challenges: to Hydroform or not to?

- R&D Campaign (simulations, tests)
  - T-Bulged Tube
  - Elliptical Monocell Cavities: 400 MHz to 1.3 GHz
1.3 GHz Cavity Monocell

**Process strategy definition by CERN.** Baseline:
- Necking of straight tube
- Hydroforming to final geometry in just one step
- Die displacement and internal pressure:
  - Specific values, applied simultaneously
- No Intermediate Annealing
1.3 GHz : Test Campaign Status

- **Material @ CERN**
  - Properties check on material batch: ongoing
  - Remachining to size

- **P.O. Launched**
  - Discussion ongoing on details of test campaign
  - Spinning tools being designed

- **Dream Scenario: Annealing not needed**

- Fabrication process parameters defined (& feasible)
- Supplier identification ongoing
600 MHz Cavity Monocell: Process Sims

- **Hydroforming ONLY**
- From tube to final geometry in two steps
- Intermediate annealing

- Initial **tube, standard** from industry:
  - OD 216.6 mm, thck. 4.3 mm
  - L ~ 500 mm

*Many thanks F. Peauger*

**Thinning ~ 33%**
400 MHz Cavity Monocell: Process Sims

- Hydroforming ONLY
- From tube to final geometry in two steps
- Intermediate annealing
- Initial tube, standard from industry:
  - OD 311 mm, thck. 5.5 mm
  - L ~ 600mm
  - LIMIT!

\[ \text{Thinning} \sim 50\% \]
Conclusions

Enhanced capabilities all around hydroforming. Most of past challenges can be tackled through:

- State of art process simulations
- Industrial partners

Numerical simulations for hydroforming:
- Building on established previous knowledge
- Validated on T-bulge

1.3GHz / 600MHz / 400MHz Cavities:
- Our target: from tube to cavity in two steps
- Always aiming at the industrially feasible

Ongoing activities:
- X-Bulge fabrication trial to be compared with further advanced simulation
- Bespoke material failure for SRF ("SRF2LD")
- 1.3 GHz trials launched
Thanks for your Attention!