Deformable RF Fingers with Axial Extension

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Outline

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  - Concept
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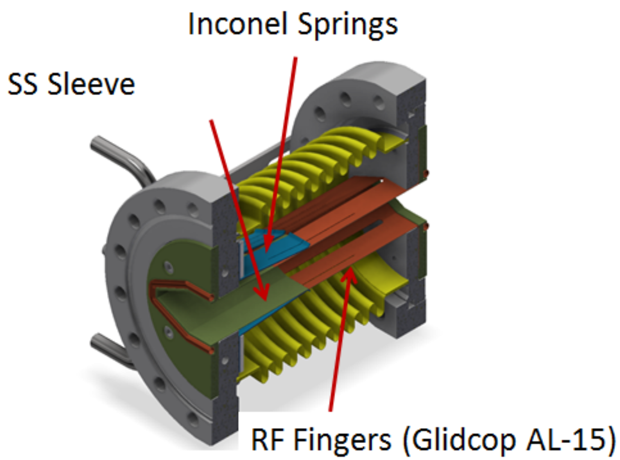
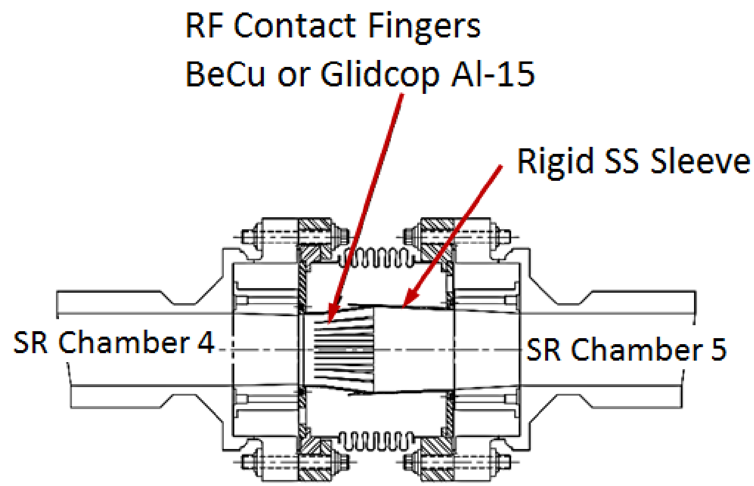
Conventional Design of RF Shielded Bellows



NSLS-II Bellows Assembly

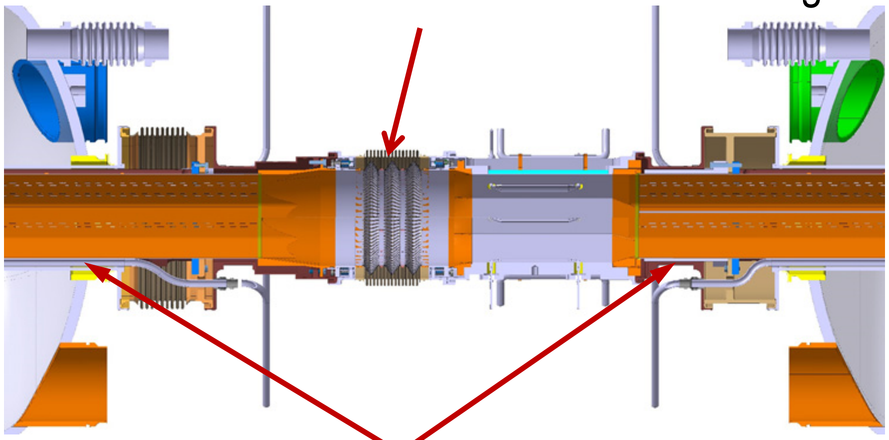


APS Bellows Assembly

- RF fingers in bellows maintain electrical continuity and keep a smooth beam aperture while compensating for misalignments, axial gap and thermal expansion.
- In most of the designs the RF fingers slide on the outer surface of a SS sleeve and are compressed by additional springs for better electrical and thermal contacts.
- An inside-sliding RF finger design has been used successfully at APS.

Deformable RF Fingers for LHC

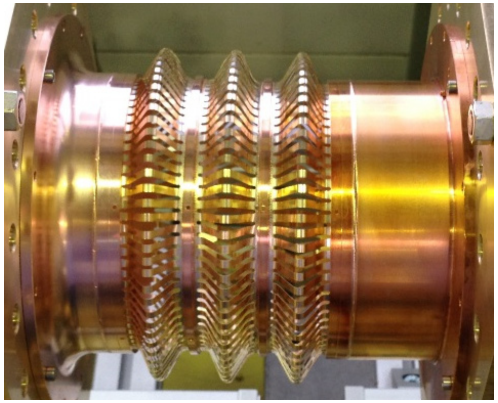
Bellows Interconnection with Deformable Fingers



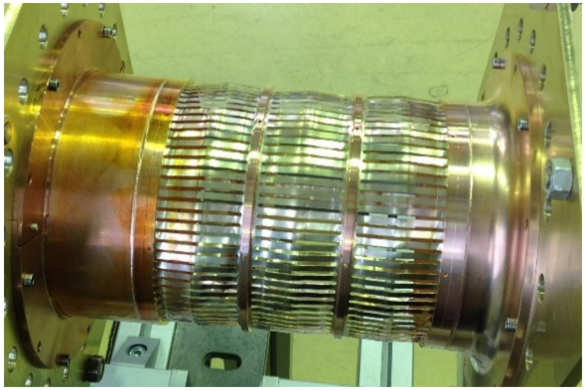
LHC Standard Vacuum Modules

- BeCu (C17410) Fingers
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- Circular aperture (ϕ 63.1 mm)
- The design is optimized to prevent buckling (local and column) and over-extension
- Large extension (12.3 mm) per convolution.

The fingers are not fully extended in operation.



RF Fingers as Installed



RF Fingers in Operation

C. Garion, "Design and Tests of the Shielded Beam Screen", HL-LHC Annual Meeting, Madrid, Spain (2017)
https://indico.cern.ch/event/.../HL_LHC_AnnMeeting_17_beam_screen_CG.pptx

Proposed Design

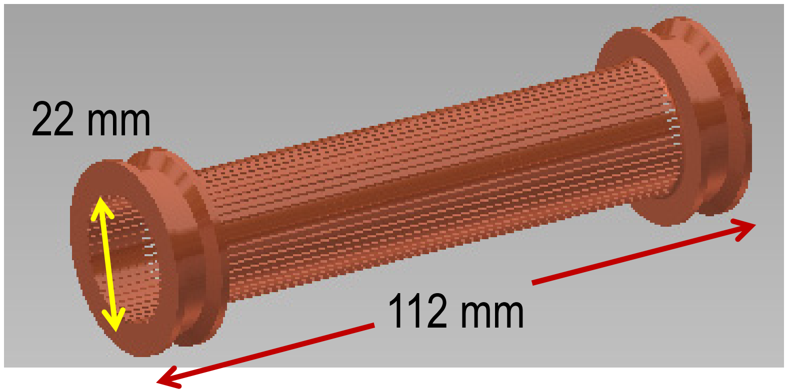
The proposed design is based on:

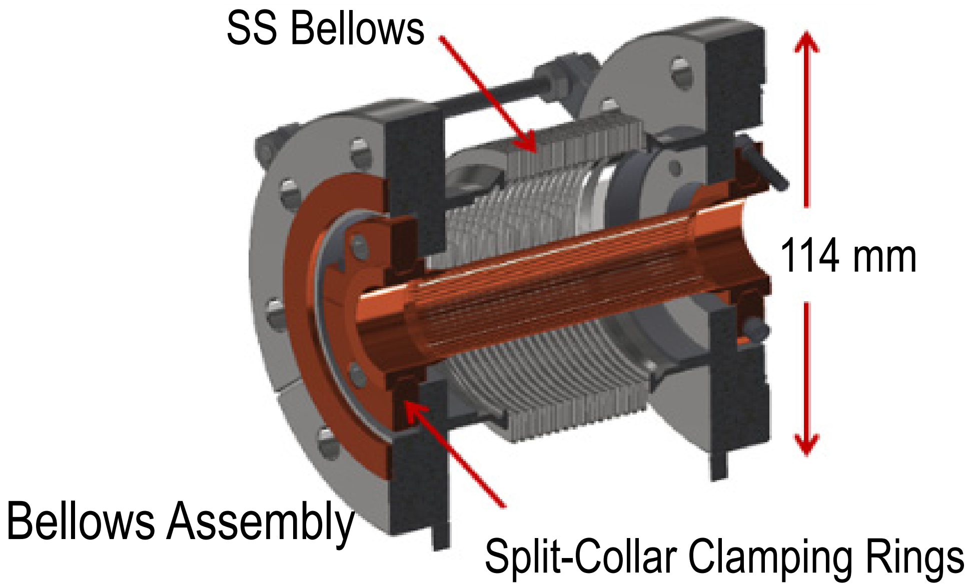
- RF fingers are made as a straight finger spool with radial cuts
- Axial gap: axial extension of up to 2 mm
- Bake-out compression: Large nonlinear deformations including buckling

Design Requirements:

- Bellows insertion length < 120 mm
- Misalignment: 2 mm transverse; axial gap: 2 mm
- Number of fatigue cycles to failure: > 30 (1 bake-out per year)
- No significant change (steps) in the beam aperture
- Compression during bakeout: 10 mm

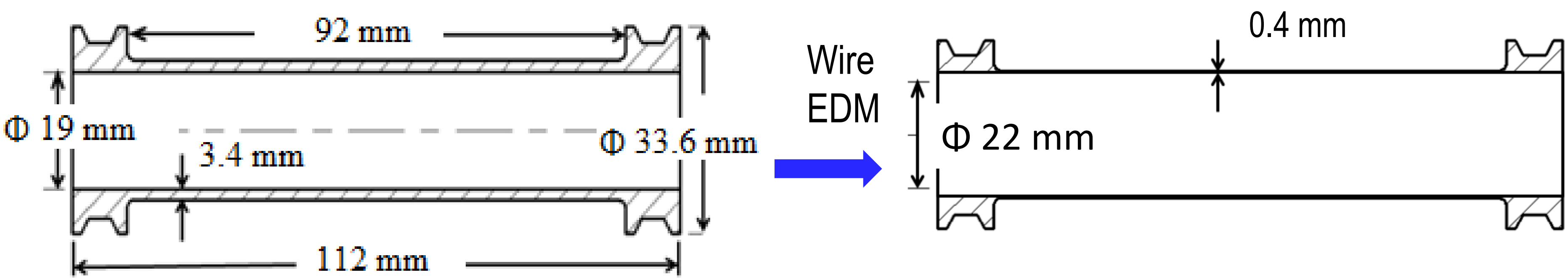
Proposed Design – Contd.





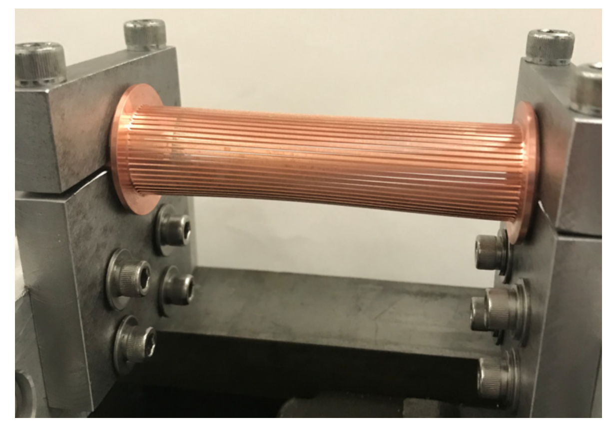
- RF finger spool is a single- piece construction.
- Material: CuCrZr or Glidcop AL-15 (higher thermal and electrical conductivities)
- Inside aperture, 22 mm, is continuous (without steps).
- Attached to the flanges with Cu-alloy split-collar clamping rings. (CuCrZr spool can be welded directly to SS flanges.)

Fabrication



Spool Piece

- A spool piece is first made with dimensions as shown. The wall thickness at the center is 3 mm greater than the fingers' thickness (0.4 mm).
- Wire EDM removes the extra 3 mm material in the first step.
- Wire EDM in the second step creates 50 RF fingers of approximately 1.25 mm width by making 0.4 mm radial cuts every 7.2°.



RF Finger Spool in a Test Fixture

Mechanical Properties – CuCrZr

Shape	Thickness / Diameter (mm)	Temper	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)
Sheet	0.3-10	A*	440	390	10
Rod	50-120	Extruded and Drawn	465	410	18
Rect. And Sq. Bars		Extruded and Drawn	370-470	270-440	8-18
Round Bar R200			Min 200	60	Min 30
		B*	318	200	30

A: Solution heat treated , artificially aged.*
B Prime Aged +600 ºC for 1 hour*

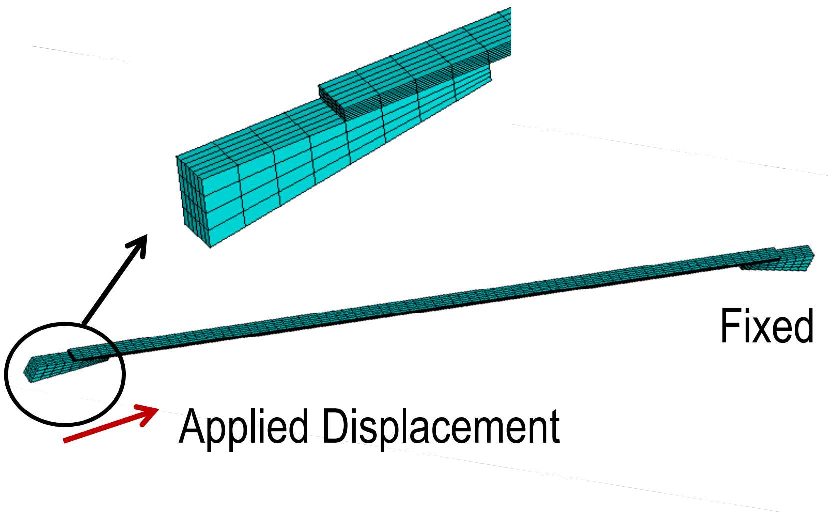
http://conductivity-app.org/alloy-sheet/19

Mechanical Properties – Glidcop AL-15

Shape	Thickness/ Diameter (mm)	Temper	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)
Flat	0.15	CW 98%	661	613	6
Plate	> 25 Up to 130	As Const.	365	255	26
Rounds	Up to 760	As Const.	365	255	26

https://www.hoganas.com/globalassets/media/sharepoint-documents/BrochuresanddatasheetsAllDocuments/GLIDCOP_AL15.pdf

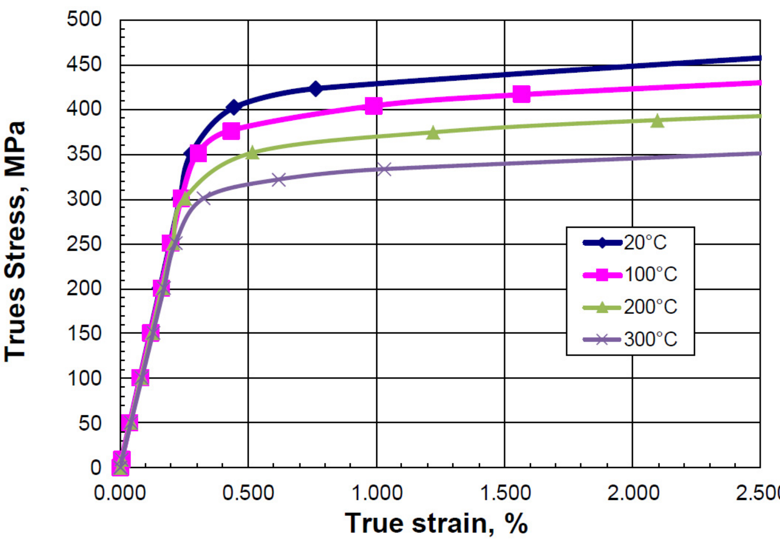
FE Analysis



Yield Strength = 350 MPa
Tangent Modulus = 1,300 MPa

E = 125,500 MPa

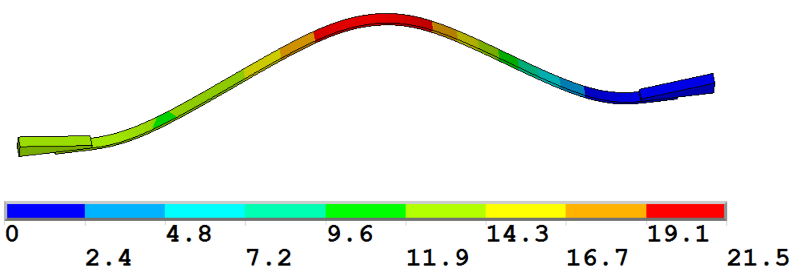
ITER Material Property Handbook Documentation, 2232 HM, "Cu-Cr-Zr – Engineering and True Stress-Strain Curves, Page 11



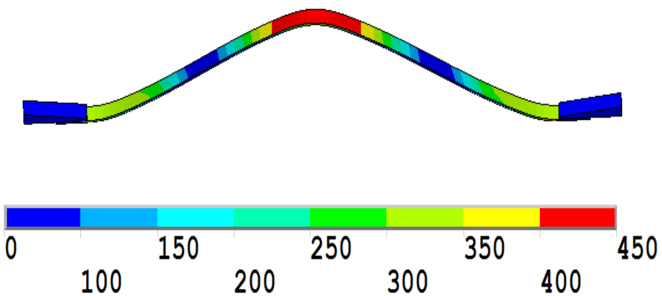
ANSYS FE model includes:

- Large deformation
- Bilinear plasticity with kinematic hardening
- Stress stiffening

FE Results



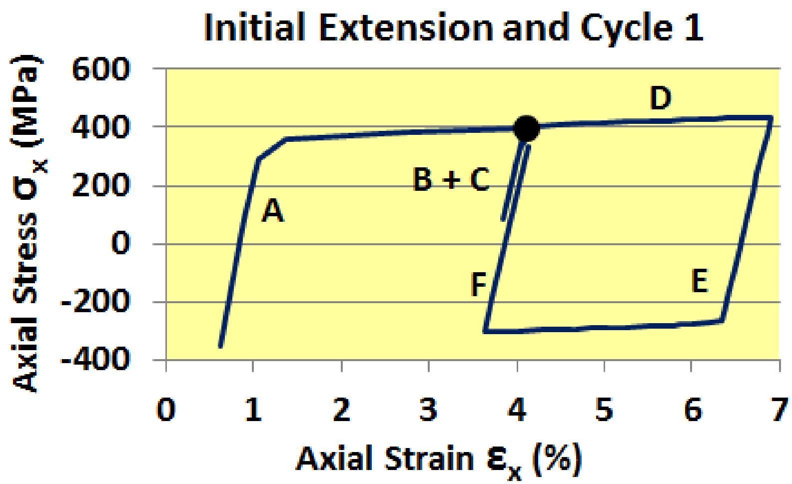
Vertical Displacement, Uy (mm), Contours

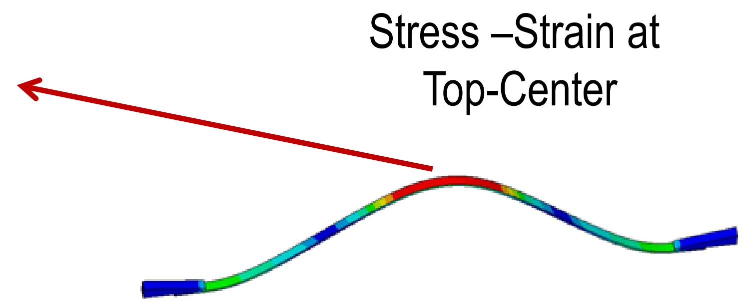


Equivalent Stress (MPa) Contours

- For an initial preset cycle, a small transverse pressure (0.03 MPa) is applied to select buckling direction, then a compression cycle of 6 mm.
  → Residual stresses dictate buckling direction.
- Transverse misalignment of 3 mm, axial extension of 3 mm.
- Two compression (bake-out) cycles 1 and 2 , applied compression of 15 mm.
- After second cycle → max. Uy = 21.5 mm, max stress = 450 Mpa.

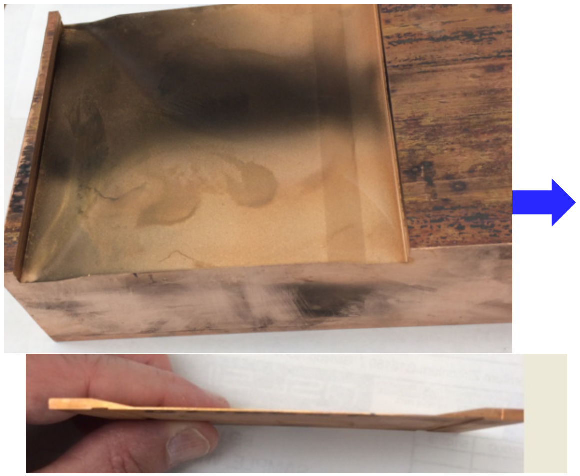
Cyclic Stress-Strain Response

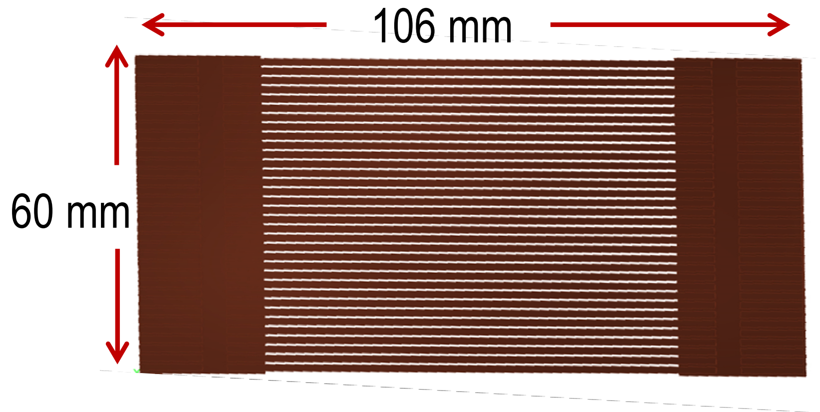




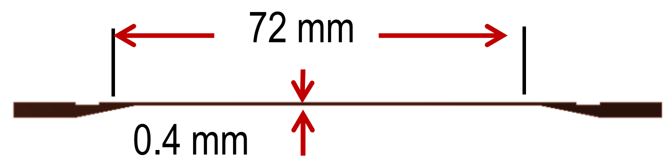
Load Excursion	Mode of Deformation
A	Elastic + large plastic deformation during initial extension of 3 mm. (cycling starts at position ●)
B + C	Buckling at the beginning of compression (starting at ●)
D	Additional plastic deformation during compression
E	Reversal of compression, elastic + large plastic deformation
F	Stress reversal , tensile stress at zero compression (at ●) which leads to straightening of the finger.

Cyclic Fatigue Test Samples





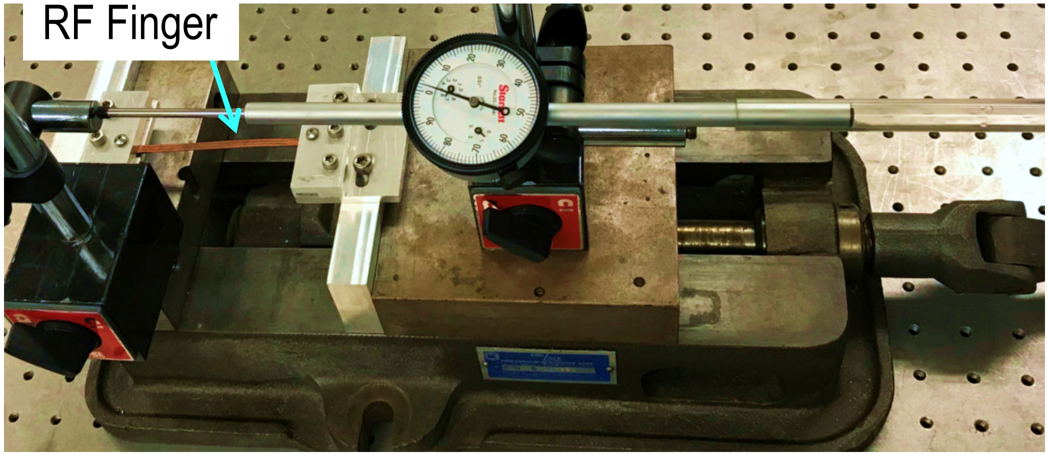
EDM of Fingers



Test Piece (3 fingers)

- The flat test samples are made in similar steps as the round finger spool.
- A thin flat piece is machined (EDM) from a larger stock with extra 3 mm of material in the middle.
- The extra material is removed and RF fingers are created by wire EDM.
- Test pieces with 3 fingers are cut from the larger sample.

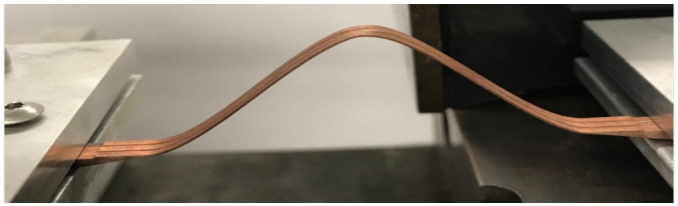
Test Set up



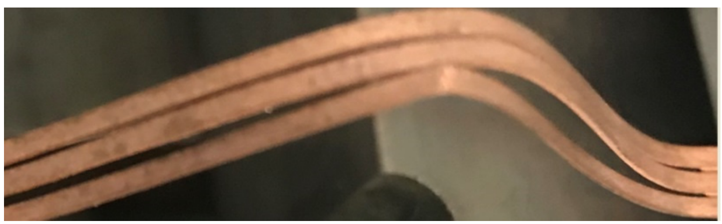
- The test samples were clamped in a precision vise with fixtures.
- Applied displacements and Uy were measured with Starrett dial indicators (resolution of 0.025 mm).
- All cyclic tests were performed with a transverse offset of 3 mm.
- For the initial preset cycle a slight pressure was applied to start buckling in the upward direction.

Cyclic Tests - Pictures

CuCrZr Sample



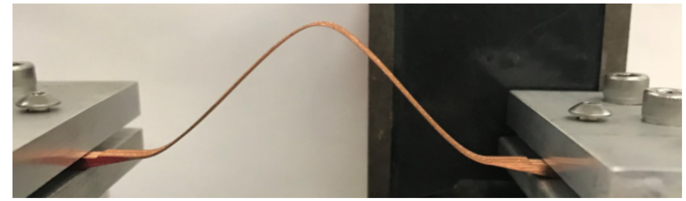
Cycle 80



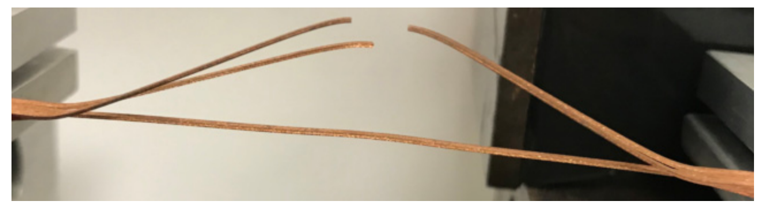
Cycle 129

Cycle 130

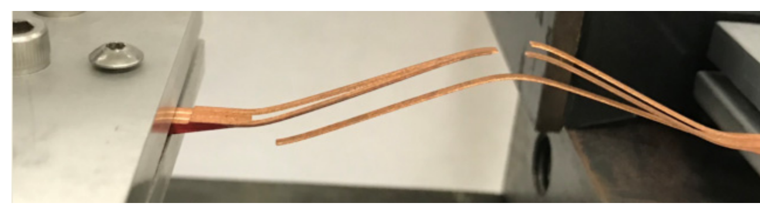
Glidcop Sample



Cycle 200



Cycle 288



Cycle 392

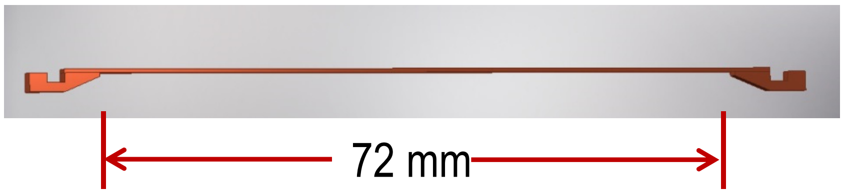
Cyclic Test Results

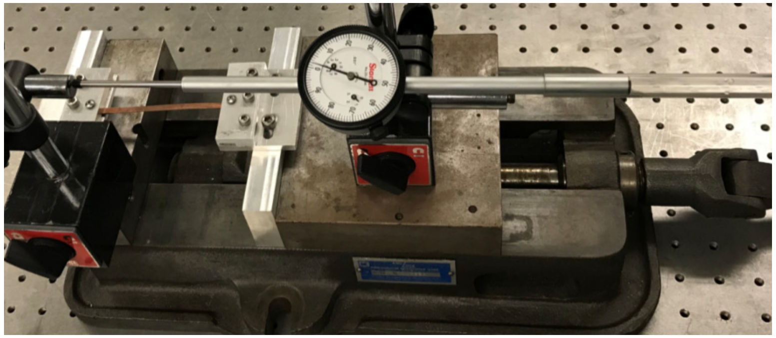
3 mm extension, 3 mm offset
15 mm compression

Cycles to Failure		
Finger / Sample	CuCrZr	Glidcop
Finger 1	130	268
Finger 2	199	288
Finger 3	222	392

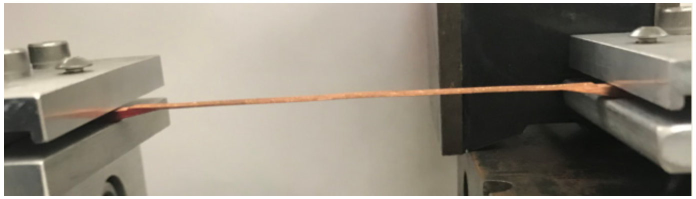
- The fatigue life of all fingers tested was substantially higher than 30 cycles.
- Glidcop AL-15 fingers have a better fatigue life than CuCrZr fingers. This is probably related to higher ductility of Glidcop AL-15 used for fingers.

Ductility of the CuCrZr and Glidcop AL-15 Samples





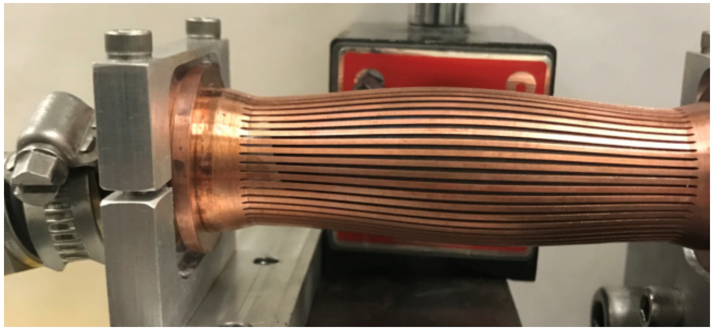
Test Setup



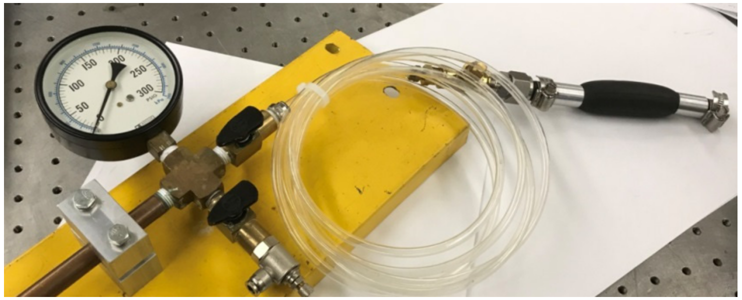
CuCrZr Extension = 5.46 mm → Elongation 7.6%
Glidcop Extension = 8.38 mm → Elongation 11.6 %

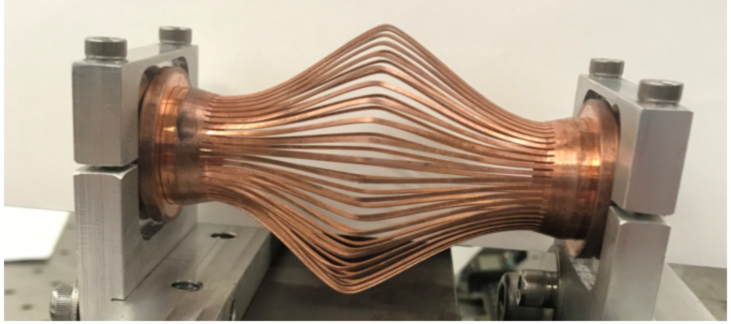
Our stock plates of CuCrZr and Glidcop AL-15 have low ductility values.

RF Finger Spool - CuCrZr



Setup with Inflatable Rubber Sleeve





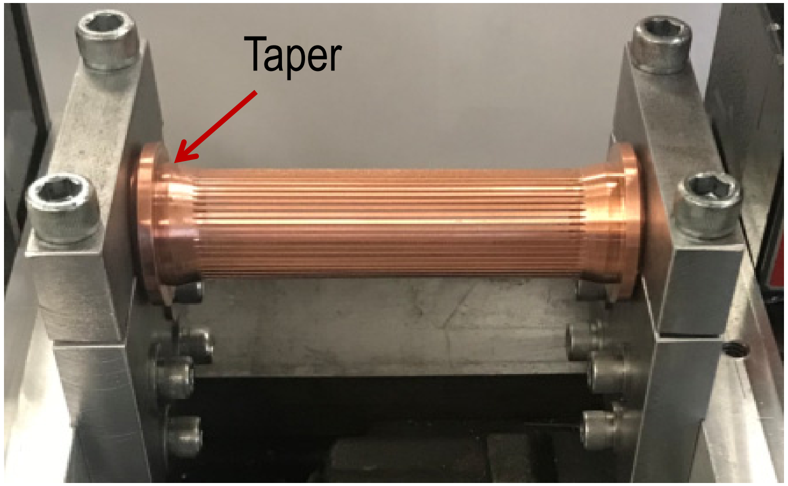
Preset Compression (12 mm)

Fixture Distortion

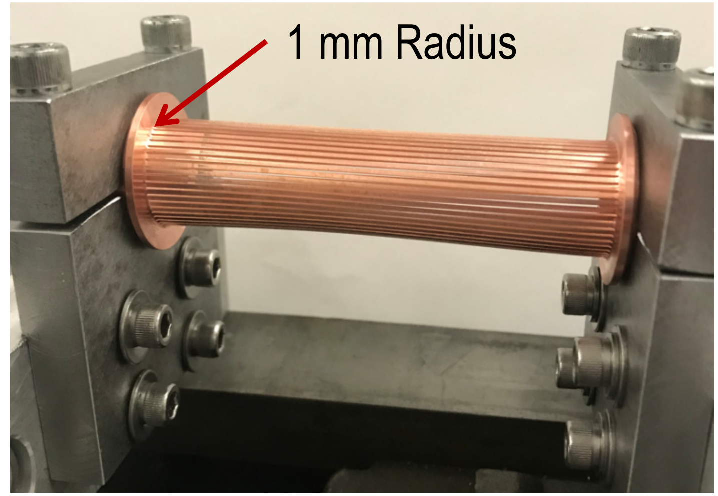
Setup Problems:

- The spool was over compressed for preset causing kinks in the middle.
- The weak Aluminum clamping fixtures distorted during 2 mm extension. This led to uneven stretching of the fingers.

RF Finger Spools - Glidcop



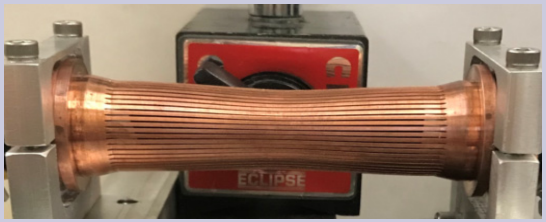
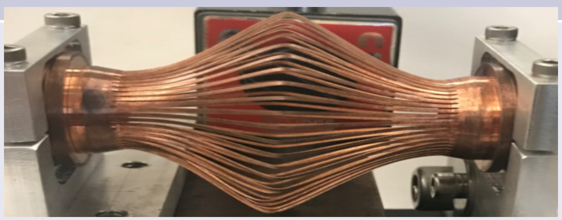
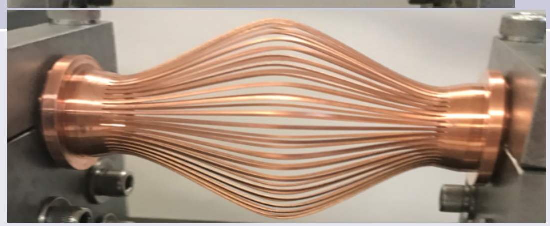
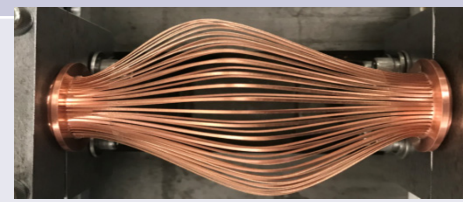
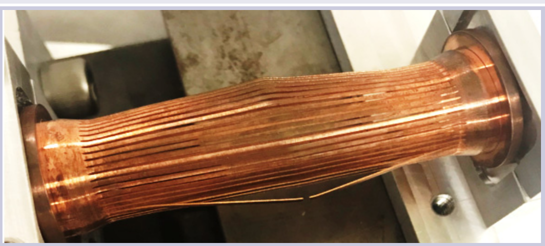
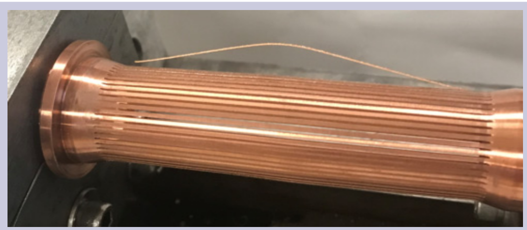
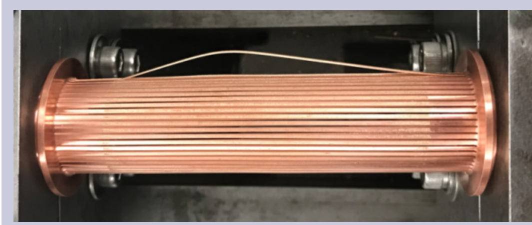
Glidcop Spool 1



Glidcop Spool 2

- Stronger clamping fixtures were used for the Glidcop RF Finger spools
- The initial compression for the preset cycle was lowered to 10 mm.
- In Glidcop Spool 2 the end tapers were removed to increase the lengths of the fingers from 72 mm to 90 mm

Cyclic Tests - Pictures

CuCrZr Spool	Glidcop Spool 1	Glidcop Spool 2
		
		
		

- All spools had 2 mm extension and 2 mm offset.
- The spools were cycled at different levels of compression.

Cyclic Test Results

CuCrZr Spool		Glidcop Spool 1		Glidcop Spool 2	
Compression(mm)	Cycles	Compression (mm)	Cycles	Compression (mm)	Cycles
10	30	10	132**	10	50
12	8*			12	60
				14	27**

* Failure at the middle of the finger.
** Failure at the ends of the fingers

Summary and Conclusions

- A new design of deformable RF fingers with fixed ends has been developed and tested.
- The design is based on large nonlinear deformation (including compressive buckling) of the fingers.
- The fingers can accommodate 2 mm of axial extension and 2 mm of transverse misalignment.
- The fingers provide for a smooth beam aperture without steps.
- The single piece design of the RF finger spool is easy to manufacture from CuCrZr or Glidcop AL-15.
- Glidcop fingers appear to have a better fatigue life than CuCrZr fingers.

Thank you
for your attention.