research instruments

Remarks on the industrial production of FPC

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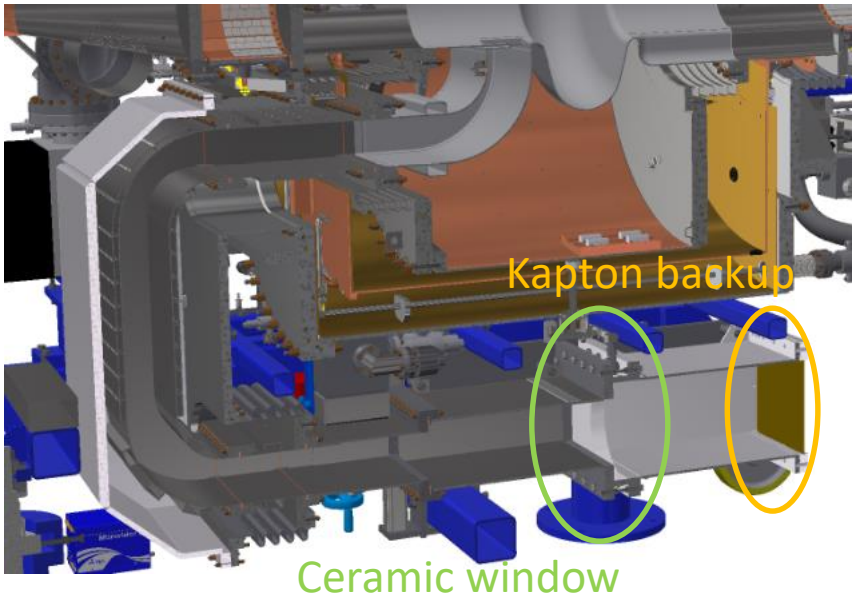
Content

- A short overview of FPC production at RI
- Critical processes (“*head aches*”) from RI point of view with respect to *their specification*:
  - Mechanical tolerances
  - Copper plating on stainless steel
  - TiN coating
- Cost issues
- TTF-3 coupler – still a design for the future?

Waveguide couplers for CESR-B cryomodules

- Fixed Q_external (external adjustment possible)
- High CW power (up to 500 kW)
- Single disc window (by Thales) / Kapton backup
- UHV Waveguides (RI):
  - built from stainless steel/ copper plated
  - Rectangular CF flanges
  - Partly Helium- / LN2-cooled
- Cavity E-bend made from Niobium

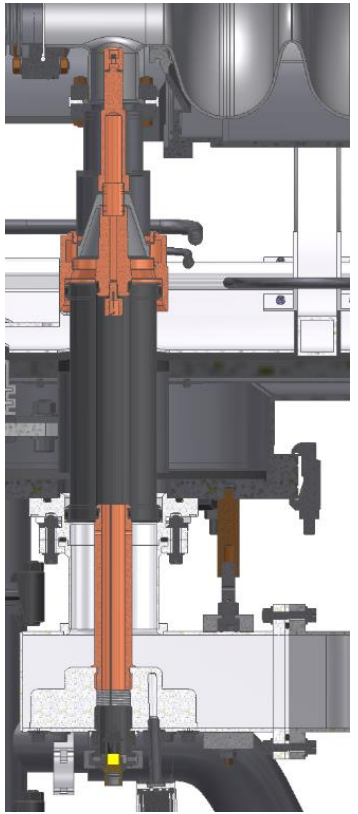


<u>Remarks:</u>

- Tolerances challenging (welded metal “boxes”)
- CF gaskets require special procedure
- Copper plating of curved „elbow“ (double E-bend) is challenging
- >15 cryomodules (RI) in operation worldwide

Coaxial ELBE style FPC

- Fixed Q_external (replaceable antenna tip)
- CW operation at medium power is possible
  - 20 kW in warm test stand proven
  - >3 kW in cryomodule (MESA) shown, more to come
- Conical ceramic window, LN2-cooled (o.c.)
- Coaxial part made from copper plated stainless steel
- “sliding” warm part with contact springs
- Modified “off the shelf” doorknob
- Waveguide quartz window (WR650), commercial product



Remarks:

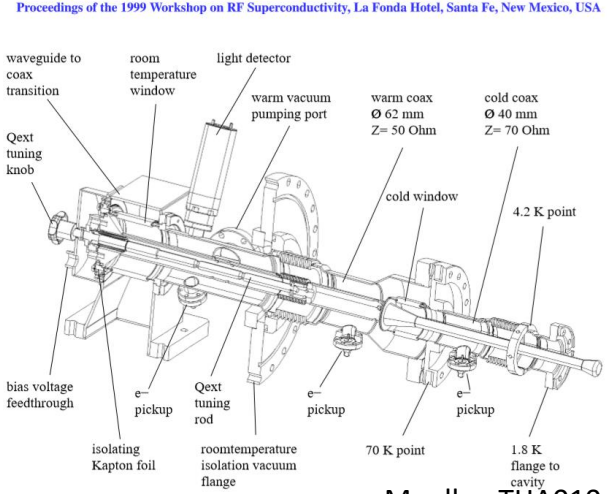
- Copper plating uncritical (all straight tubes)
- About 20 sets produced, 12 installed in CM (4GLS, TARLA, MESA)

TTF-3 and „family members“

TTF-3 (1990s)

Basic design of TTF-3 FPC.

(see Aune, Moeller, etc.)



Moeller, THA010

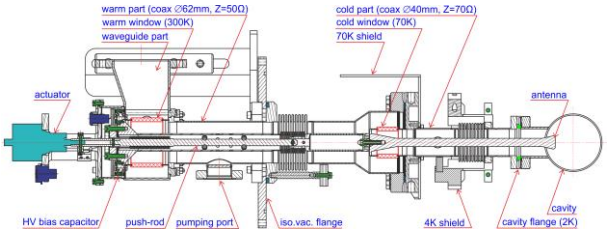
Ca. 60 units built by RI
(2000-2010).

EU-XFEL / LCLS-II

Design close to TTF-3,

Remote Q_{ext} adjustment.

LCLS-II: Increased copper plating thickness at WIC.



Kostin, TTC2020

E-XFEL: 670 units by RI/TH

LCLS-II: 150 units by RI/TH

cBETA / HZB Bessy-VSR

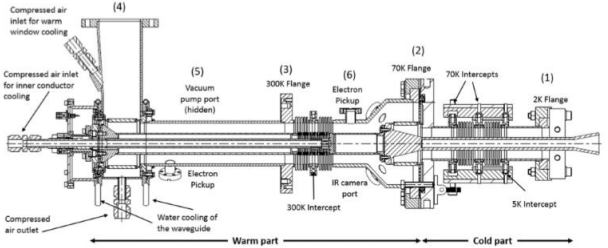
cBETA: (built by CPI)

Redesign of cold window for CW operation >50 kW.

Bessy-VSR:

Scaled for 1.5 GHz

Smaller cold part dia.



Sharples, TTC2020

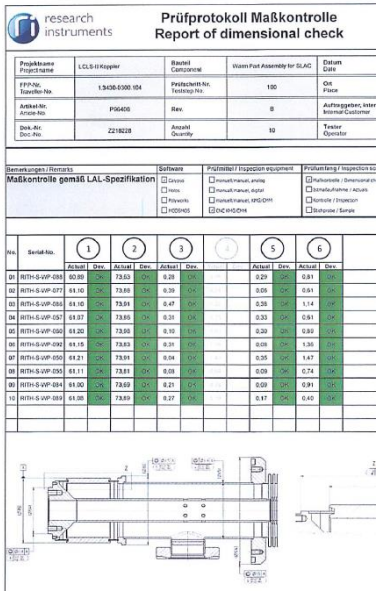
Contract awarded to RI/TH.

Headache 1: Mechanical tolerances

Specified tolerances seem to follow the “perfect world”, BUT:

FPCs are mainly built from sheet material, being formed, welded, brazed etc.

→ Shrinkage and Deformation have to be expected!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Prüfprotokoll Maßkontrolle
Report of dimensional check

Maßkontrolle gemäß LAL-Spezifikation

Tooling and procedures can be adjusted, but this requires:

- R&D effort and prototypes (= money)
- Preparation time (schedule!)

The tighter your tolerances, the more of both is needed to meet your specification!

Remember: R&D effort is almost independent of the amount of FPCs!

My personal opinion: Some tolerances seem to be overshooting

→ The coaxial system is matched, but remains „unperfect“ by it‘s design, so why shoot for perfect Z in the straight parts?

→ Remember, this is still a welded, brazed and baked „steel can“ ;-)

Headache #2: Copper plating (1)

Copper plating on stainles steel is a basic requirement for FPC in SRF applications.

- Skin depth of few µm (500 – 3900 MHz) does require only small thickness
- Additional thickness can be required for thermal reasons.

Location / Project	EU-XFEL	LCLS-II
Tube	10 / 30 (+/-20%)	10 +/- 5 µm 150 +/- 30 µm
Bellow	10 / 30 (+/-30%)	

Tolerances of plating often seems “randomly” picked…

→ Minimum Thickness: Required for good RF properties

→ Maximum Thickness: Limit heat transfer to cryogenics in static losses!

Why then “symmetrical” tolerances? Why not 10 (-4/+10) µm?

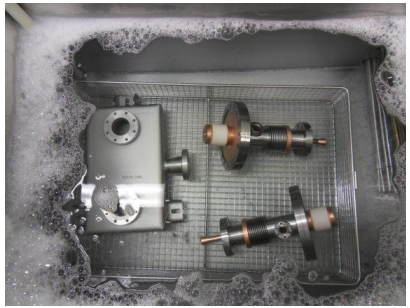
For CW machines: static losses are neglectable compared to dynamic losses!

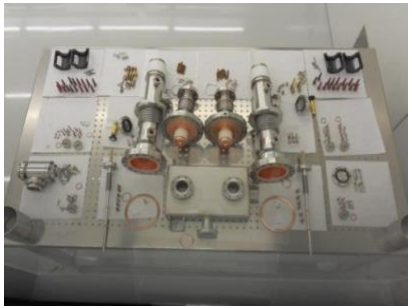
Don’t tighten down the thickness if not needed!

Headache #2: Copper plating (2)

Cleaning and assembly of the FPC in the cleanroom are well established procedures.

However, the power of the US-degreasing bath has to be matched to the copper plating thickness and quality.
We experienced slight delamination/stains with the first batches.



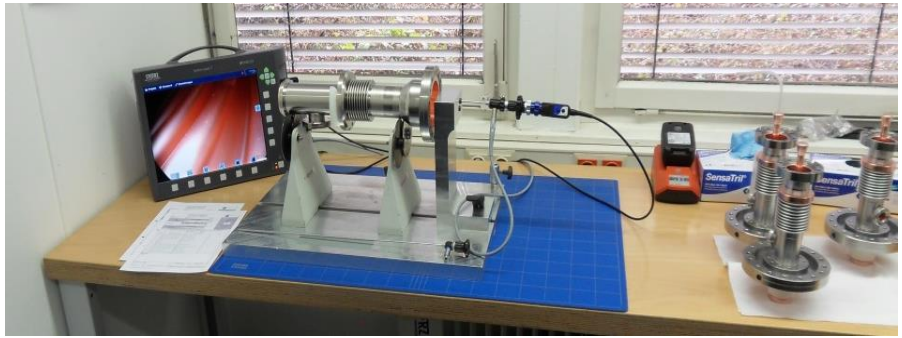


RI FPC cleanroom with cleaning facilities and furnace

Headache #2: Copper plating (3)

Proper control of the plating thickness and uniformity can only be done by destructive testing, thus not during serial production.

Be aware that visual inspection and samples are the only way for process control!



Visual inspection of the copper plating at RI

Finally: RI/TH and the customer always found a common solution, but with large effort!

Please get in contact during the design phase to check what is achievable!

Headache #3: TiN coating

TiN coating is required to reduce the secondary electron emission.

- The TiN coating is specified (XFEL: 10 (+20/-5)nm), but
  - How to measure nm in a serial production? Impossible!
  - Control of the uniformity cannot be done!

→ Only parameters of the coating process can be recorded.

→ Visual inspection & surface resistance measurement can only serve as indications!

→ Some uncertainty remains…please be aware of that!

Remember: Other shapes / sizes do require early stage R&D!

TiN coating facility at RI

TTF-3 Coupler …outdated?

- …was developed in the 1990s.
- …was designed for pulsed operation (high peak power, low average power).

- Today many machines (EU-XFEL upgrade, LCLS-II, cBETA, Bessy-VSR, etc) go for CW (medium average power) but still use FPC from the TTF-3 family?

- Mircea Stirbet (JLAB): "…this is a complex coupler, I wished it was simpler. "

- **Maybe it is time for the TTC to think of a new generation of "standard FPC"!?**
- **There were many inspirations shown in the first sessions of WG2!**

Cost issues

The TTF-3 coupler is a complex structure, it includes:

- Stainless steel components with copper plating
- Copper components
- Ceramics with metallization and TiN coating
- Brazing of metal, ceramics and both
- EB welding
- Cleaning and cleanroom assembly

We think that the price, that was established for large scale series (EU-XFEL) are well developed and respond to the value of the FPC within the cryomodule.

From our point of view, lower prices are possible, but only for higher numbers and relaxed specifications!

Acknowledgements

Special thanks to

- WG2 conveners for inviting us to share our experiences with the TTC community and to raise provocative comments!
- Michael Knaak and Lucas Zweibaeumer (RI) for their input!
- Thales team for going the long way with us through all challenges in the past, present and future!

…. AND…

Thank you for your attention!

Provocative topics

For discussion

- Think about your specifications for:
  - Mechanical tolerances
  - Copper plating
  - TiN coating
- Contact vendors early during the design stage to check what can be realized (in serial production) and what needs R&D!

- Think about an updated FPC design for today‘s (CW) machines!