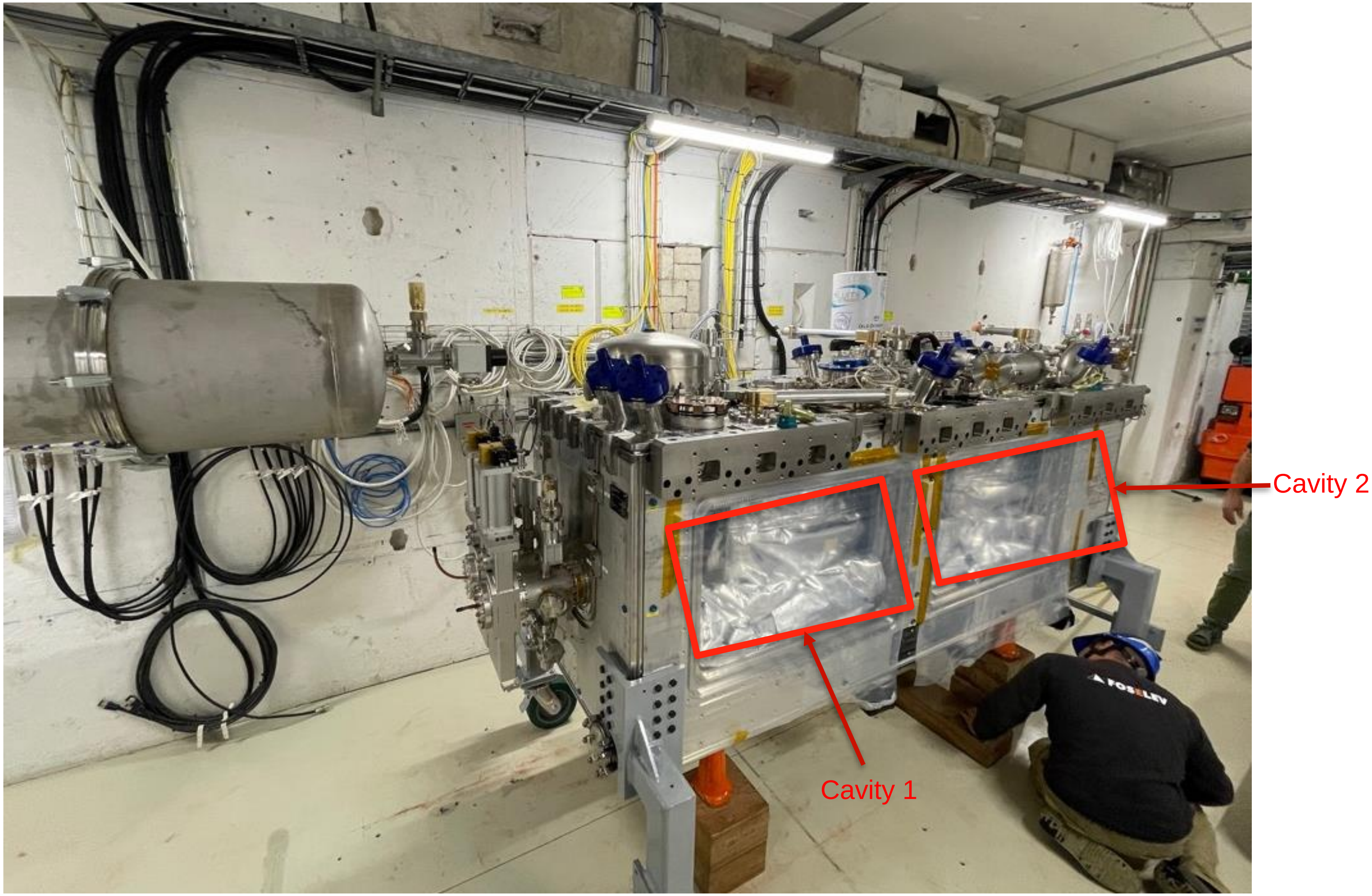
WP4-RFD/SPS– NCR and repair action for FPC 1 & FPC 2

18th of June 2024

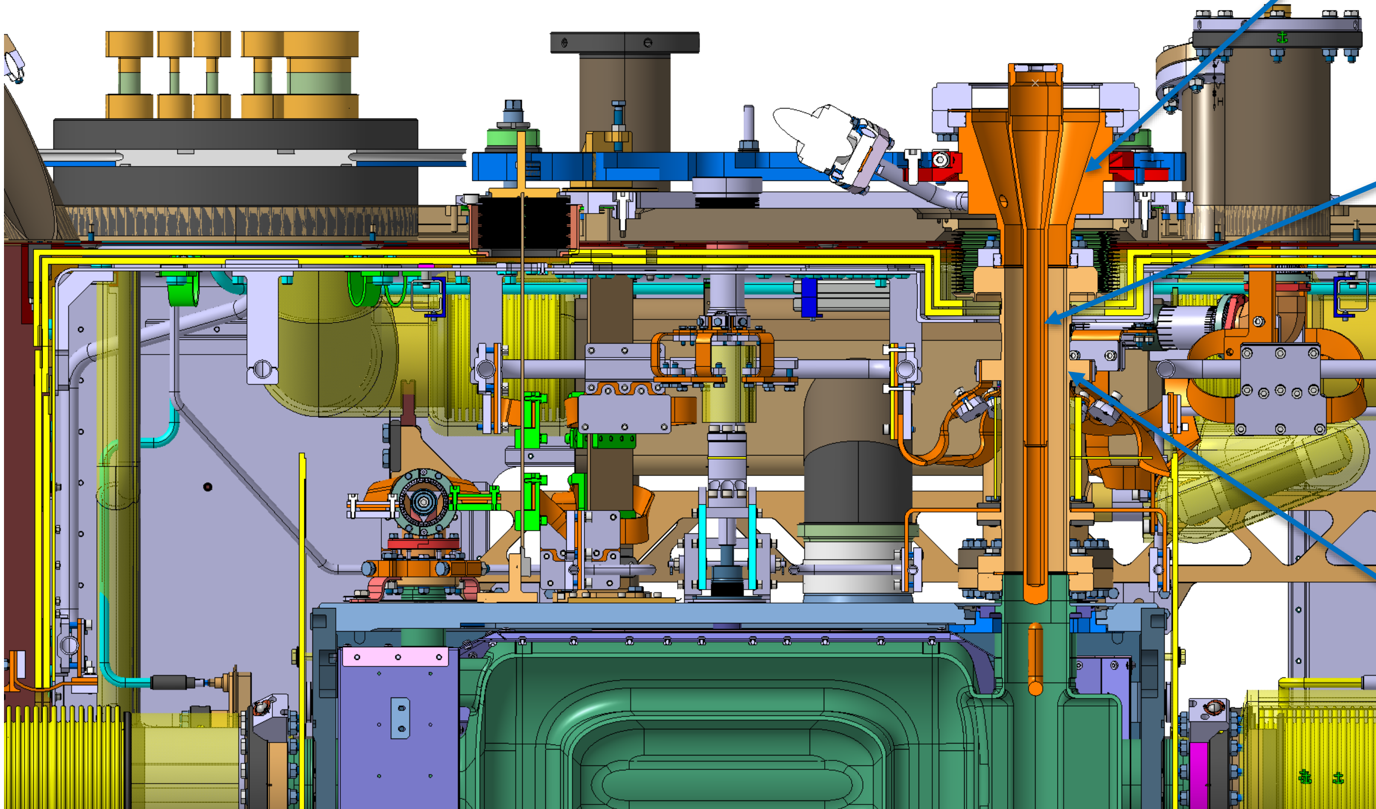
Teddy Capelli on behalf of engineering team with inputs from E.Montesinos, V.Rude, A.Porret, J.Swieszek, P.Minginette, S.Barrière, N.Valverde & K.Turaj

Cryomodule overview in SM18

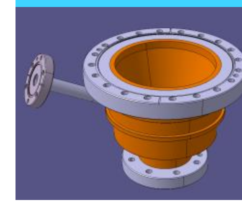


FPC cavity 1

- Non-conformity identified during SM18 tests : NCR: EDMS 2995980
  - Tilt of the FPC on Cav 1 – short circuit



FPC Body

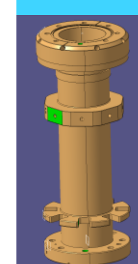


Dwg ref : LHCACFMC0001

FPC HOOK

Dwg ref : LHCACFMC0019

FPC Outer pipe



Dwg ref : LHCACFMC0163

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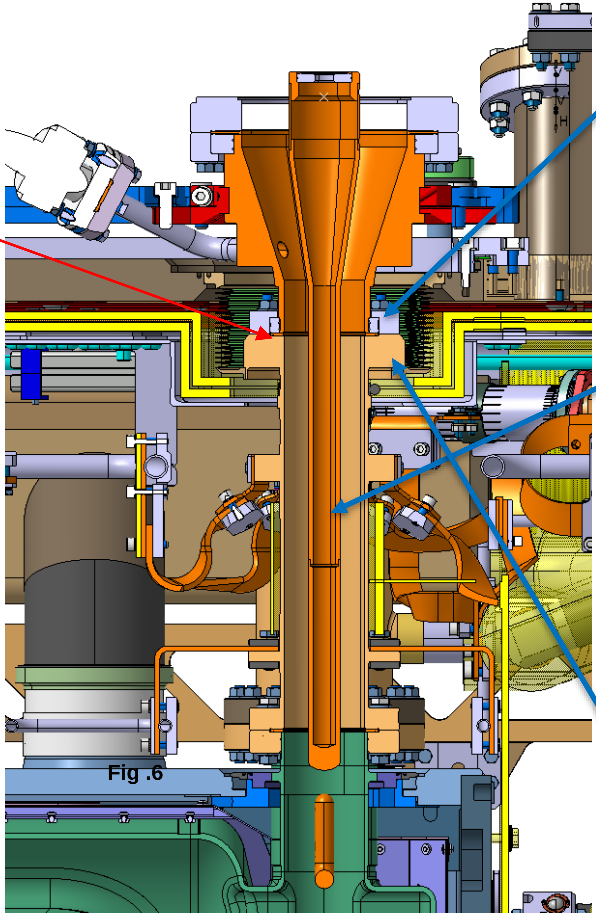
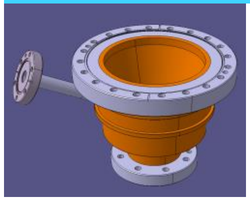
FPC cavity 2

- Non-conformity identified during SM18 tests : NCR: EDMS 2995891
  - Tilt & Vacuum leak on the FPC of Cav 2

Position of the leak



FPC Body

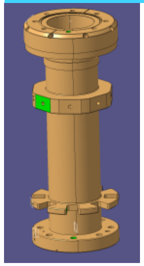


Dwg ref : LHCACFMC0001

FPC HOOK

Dwg ref : LHCACFMC0019

FPC Outer pipe

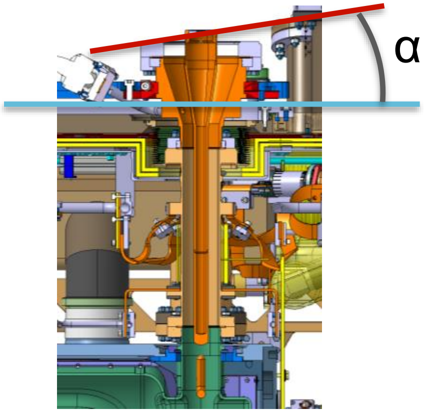


Dwg ref : LHCACFMC0163

First observations

- Preliminary RF checks perfomed by E.Montesinos and his team showed a problem on FPC of cavity #1
- A measure of electrical continuity between inner and outer conductor of the FPC showed a contact between the conductors
- Visually, the top flange FPC look tilted

WRT the surrounding elements



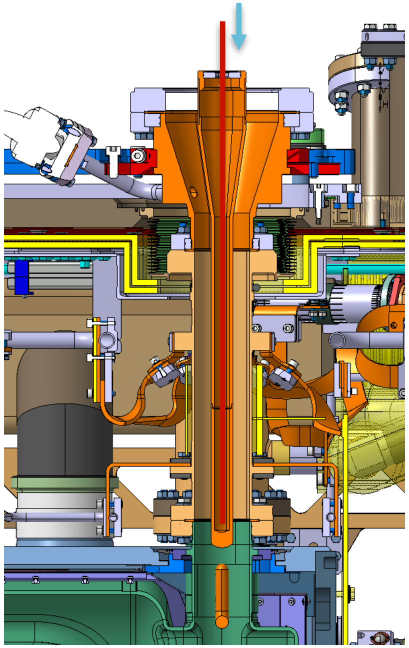
- A similar but smaller deformation is also visible on FPC cavity #2 but without electrical short and no undesired behaviour noticed during RF checks. This bending is very likely to have caused the vacuum leak.

Mechanical evaluation

- Both FPCs Cavity #1 and #2 are equipped with optical fibers **(see talk of M.Guinchard)**
- The optical fiber sensor installed on both FPCs show no significant strain, excluding a permanent deformation of the FPC outer pipe

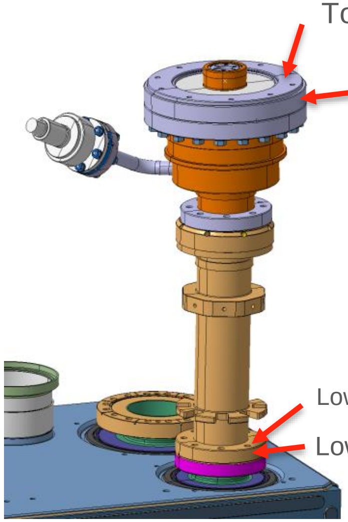
- A Ø15.5mm rod has been fitted inside the cooling channel of the hook to exclude a large bending of the hook

(*a large deformation of the hook would have prevented us from fitting this rod*)



FSI Measures – V.Rude

- A measure of both the top FPC flange and the lower FPC outer pipe flange (Plane + axis for both) show a deviation as described on the sketches bellow :



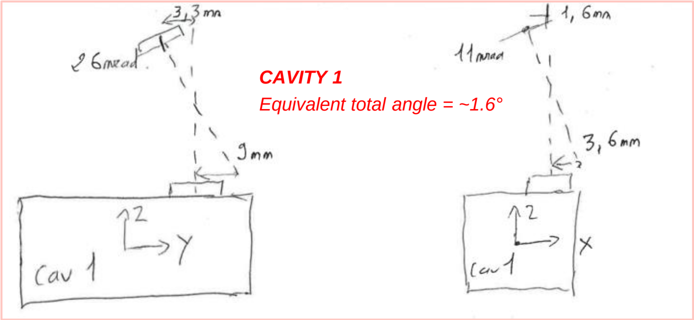


Fig .5 *Measured using laser tracker – V.Rude*

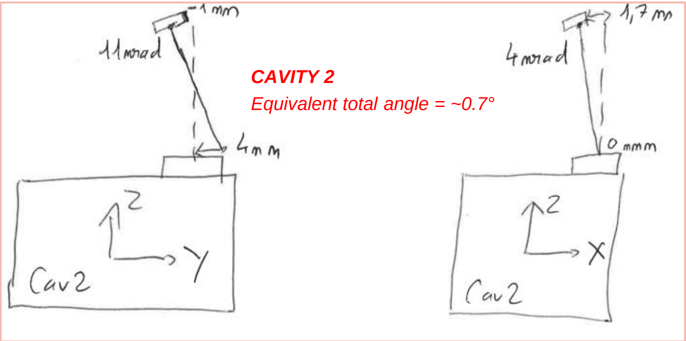
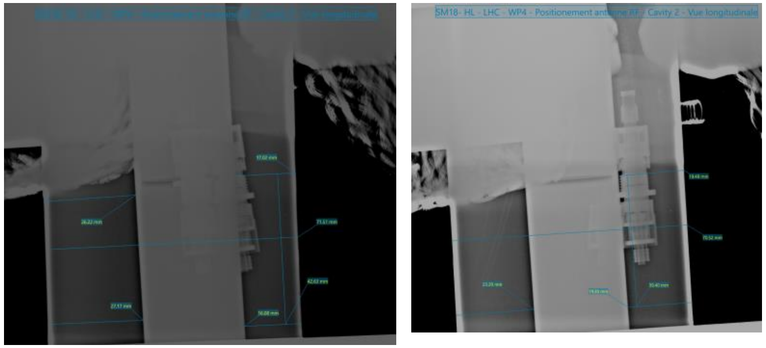


Fig .6 *Measured using laser tracker – courtesy V.Rude*

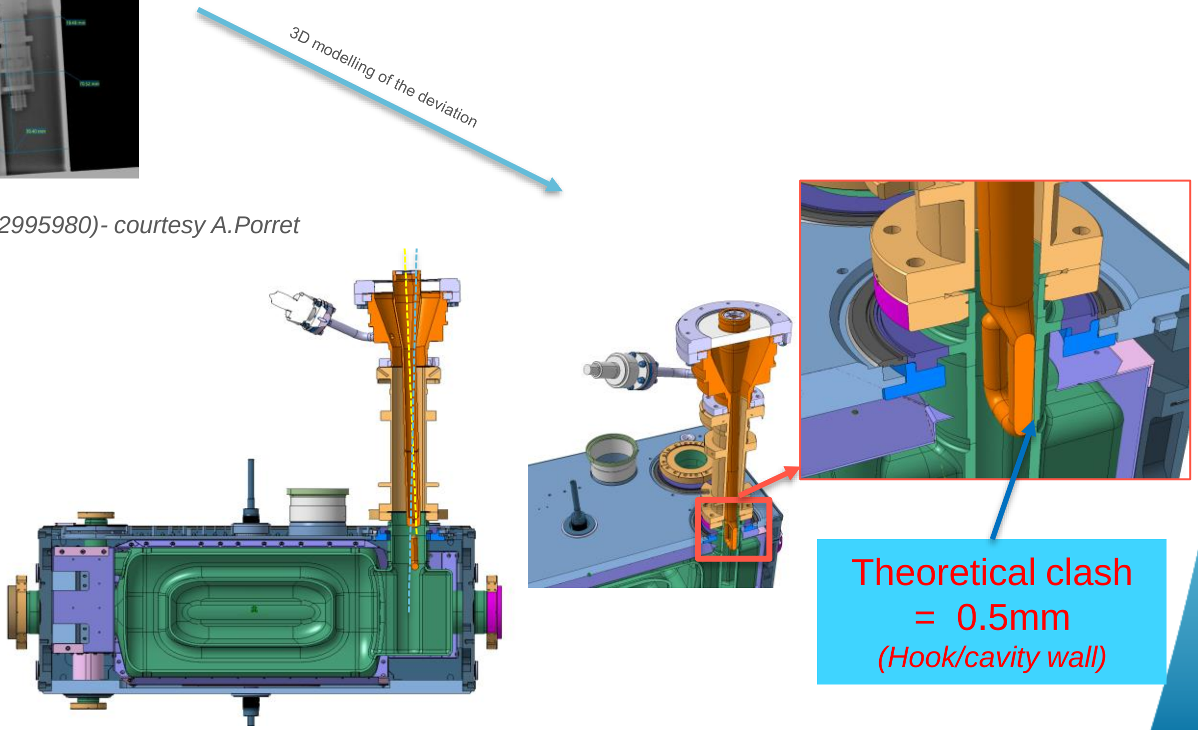
Radiographic measures – A.Porret

Set up preview - courtesy A.Porret

- X-ray confirms our preliminary observations :
  - The hook isn't bended
  - The deviation starts from the top

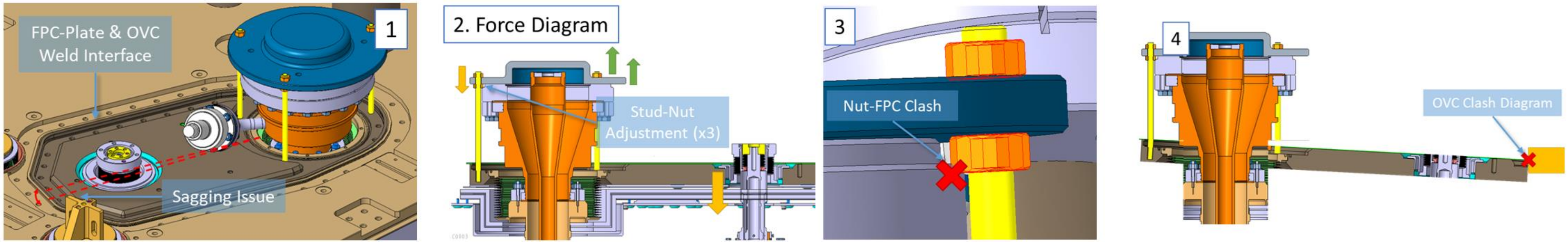


Result of radiographic measure (see full results in EDMS 2995980)- courtesy A.Porret



Root cause analysis - STFC

- Preliminary review from STFC suggest that this deformation happened during step 5.8



Draft document from N.Templeton (STFC)

- Quote from draft document :

The root cause was determined to be same for both FPCs; a multi-problem case during step5.8:

  - *The FPC-Plate to OVC interface could not be welded due to cantilever sagging.*
  - *Correcting the plate pitch was challenging with the FPC-Plate tooling.*
  - *A clash between tooling nuts and the FPC caused nuts to round when adjusting and loss of torque feel.*

However, these 3 problems alone can not cause damage since a bellows decouples the FPC and FPC-Plate.

  - *As the weld interface correction was attempted, it's suspected an unknown clash between the FPC-Plate and OVC created the force path through the FPC.*

Root cause analysis - CERN

- Mechanical simulation : EDMS 2977959 – J.SWIESZEK
- Tooling design to repair both cavities : EDMS 2977959 – P.MINGINETTE

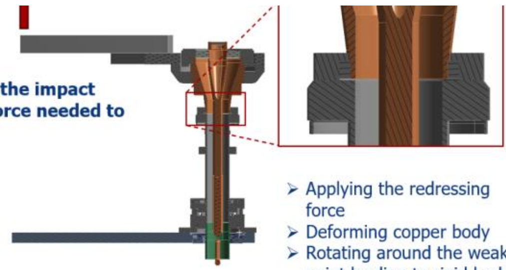
Model description

The scope is to **understand the assembly state due to the impact** causing FPC antenna displacement and to **estimate the force needed to redress** the antenna.

Introductory analysis
Simulating the initial impact on the FPC copper body, causing the deformation of the antenna

1) Applying bending force F_1 (downstream)
2) Springback (realizing the force)

Getting pre-deformed shape and copper material hardening for the redressing analysis

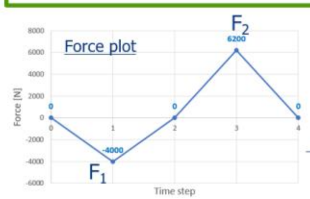


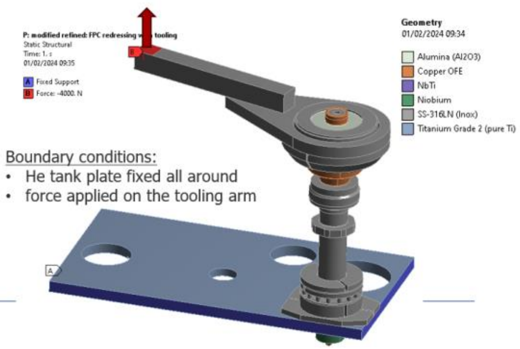
- Applying the redressing force
- Deforming copper body
- Rotating around the weakest point leading to rigid body motion of the antenna

Actual simulation of the FPC antenna redressing

3) **Applying counter force F_2** (upstream)
4) **Springback**

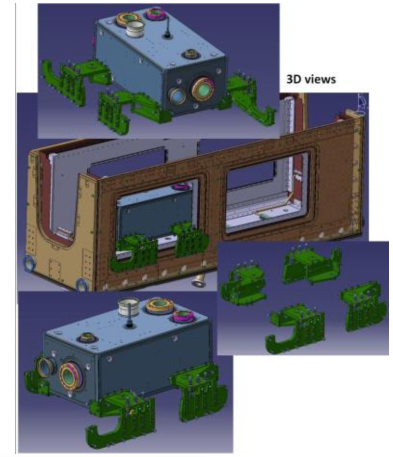
Estimate the force needed to deform back, checking strength of the intermediate elements

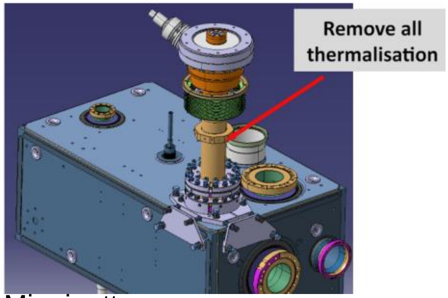




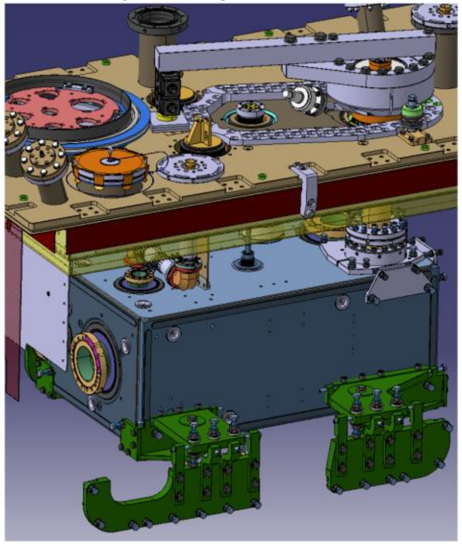
Boundary conditions:
- He tank plate fixed all around
- force applied on the tooling arm

courtesy J.SWIESZEK





courtesy P.Minginette



The calculation and the design were iterative and includes the inputs from S.Barrière, Prever Loiri and SY/RF (S.Calvo, E.Montesinos)

Root cause analysis - CERN

- Mechanical simulation : EDMS 2977959 - JOANNA SYLWIA SWIESZEK
  - The estimated force for the bending of the body of FPC cavity #1 is ~4.2KN

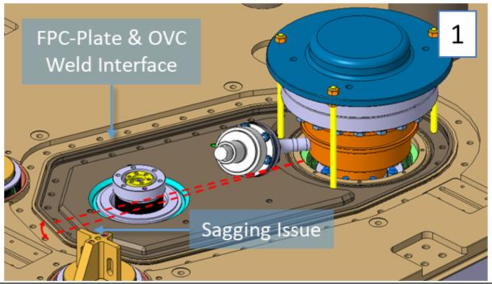
  (force applied ~530mm away for FPC axis)
  - The estimated force it to recover its nominal position is ~6KN

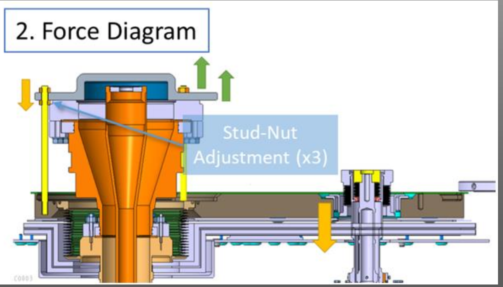
Comment on STFC analysis

- The force needed on the M8 rods to bend the FPC body would have been ~28KN

(force applied ~75mm away for FPC axis)

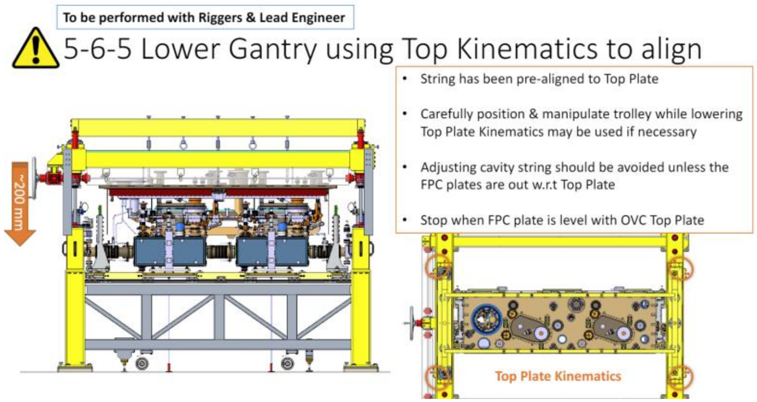
- The load to tighten the M8 nuts added to the axial load would have exceeded the maximum allowed stress of the M8 rods.





Root cause analysis - CERN

- The only activity when such forces are involded happens during step 5 when the top plate is lowered onto the cavity string (Step 5)

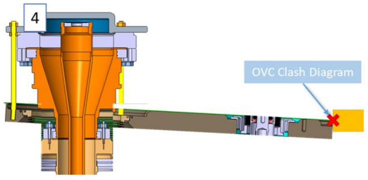


- A misalignment of the top plate WRT cavity string was measured before the top plate has been lowered but noticed only after the top plate has been lowered in position

point name	points to set			measured points			Delta			
	X	Y	Z	X	Y	Z	X	Y	Z	Mag
OVC45	360.91	650.98	574	360.62	642.49	571.34	-0.29	-8.49	-2.65	8.9
OVC46	360.49	1101.41	574.18	360.48	1092.85	569.07	-0.01	-8.56	-5.11	9.97
OVC47	359.92	1877.51	574.56	360.36	1868.85	566.64	0.43	-8.66	-7.92	11.74
OVC48	358.75	2689.95	575.15	359.72	2681.19	564.61	0.97	-8.76	-10.54	13.74
OVC54	-453.55	59.15	573.83	-454.05	51.2	579.42	-0.5	-7.95	5.59	9.73
OVC56	240.18	58.72	574.2	239.61	50.35	575.72	-0.58	-8.37	1.52	8.53

- The misalignment on Y axis *(-7.95mm min)* is larger than the FPC aperture marging *(+/-2.5mm)*

- There is a possibility that the top plate misalignment lead to a collision on the FPC plate



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Repair strategy – EN-MME / SY-RF

- Following discussion and recommendations from all the experts involved (RF, manufacturing, vacuum & Al.) and considering that redressing FPC body represent a risk of critical damage that could geopardize cryomodule and cavities cold test K.Turaj and N.Valverde prensented the following plan :

  - **1** : Cavity 2 leak repair (see details in EDMS 3120529 - S.Barrière) – **EN/MME – SY/RF**

  - **2** : Cold test of the cryomodule (results presented by K.Tujaj on 12/06)

  - **3** : Cavity 1 redressing (see EDMS 3120529 - S.Barrière) – **EN/MME – SY/RF**

  - **4** : Cold test of the cryomodule

- Leak closure on FPC cavity #2 was performed successfuly and cold test were possible operating only cavity #2

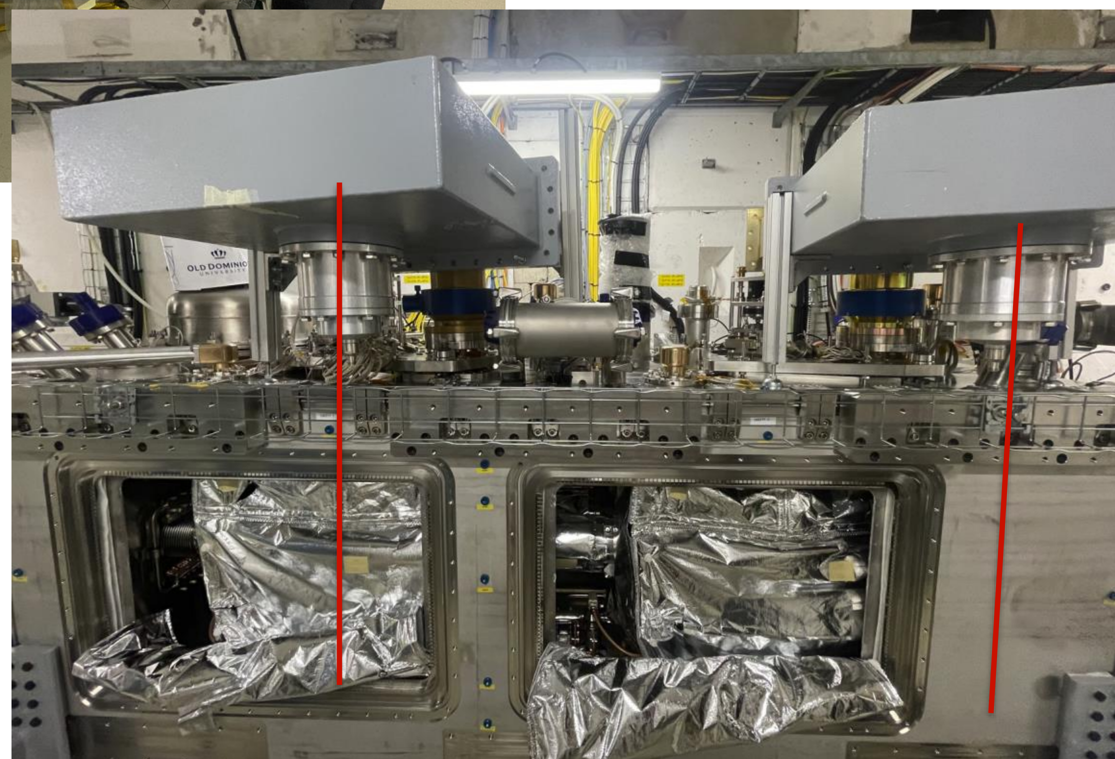
- FPC Cavity #1 repair started on Monday 17th of june and is expected to be finished by the end of the summer for cold test in spetember

Suggestions for the series production

- Because of the tight environnement it is really hard to properly look at the FPC plate passing through the aperture of the top plate. Nevertheless it is of crucial importante that this happens without collision.

- A specific tooling to better adjust the position of the FPC plates need to be designed

- Use the optical fiber installed on the FPC outer pipe to better monitor potential issue.



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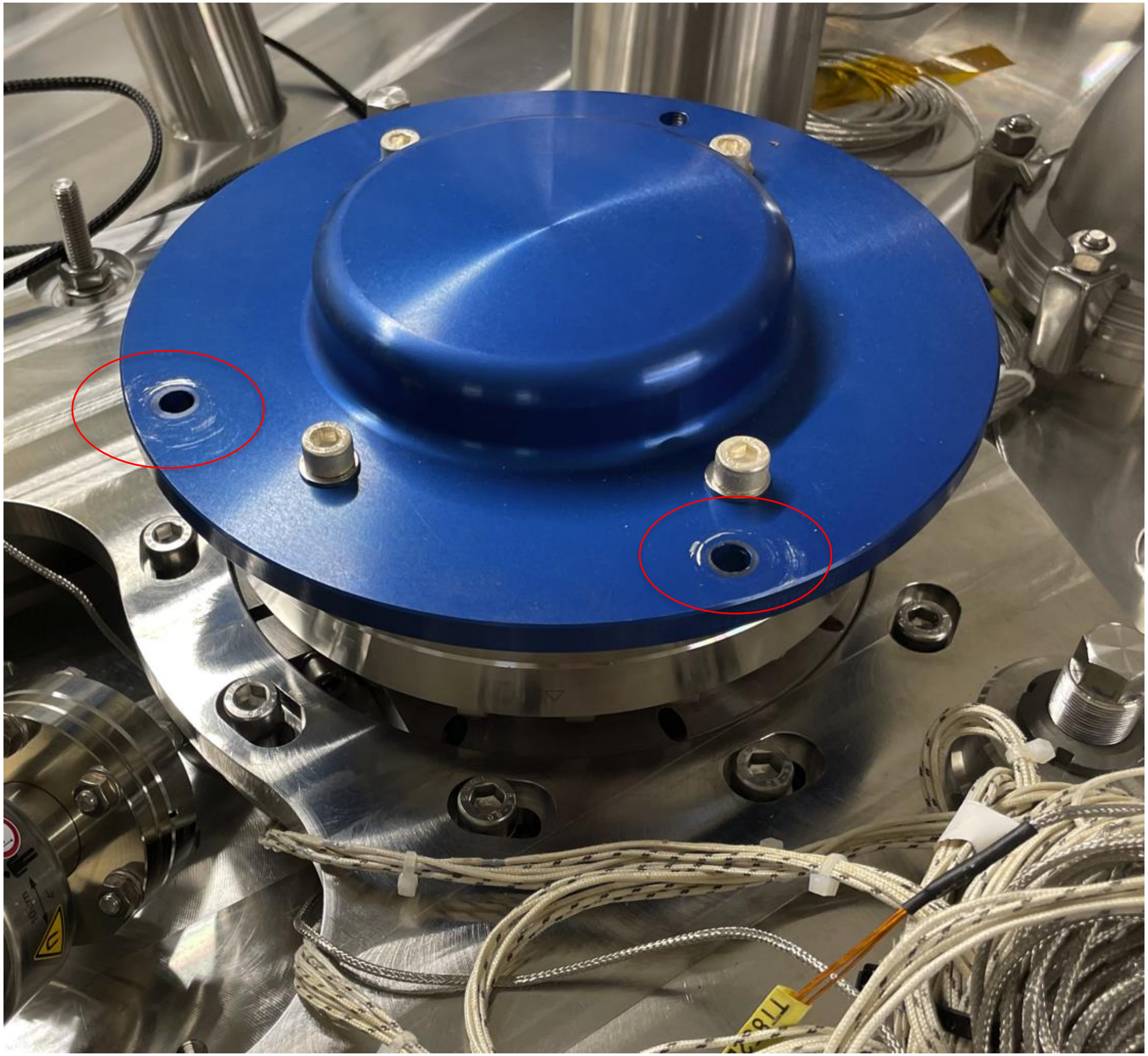

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