



Crab cavity tuning SPS results and HL-LHC

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16/10/2018

Outline

- Tuning principle
- SPS DQW Pre-tuning results
- SPS DQW tuner motorisation + instrumentation
- Analysis and documentation
- SPS DQW tuner assembly
- SPS DQW tuner cold tests
- SPS Lessons learnt
- Status RFD tuner
- HL-LHC

Tuning principle

FINE TUNING PRINCIPLE

Symmetric actuation through tuner frame and concentric tubes. Actuator outside cryostat and floating

DQW

318 kHz/mm*

S. Verdú Andrés, A. Amorim Carvalho

Tuning range

± 509 kHz

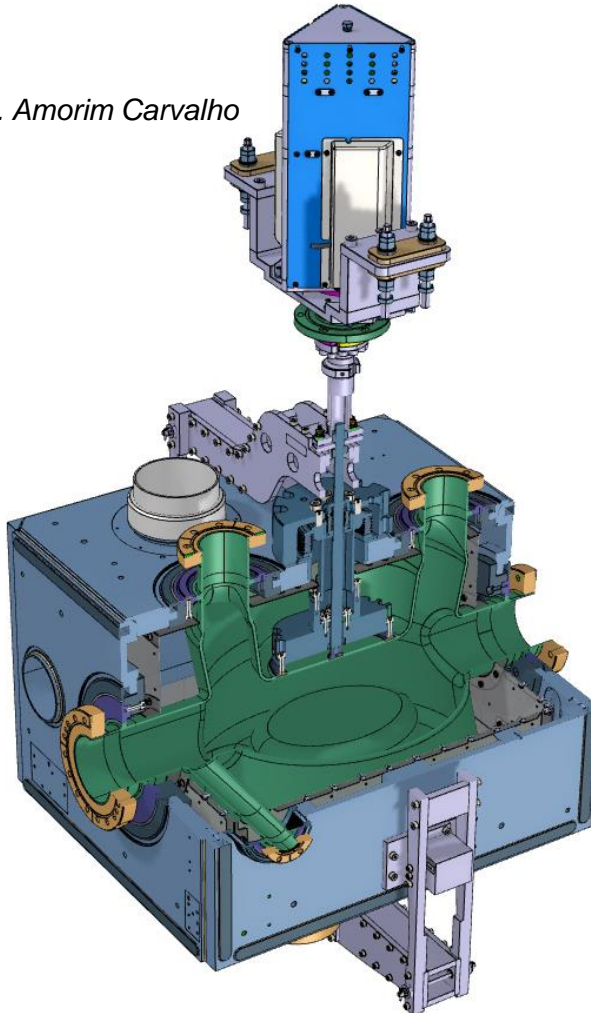
± 1.6 mm*

elastic range at 2K

Max. force:

± 3.7 kN

2.3 kN/mm*



RFD

529 kHz/mm*

E. Cano Pleite

Tuning range

± 1.3 MHz

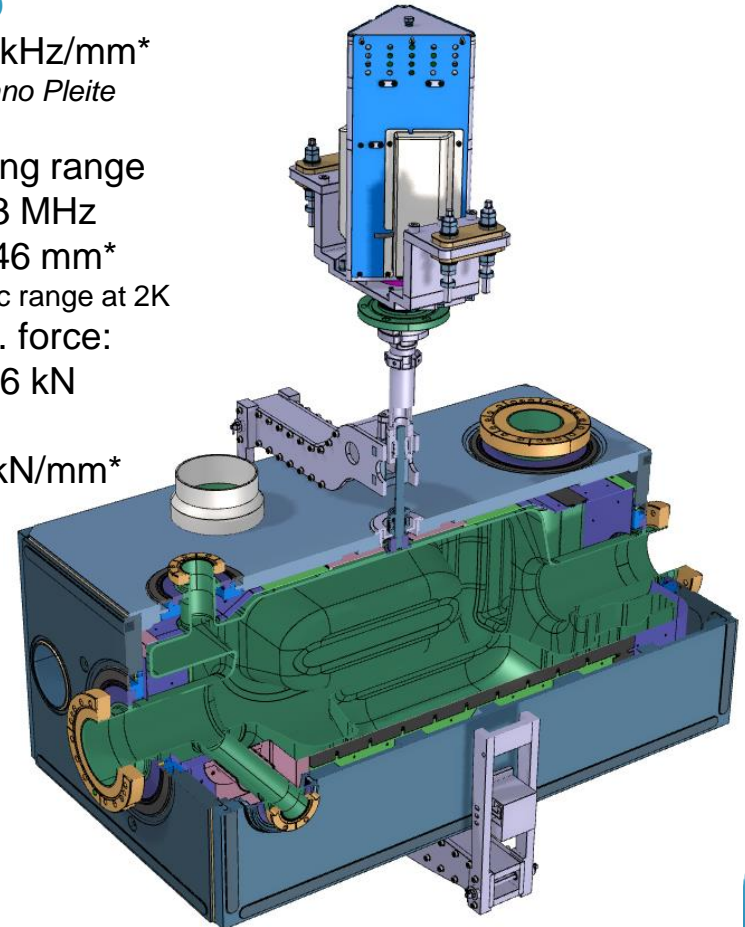
± 2.46 mm*

elastic range at 2K

Max. force:

± 7.6 kN

3.1 kN/mm*

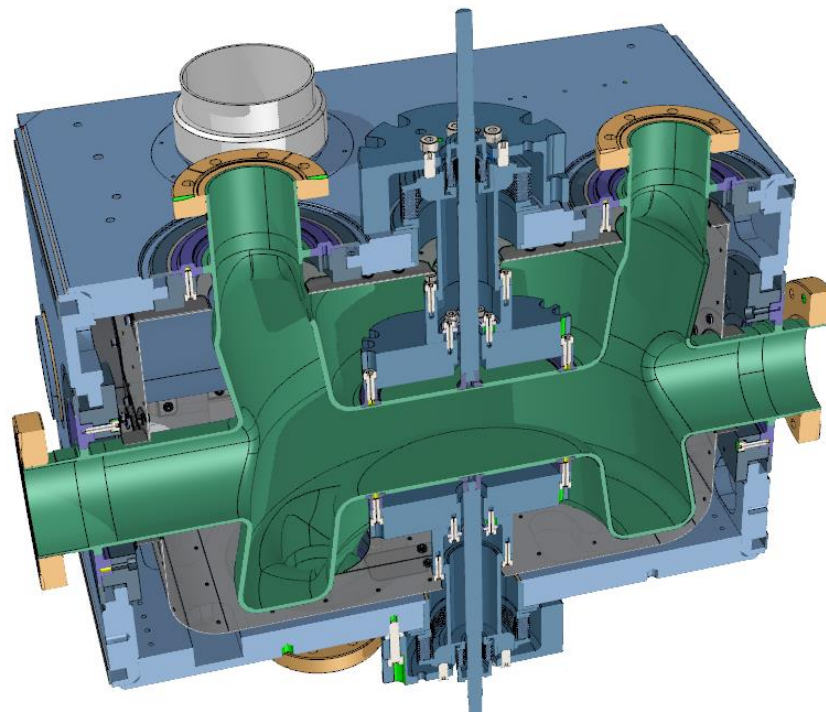
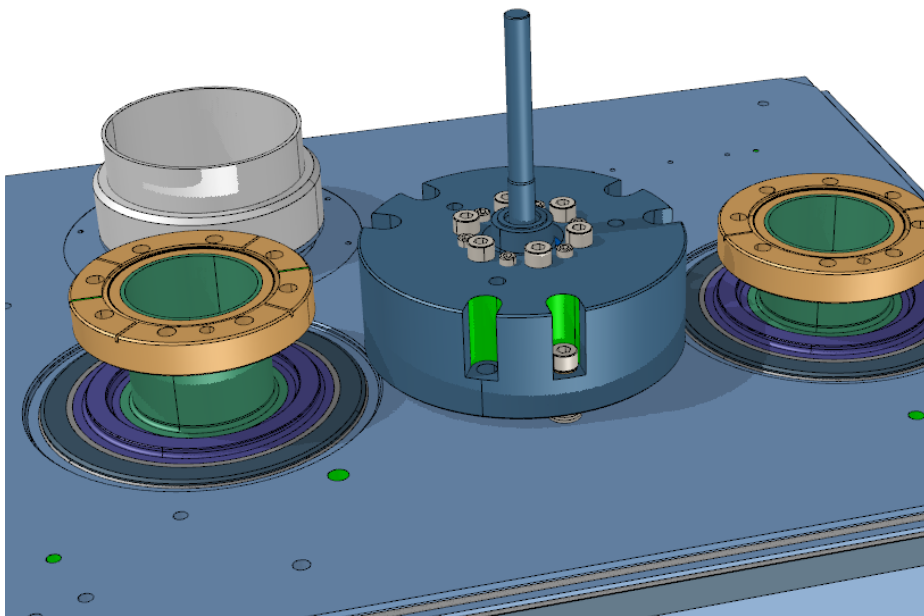


*Measured as tuner stroke or Δ distance between 2 plates

Tuning principle

- | | |
|------------------------|------------------------|
| ■ DQW: | ■ RFD: |
| 1. pre-tuning at warm | 1. - |
| 2. fine tuning at cold | 2. fine tuning at cold |

PRE-TUNING PRINCIPLE



Pre-tuning sensitivity: 1046 kHz/mm*
Pre-tuning range: ± 832 kHz

Silvia Verdu Andres

SPS DQW Pre-tuning results

Target frequency after pre-tuning: **399.960 MHz**

Cavity 1:

- Start frequency: 399.656 MHz
- 304 kHz** to compensate

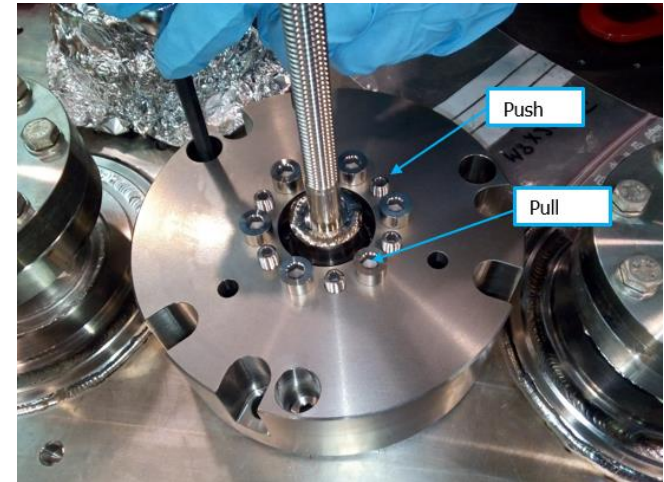
6x 2.75 Nm = 4.8 kN bottom
6x 6 Nm = 10.6 kN top

Cavity 2:

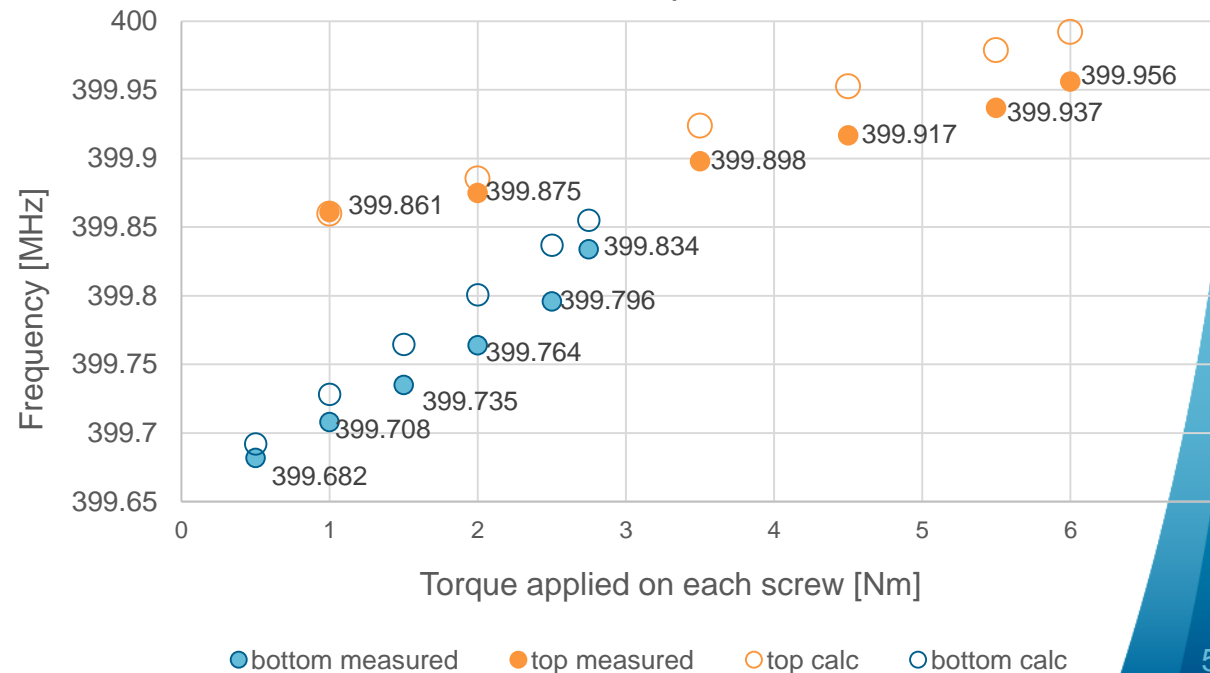
- Start frequency: 399.546 MHz
- 414 kHz** to compensate

6x 6.5 Nm = 11.4 kN bottom
6x 9.5 Nm = 16.7 kN top

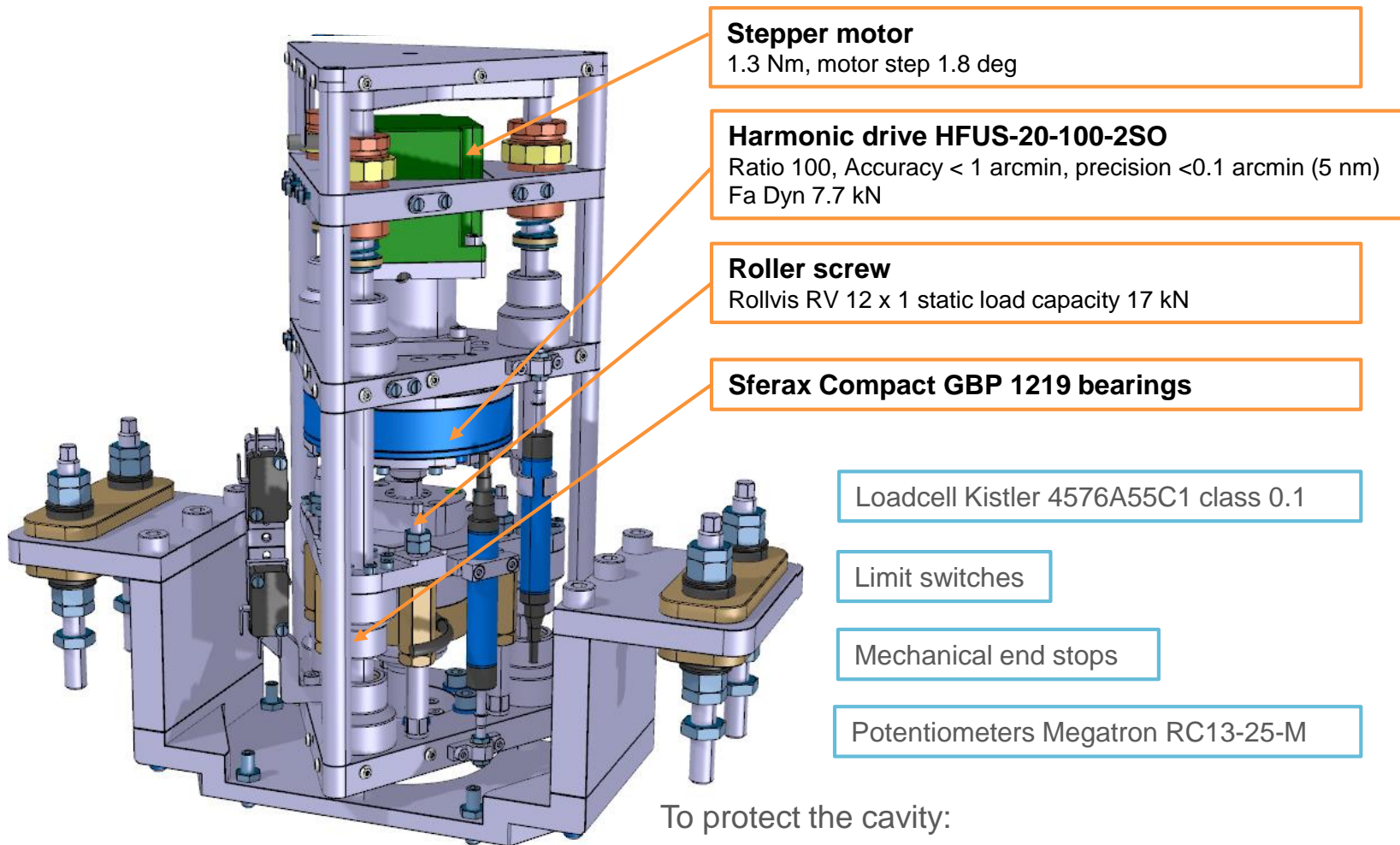
Pre-tuning sensitivity: 1046 kHz/mm*



DQW 1 - pull



SPS DQW tuner motorisation + instrumentation



To protect the cavity:

- Force sensor (limiting max. allowable force to 2kN)
- Limit switches (limiting displacement range)
- Mechanical end stops

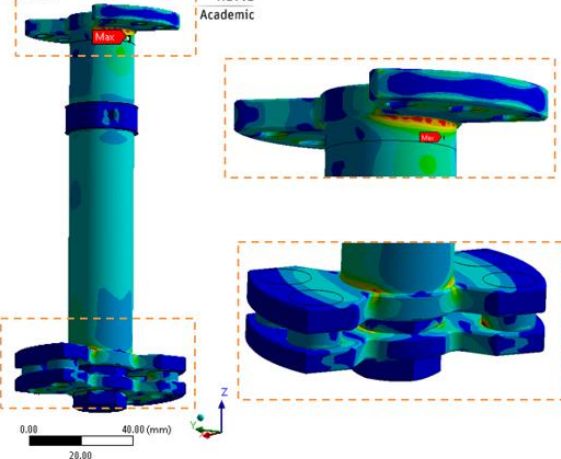
P. Minginette

Analysis and documentation

Tuner mechanism

A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
Custom
Max: 559.92
Min: 0.16307
31/07/2017 15:54

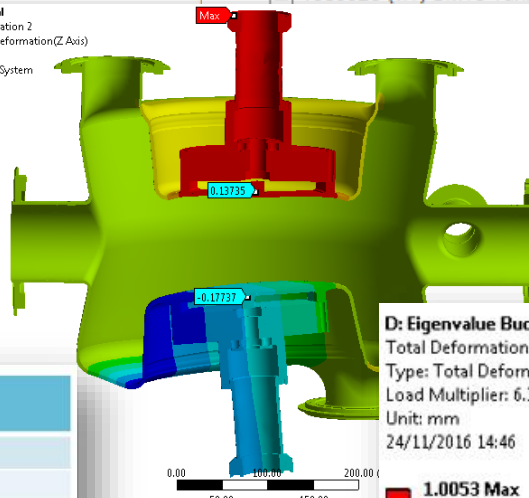
511.96
359
306.27
262.54
218.81
175.88
131.35
87.622
43.893
0.16307



ANSYS Structural analysis

A: Static Structural
Directional Deformation 2
Type: Directional Deformation(Z Axis)
Unit: mm
Global Coordinate System
Time: 1
Max: 0.18021
Min: -0.30191
18/06/2018 11:59

0.18021
0.12665
0.073076
0.019507
-0.034062
-0.087632
-0.1412
-0.19477
-0.24834
-0.30191



DQW Tuning System

- 1462559 (v.1) Fabrication CRAB TUNER motorisation SM18
- 1609909 (v.1) SM18 Tuner assembly components
- 1609928 (v.1) SM18 Tuning control

ANSYS
R18.1
Academic

Modal analysis

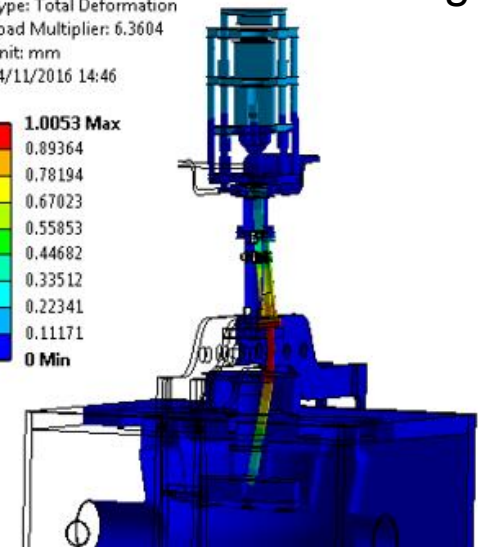
Mode number	Frequency (Hz)	Description
1	28.959	Helium tank swing around x axis
2	30.783	Helium tank swing around y axis
3	43.467	Helium tank rotation around z axis
4	46.661	Tuner frame rotation around y axis



Buckling

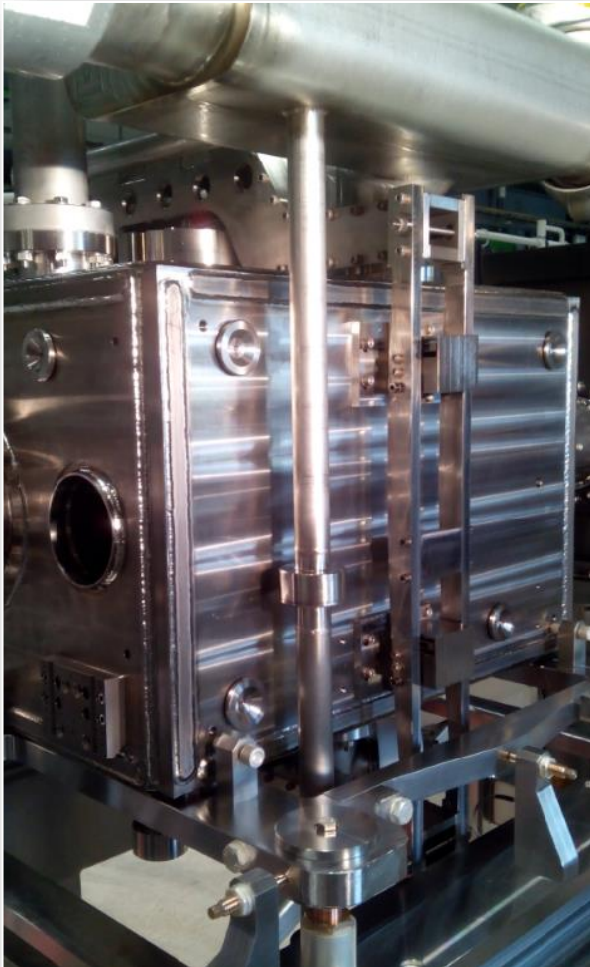
D: Eigenvalue Buckling
Total Deformation
Type: Total Deformation
Load Multiplier: 6.3604
Unit: mm
24/11/2016 14:46

1.0053 Max
0.89364
0.78194
0.67023
0.55853
0.44682
0.33512
0.22341
0.11171
0 Min



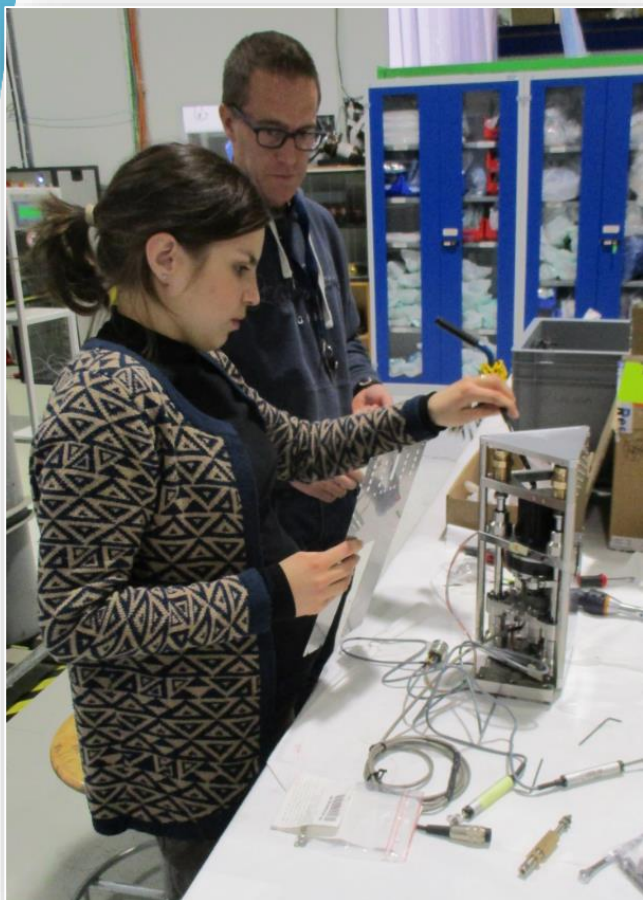
SPS DQW tuner assembly

- Limited space for installation
- Difficulties with double tube assembly

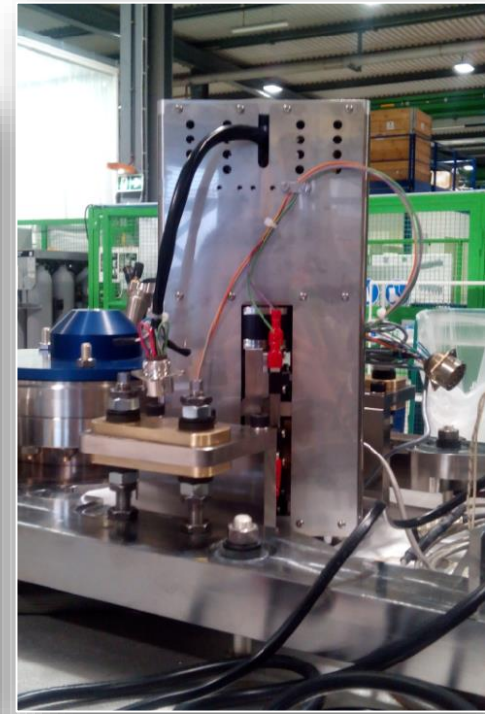
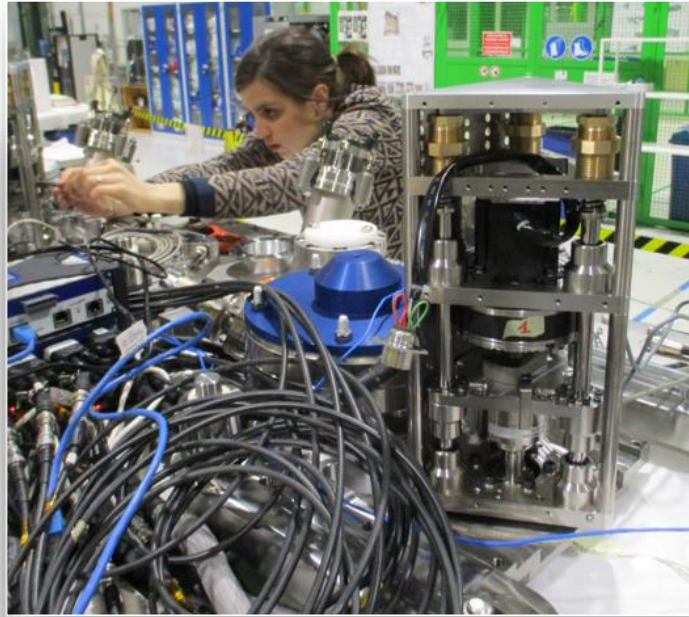
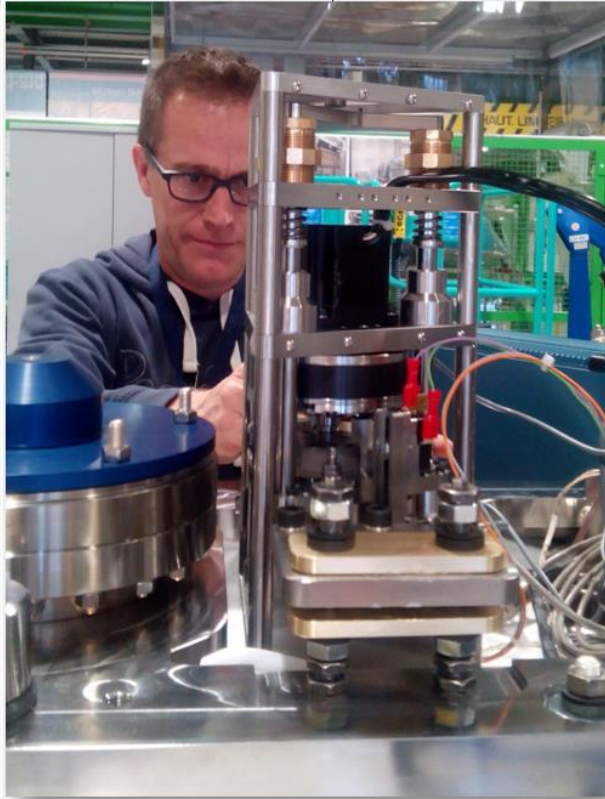


- very little space between two concentric tubes
- «butterfly» connection mech. weak point
- fitting in the double tube required lifting FPC plate
- difficult assembly alignment
- very small clearances made the installation long

SPS DQW tuner assembly



SPS DQW tuner assembly



SPS DQW – tuner cold tests

Tests in SM18

Successful tests of both tuners at 4K and 2K.

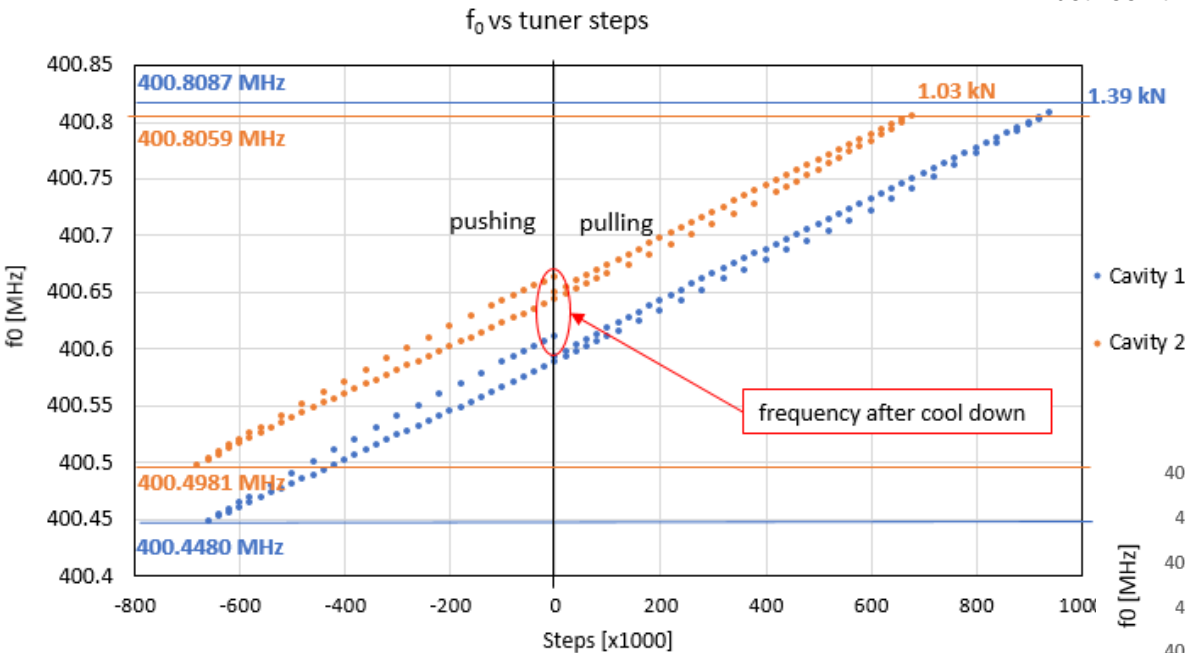
Cavity 1:

tested tuning range: **360 kHz** (400.4480 -400.8087 MHz),
maximum applied force: **1.39 kN**,
maximum cavity deformation: 0.68 mm*

Cavity 2:

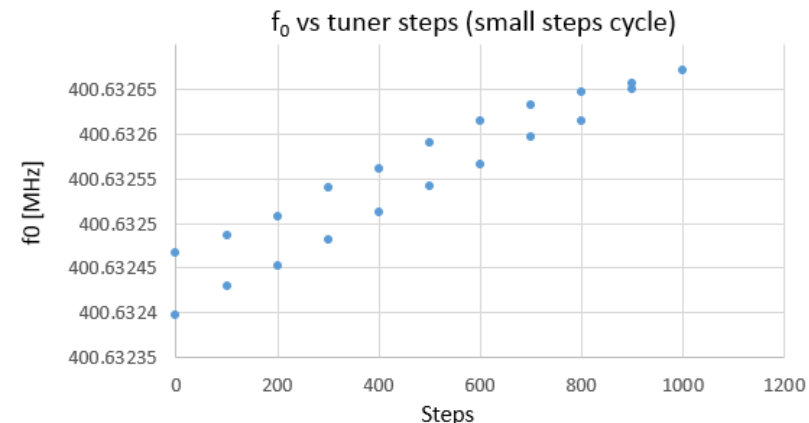
tested tuning range: **308 kHz** (400.4981 -400.8059 MHz),
maximum applied force: **1.03 kN**,
maximum cavity deformation: 0.49 mm*

* between the cavity plates, considering tuning sensitivity: 318 kHz/mm



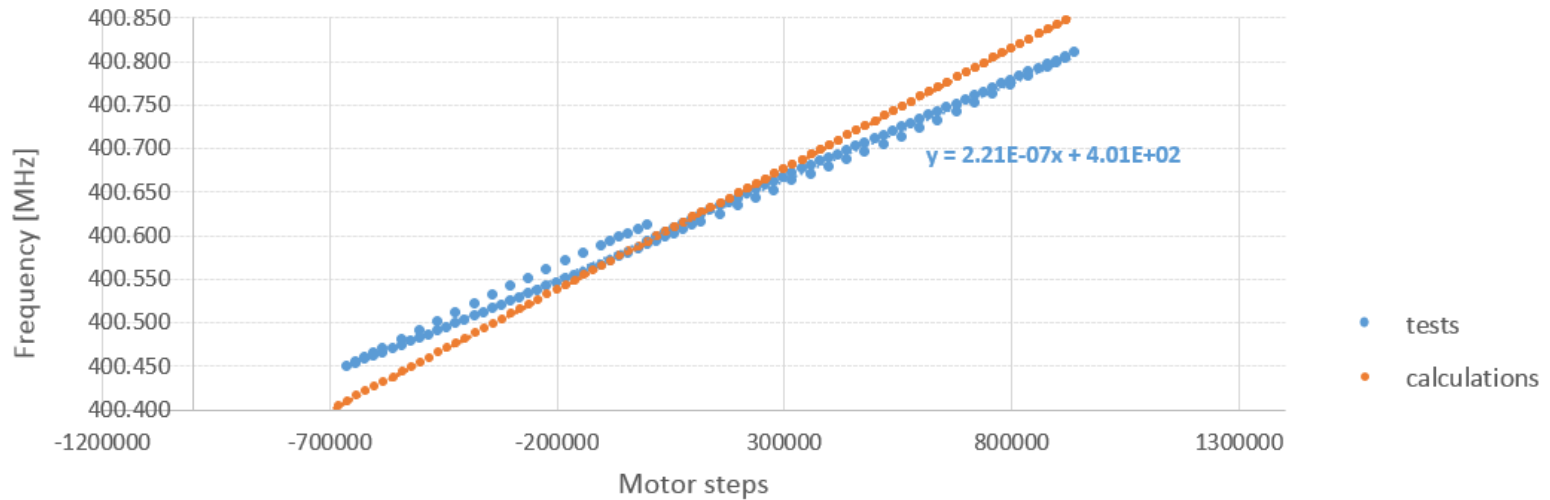
Frequency change with tuner motor step-size:
~0.21 Hz/step (calculated value: 0.27 Hz/step)

Valid also for the small steps cycles!



SPS DQW – tuner cold tests

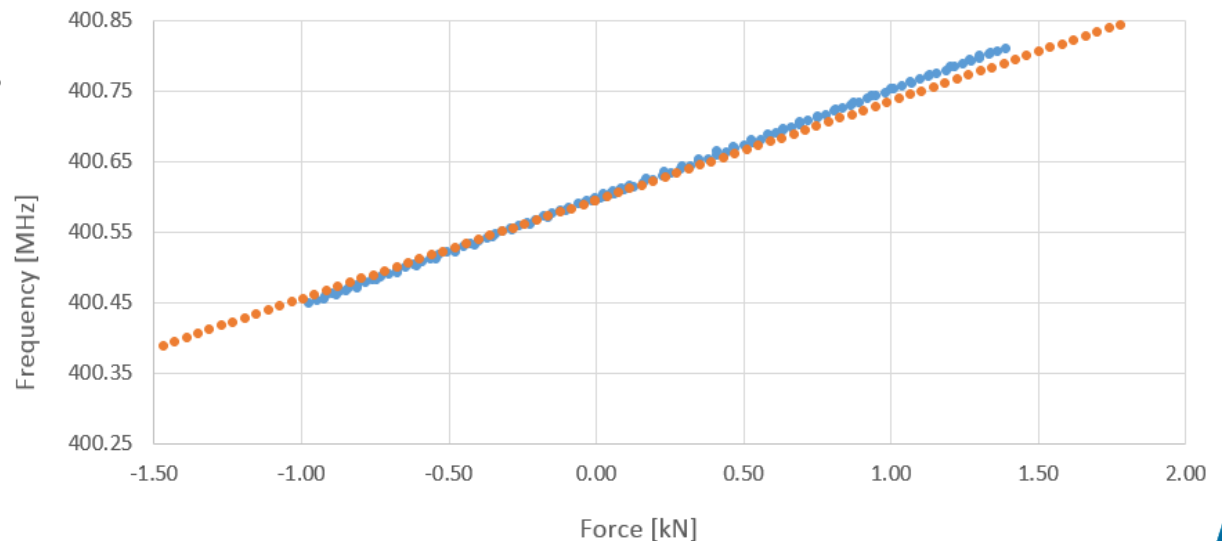
Cavity 1 - f0 vs tuner stepsize



3 variables:

- Cavity stiffness
- Equipment stiffness
- Tuning sensitivity

Cavity 1 - f0 vs force



SPS DQW – tuner cold tests

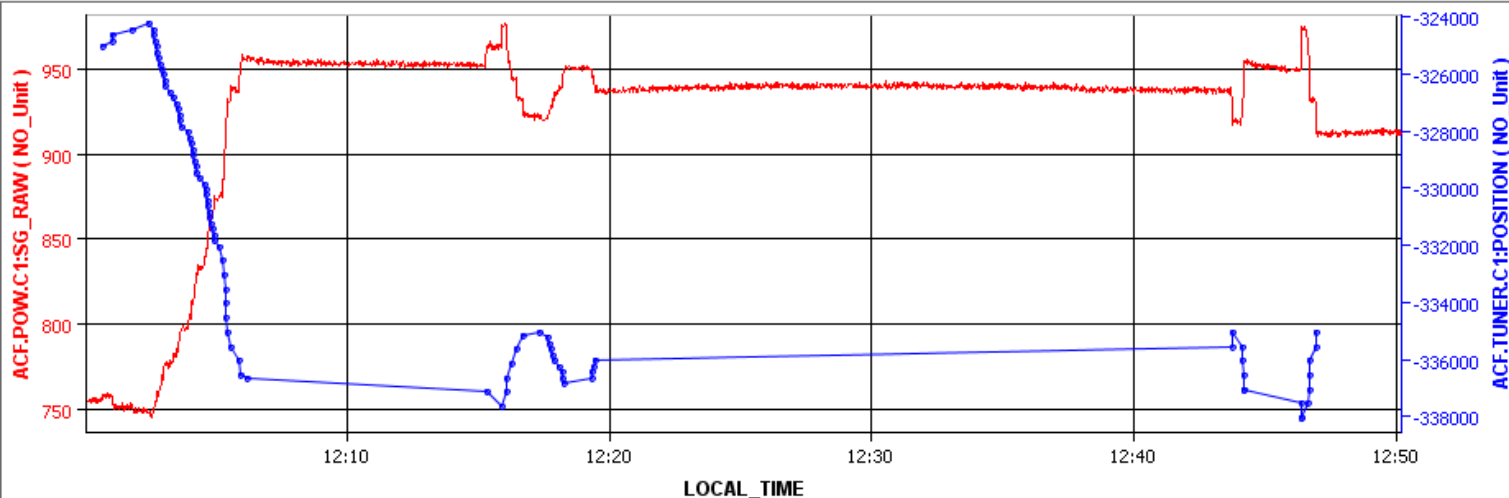
Tests in SPS still ongoing

- Successful tuning for both cavities
- SPS frequency range for tests bigger than in LHC
- Plan to do:
 - Repeat the hysteresis curves from SM18
 - LLRF implementation



Timeseries Chart between 2018-10-10 12:00:00.000 and 2018-10-10 14:39:00.671 (LOCAL_TIME)

— ACF.POW.C1:SG_RAW — ACF.TUNER.C1:POSITION



SPS Lessons learnt

Thermal cycles: Change of elastic limit

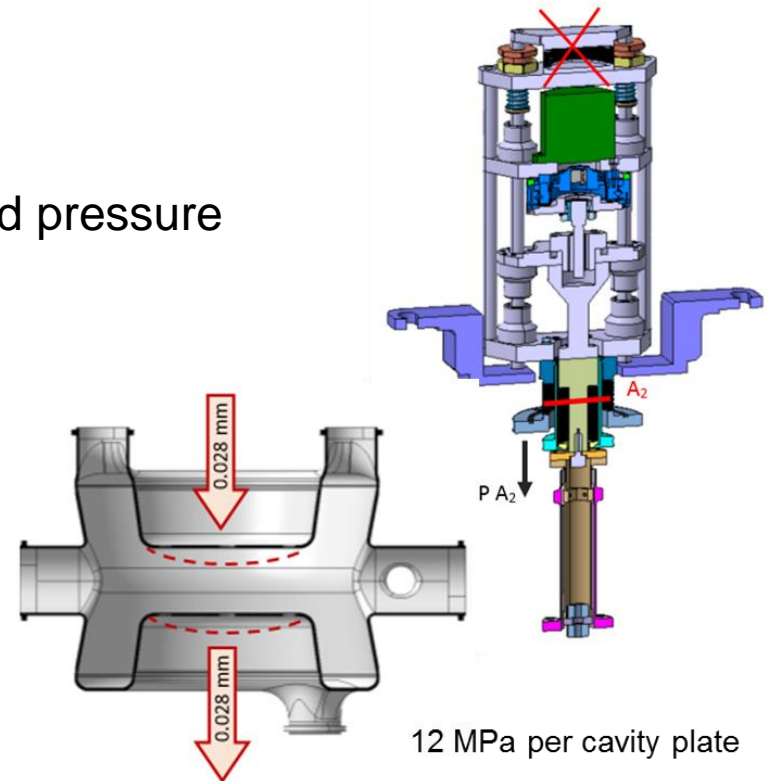
Niobium: 65 MPa at warm, 480 MPa at cold

+ some stresses from thermal contraction and pressure

It is essential to place the tuners at the same position as at assembly during thermal transitions between room temperature and cold

- Data acquisition improvements
- Implementation of load cell very important and useful

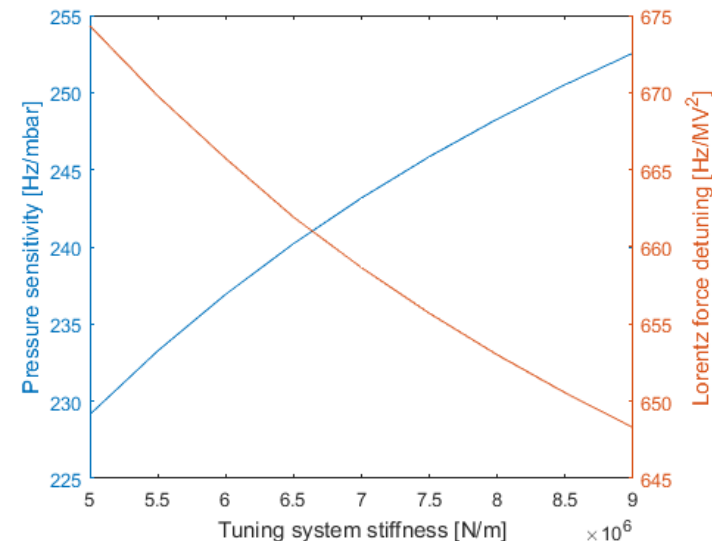
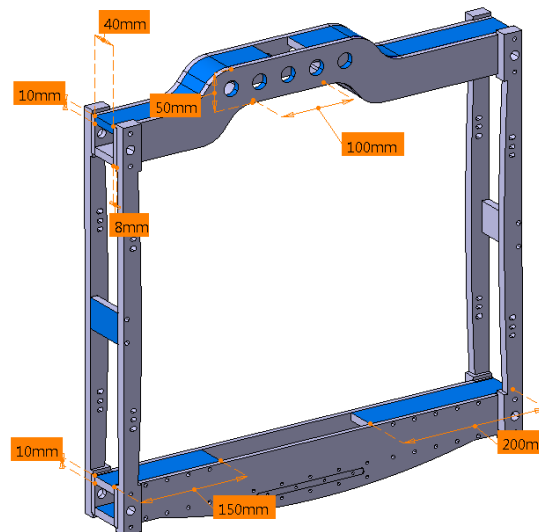
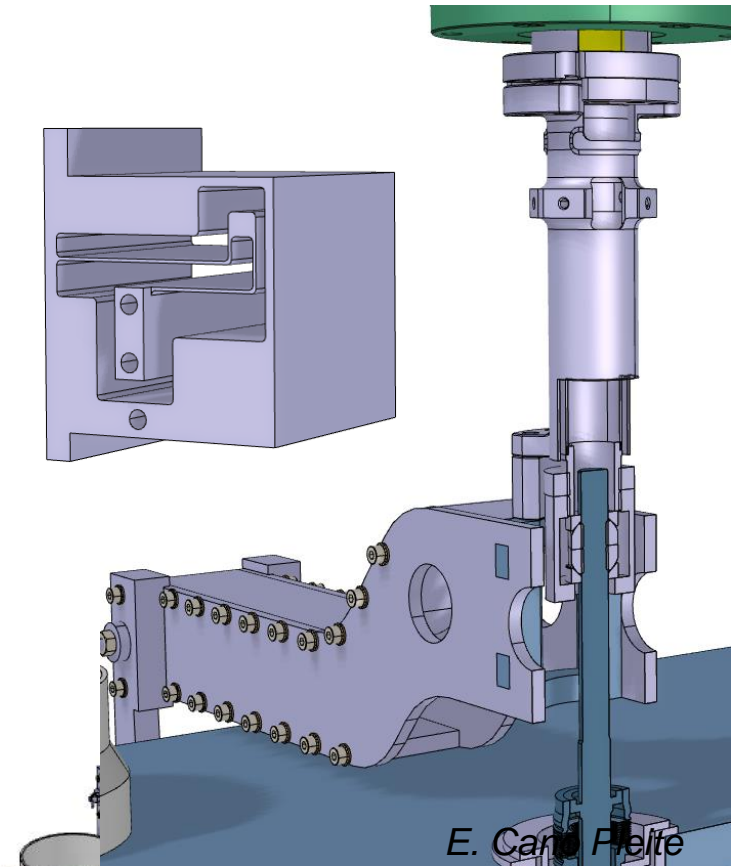
Since last week some issues on tuning of cavity 1 : under investigation



12 MPa per cavity plate

Status RFD tuner

- New requirements compare to DQW cavity:
 - larger force required
 - Redesign of some components (double tube)
 - Motorization changes (harmonic drive)
 - larger displacement expected
 - New flexural guidance design
- Optimisation work done
 - Tuner system stiffness optimisation (w.r.t pressure sensitivity, Lorentz force detuning)
 - assembly improvements (double tube design, tuning rod connection)



HL-LHC

Procurement of the components strategy:

- Technical specification for commercial items
- Specifications include **testing** and **validation** of each component at CERN

Test stand with tuner motorisation:

- Lifecycle
- Fatigue
- Radiation resistance





Thank you for your attention!

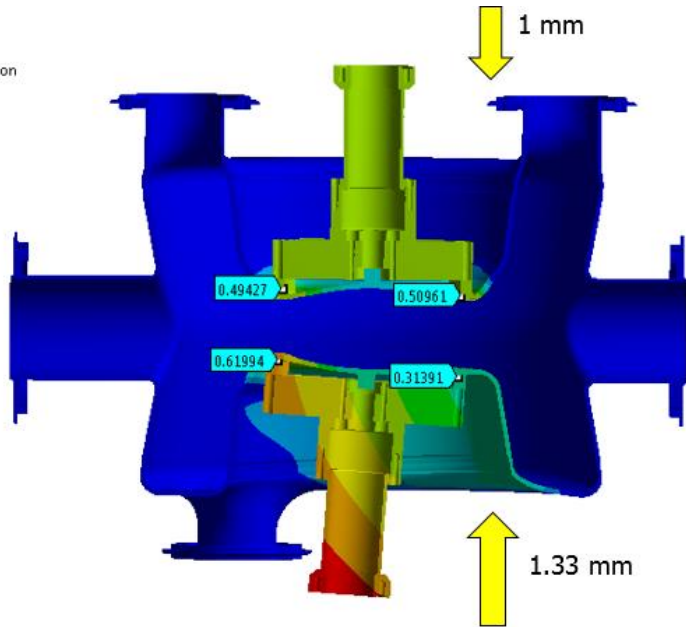


SPARE: SPS DQW - pre-tuning

B: Push 1/1.33

Total Deformation
Type: Total Deformation
Unit: mm
Time: 2
03/11/2016 16:38

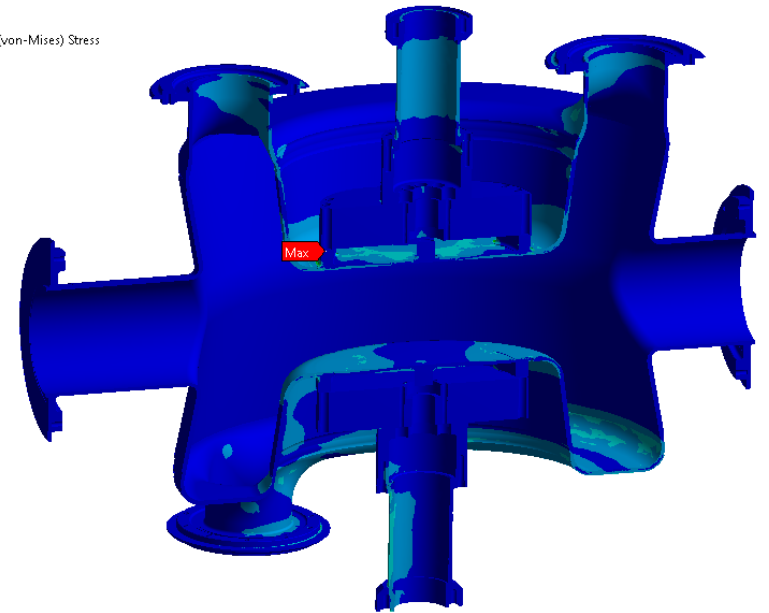
0.76613 Max
0.681
0.59588
0.51075
0.42563
0.3405
0.25538
0.17025
0.085125
0 Min



B: Push 1/1.33

Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
Custom
Max: 423.62
Min: 0.00046608
01/02/2017 16:28

423.62
376.56
329.49
282.42
235.35
188.29
141.22
94.154
47.087
0.019632



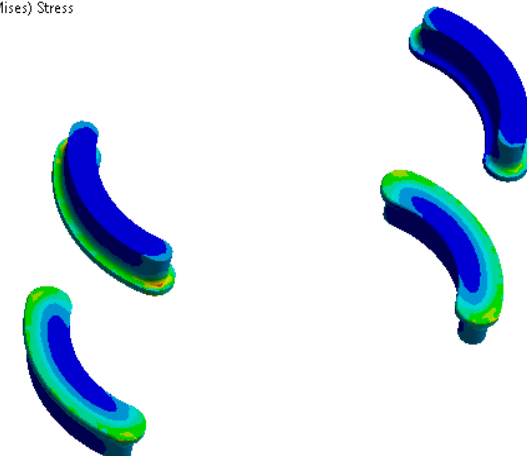
Time :	Force Reaction +(Z) [N] TOP	Force Reaction - (Z) [N] BOTTOM	Equivalent plastic strain [mm/mm] TOP	Equivalent plastic strain [mm/mm] BOTTOM
0.14286	-6848.7	4696.1	9.7661e-004	9.8395e-004
0.28571	-13476	9380.9	3.1582e-003	4.4606e-003
0.48571	-19608	14953	2.2705e-002	1.3483e-002
0.68571	-22266	18151	6.2147e-002	5.1544e-002
0.88571	-23787	20207	0.11667	0.11543
1.	-24447	21126	0.14684	0.15348
1.2	0.	0.	0.14705	0.15348
1.4	0.	0.	0.14733	0.15354
1.7	0.	0.	0.14748	0.15359
2.	0.	0.	0.14733	0.15354

0.00 150.00 300.00 (mm)
75.00 225.00

B: Push 1/1.33

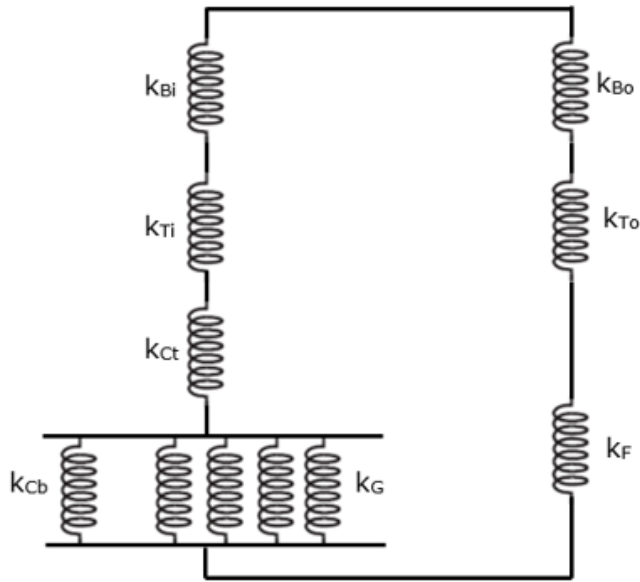
Equivalent Stress Beams
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
Custom
Max: 423.62
Min: 1.1877
14/11/2016 17:12

423.62
376.86
330.09
283.33
236.56
189.8
143.03
96.266
49.5
2.7349



SPARE: SPS DQW - Tuner setup

Tuner system – mainly components in series



Component stiffness:

k_{Bi} - inner bellow
 k_{Bo} - outer bellow
 k_{Ti} - inner tube
 k_{To} - outer tube
 k_{Ct} - cavity top
 k_{Cb} - cavity bottom
 k_G - guidance
 k_F - frame

$$k_{eq} := \left(\frac{1}{k_{Bi}} + \frac{1}{k_{Ti}} + \frac{1}{k_{Ct}} + \frac{1}{k_{Cb} + 4 \cdot k_g} + \frac{1}{k_f} + \frac{1}{k_{To}} + \frac{1}{k_{Bo}} \right)^{-1} = 1.584 \frac{kN}{mm}$$

- System stiffness: **1.584 kN/mm**
- Ratio Motor displacement/cavity deformation: **2.4mm for cavity deformation of 1.6mm (ratio 1.5)**
- Micro stepping: **800000 steps → 1 mm**
- Maximum force: **4kN**