Frequency tuning and lessons learned

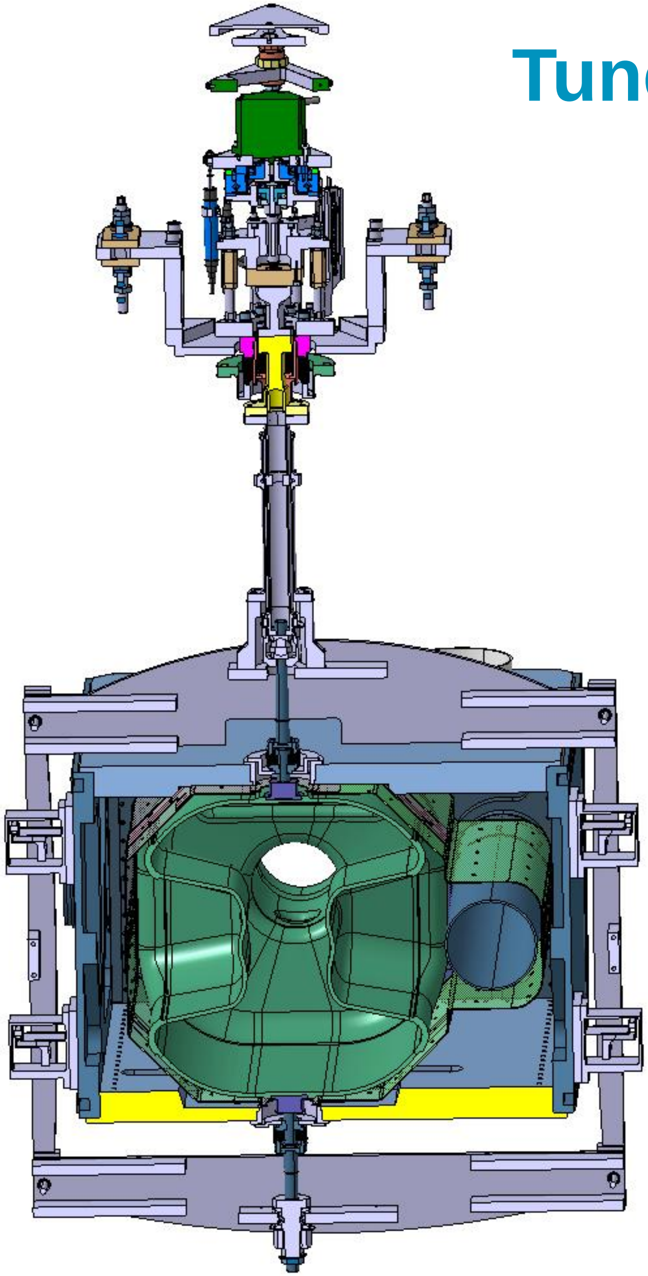
Kurt Artoos

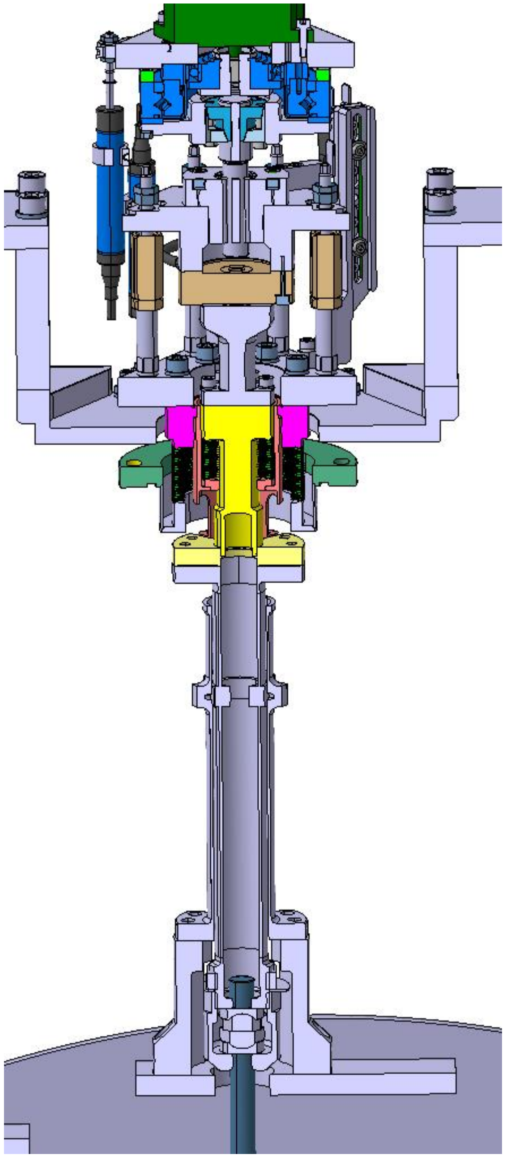
Thanks to several very great people!

Outline

- Tuning principle, ranges and forces
- SPS DQW TESTS Pre-tuning
- Assembly of the tuner
- SPS DQW tuner cold tests
- Problem with the tuners
- Design status components
- Purchasing strategy LHC

Tuner principle





Tuning principle

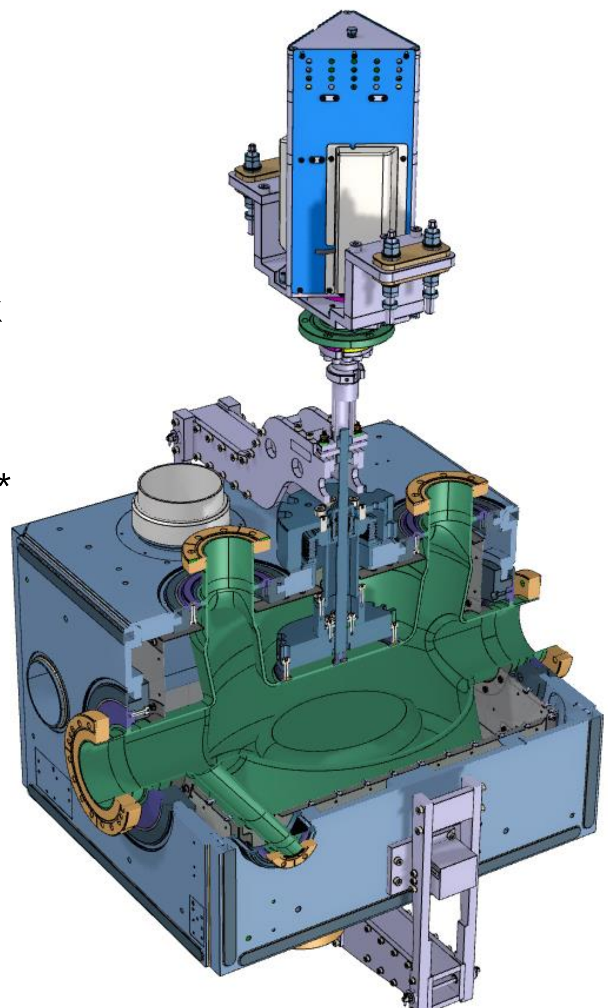
FINE TUNING PRINCIPLE

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

DQW
318 kHz/mm*
S. Verdú Andrés

Tuning range
± 509 kHz
±1.6 mm*
elastic range at 2 K
Max. force:
± 3.8 kN

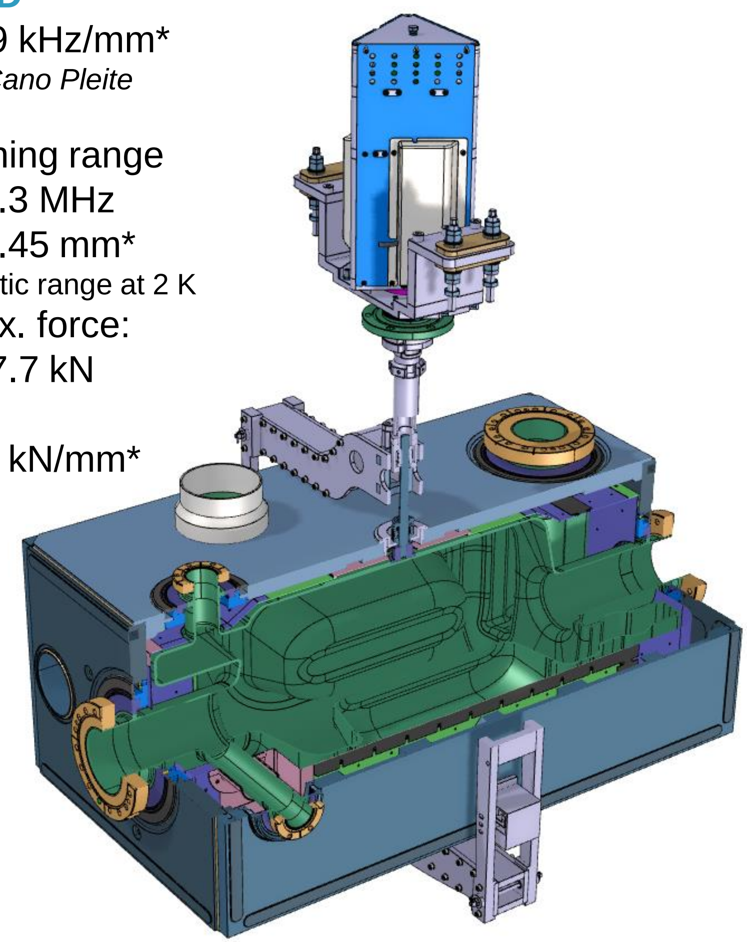
2.2-2.4 kN/mm*



RFD
529 kHz/mm*
E. Cano Pleite

Tuning range
± 1.3 MHz
± 2.45 mm*
elastic range at 2 K
Max. force:
± 7.7 kN

3.1 kN/mm*

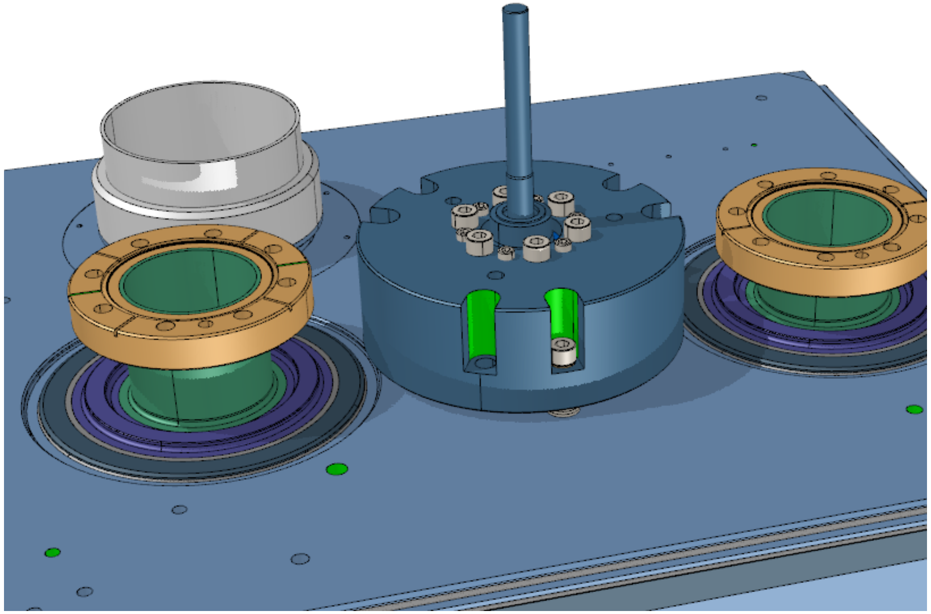


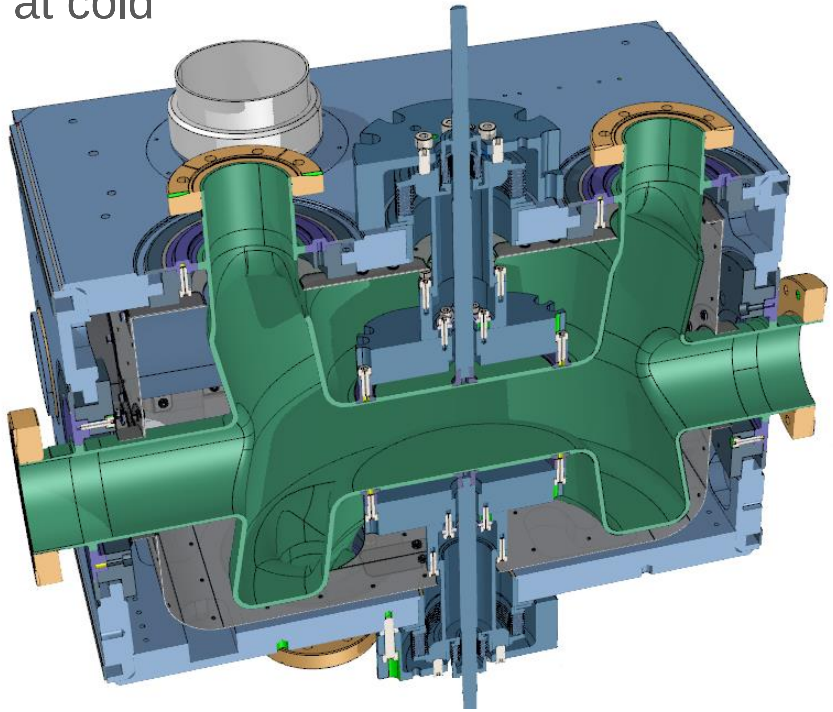
*Measured as tuner stroke or Δ distance between 2 plates

Tuning principle

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

PRE-TUNING PRINCIPLE





Pre-tuning sensitivity: 1046 kHz/mm*
Elastic Pre-tuning range: ± 400 kHz
Non-elastic range: ± 1 MHz

Silvia Verdu Andres

Trim tuning of HiLumi DQW cavities

Silvia Verdú-Andrés (BNL)

Simulations
Metrology
Trimming
Frequency measurements

Experience based on 2 LARP prototypes and 2 CERN cavities

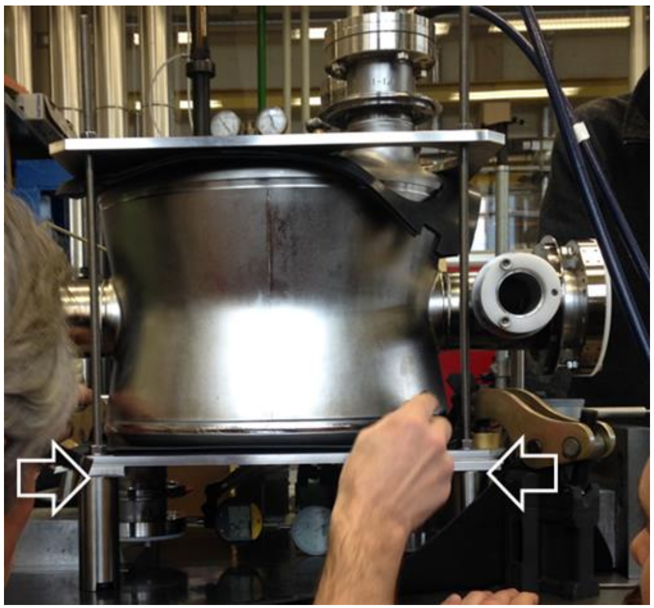


Table 4: Target frequencies for a DQW cavity.

Operation	Expected shift [kHz]	Expected frequency [MHz]	Target frequency [MHz]	Acceptance range [MHz]	Cavity status
Fabrication tolerances (before W03A/B)		N/A			
TUNING: trimming			401.05	±0.10	Clamped, in air at room temperature
Welds W03A/B (transverse shrinkage and penetration depth effects)	-0.89	400.16			
Leak check	0				
TUNING: action on inductive plates (alternative tuning)			400.16	±0.10	In air at room temperature
Bulk BCP (150 um)	+0.22	400.38			
High temperature baking					
Light BCP (30 um)					
Vessel assembly	-0.42	399.96			
TUNING: action on tank plates (pre-tuning)			399.96	±0.05	In air at room temperature
Assembly of HOM filters, pickup and FPC (in 5 mm-longer ports)*	-0.04	399.92			
Cool down with helium vessel (shifts due to ΔT, Δp, $\Delta\varepsilon$)	+0.71	400.63			
RF on (LFD)	-0.0004	400.63			
TUNING: with push/pull system			400.73-400.79	±0.005	In vacuum at 2 K

Developed new tuning methods

All well documented

SPS DQW TESTS Pre-tuning results

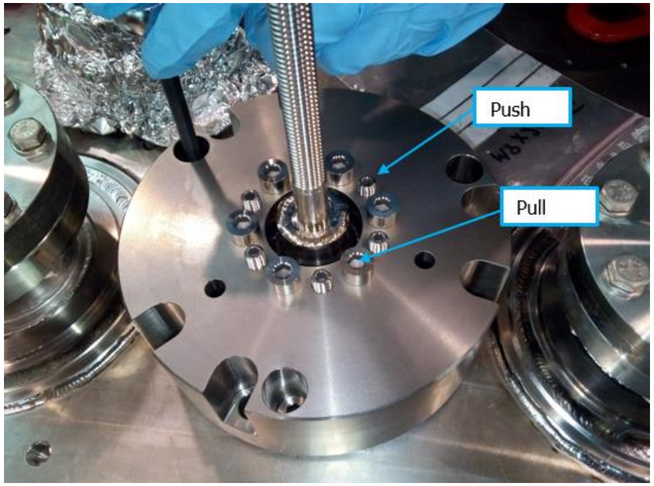
Target frequency after pre-tuning: **399.960 MHz**

Cavity 1:
- Start frequency: 399.656 MHz
- **304 kHz** to compensate

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

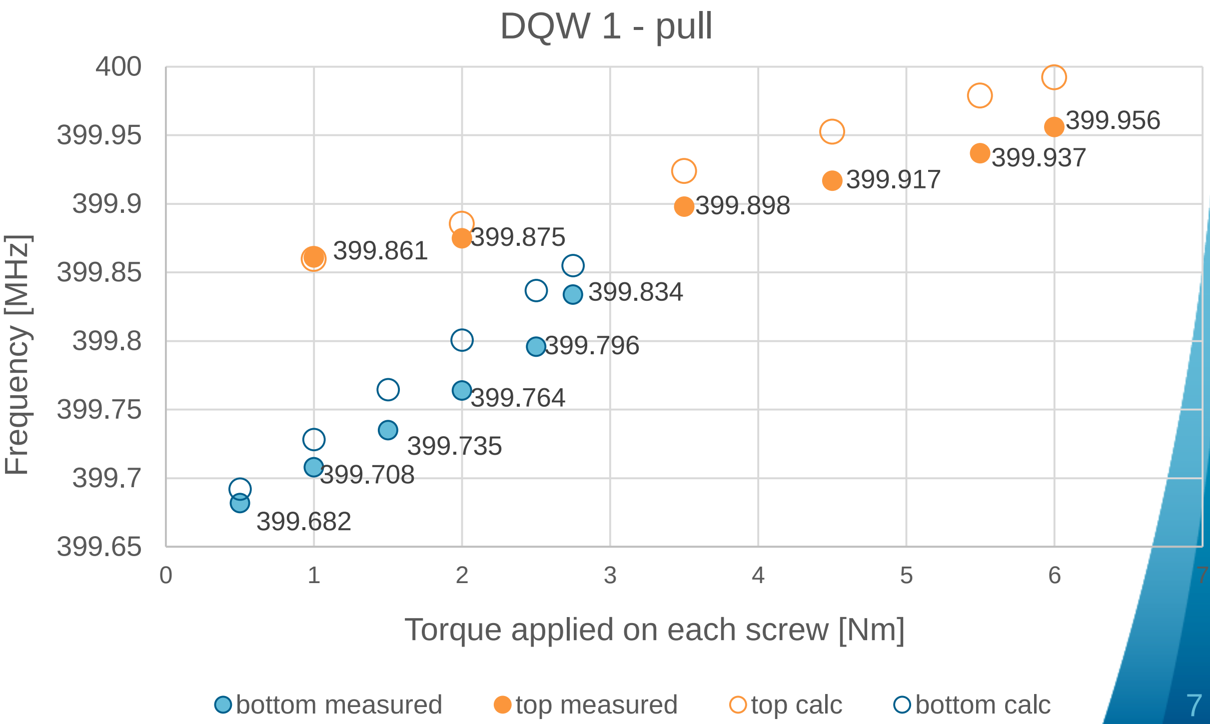
Cavity 2:
- Start frequency: 399.546 MHz
- **414 kHz** to compensate

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

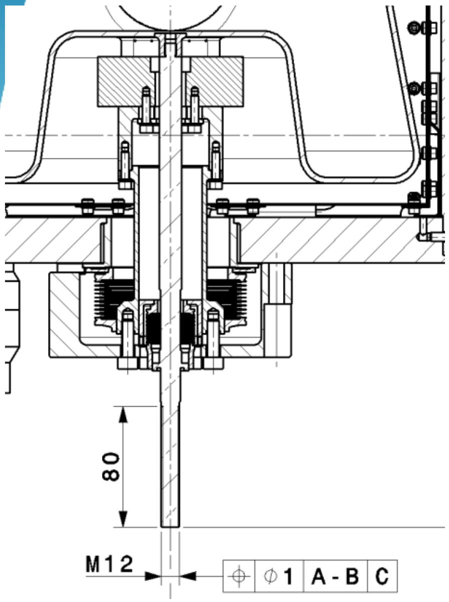


Pre-tuning sensitivity: 1046 kHz/mm*

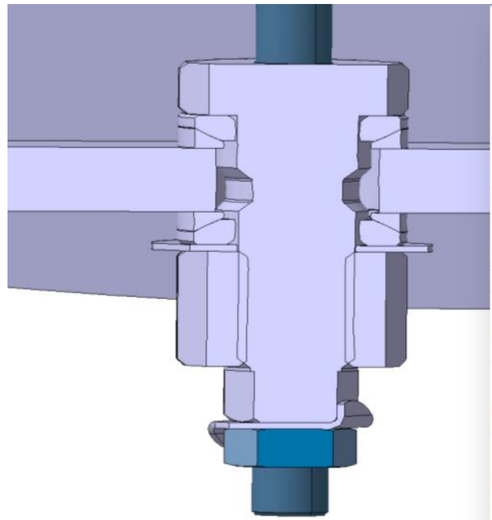
Precision ~20 kHz

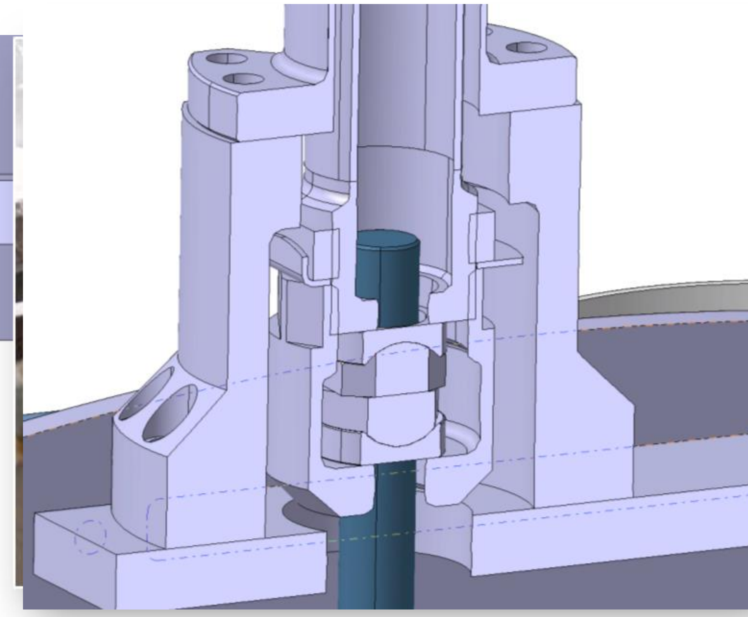


Assembly of the tuner to the cavity

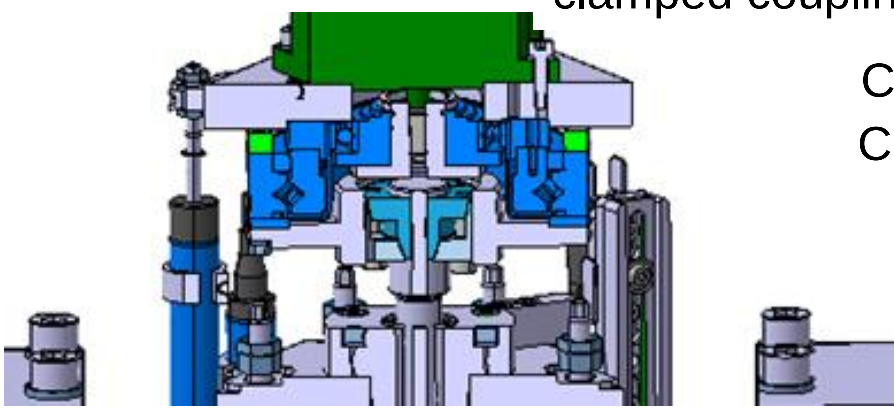


- Design features to limit frequency change





Spherical in conical clamped couplings

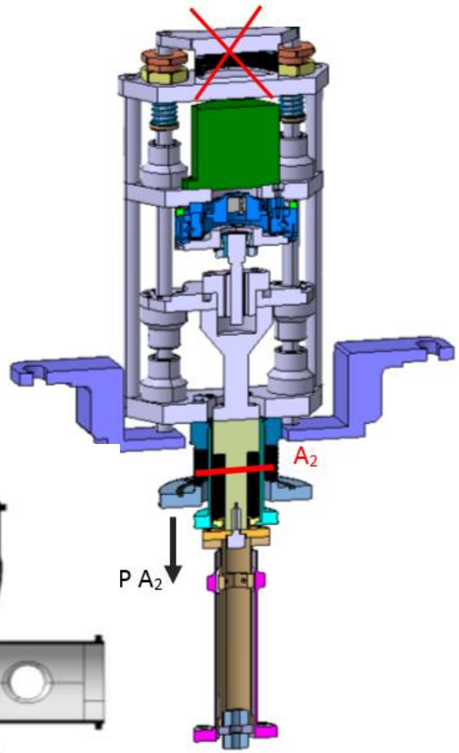


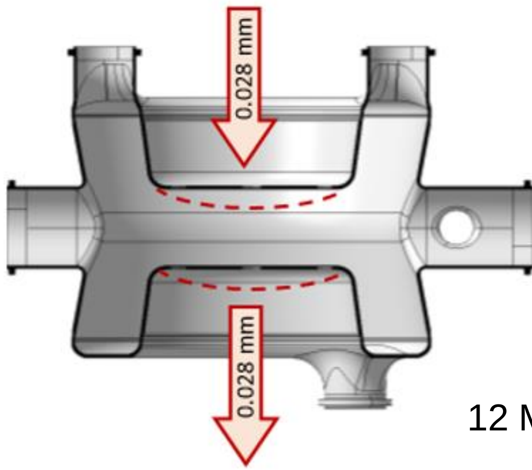
Change less than 20 kHz
Closing connection is with a conical clamp

SPS DQW TESTS fine tuning - thermal cycles

Behaviour during the cool down:

- Change of elastic limit:
  Niobium: 65 MPa at warm, 400 MPa at cold (not taking into account
- work hardening)
- Thermal contraction
  inside the tuning chain cavity->tuning rod->frame->inner and outer tube
- Pressure compensation
  two vacuum passage bellows, no pressure compensating bellow





12 MPa per cavity plate

- Thermal stresses
- Pressure stresses
- Operating/tuning stresses

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

SPS DQW TESTS – tuner cold tests

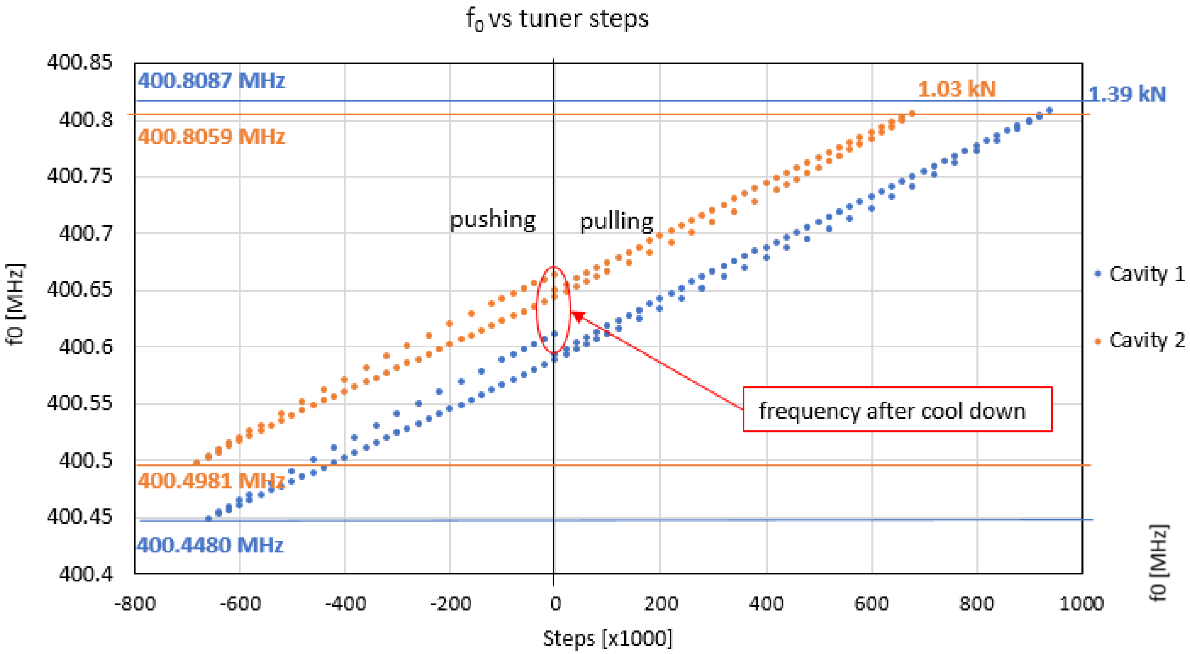
Tests in SM18

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

Cavity 1:
tested tuning range: **360 kHz** (400.4480 -400.8087 MHz),
maximum applied force: **1.39 kN**,
maximum cavity deformation: 0.68 mm*

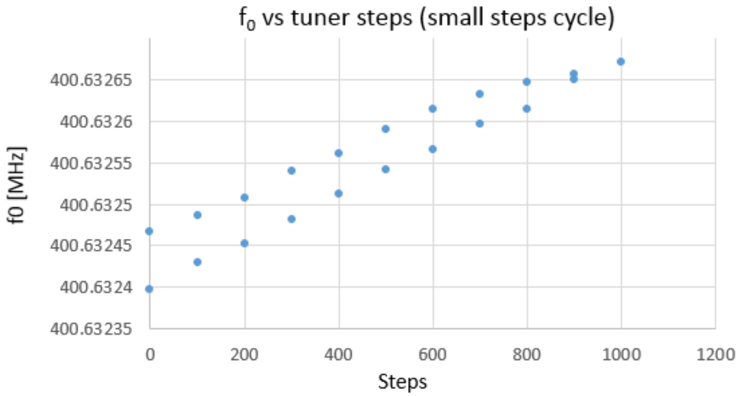
Cavity 2:
tested tuning range: **308 kHz** (400.4981 -400.8059 MHz),
maximum applied force: **1.03 kN**,
maximum cavity deformation: 0.49 mm*

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

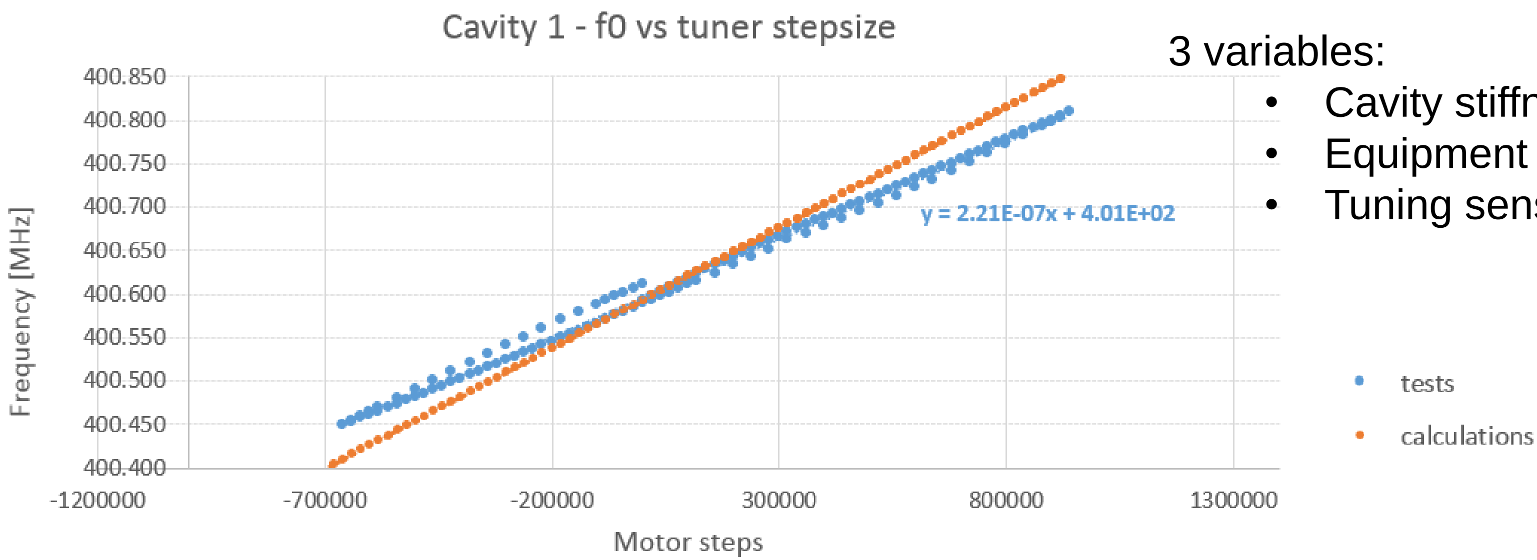


Frequency change with tuner motor step-size: **~0.21 Hz/step** (calculated value: 0.27 Hz/step)

Valid also for the small steps cycles!

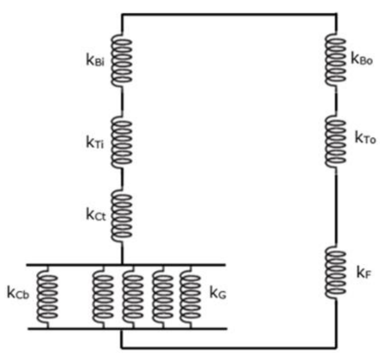


SPS DQW TESTS – tuner cold tests



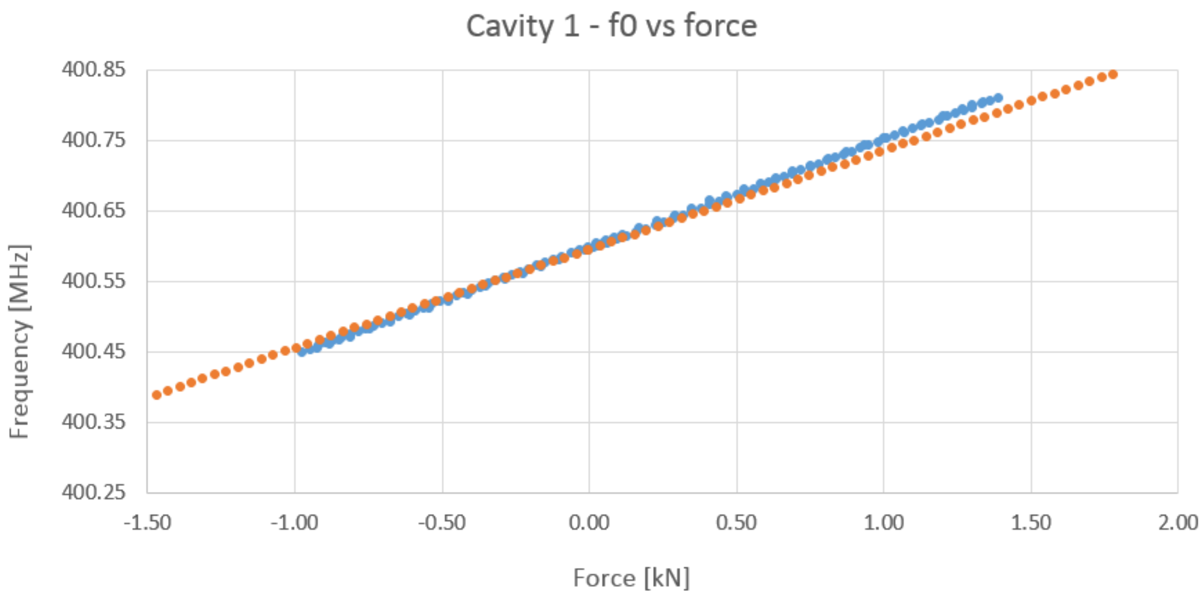
3 variables:

- Cavity stiffness
- Equipment stiffness
- Tuning sensitivity



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



SPS DQW TESTS – tuner cold tests

- Successful tuning for both cavities

Lessons learnt:

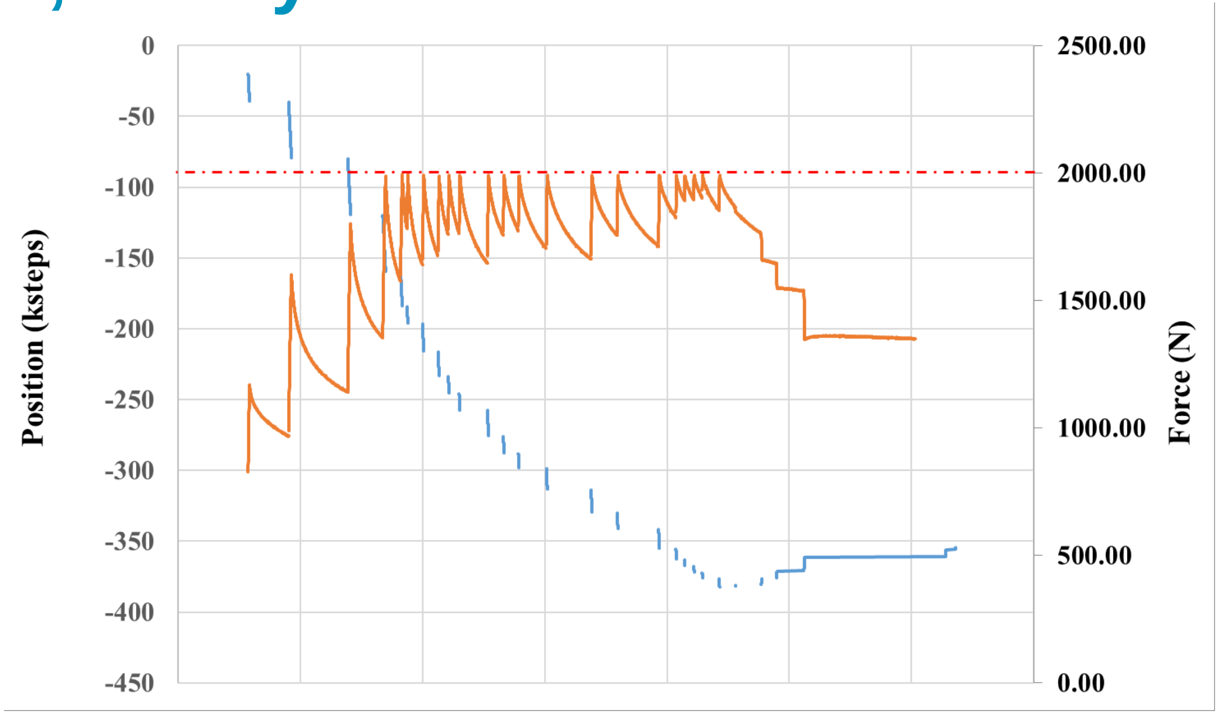
- Placing the tuner at neutral position during thermal transitions between room temperature and cold – automatic for LHC
- Data acquisition improvements
- Implementation of load cell very important and useful
- Potentiometers to be improved

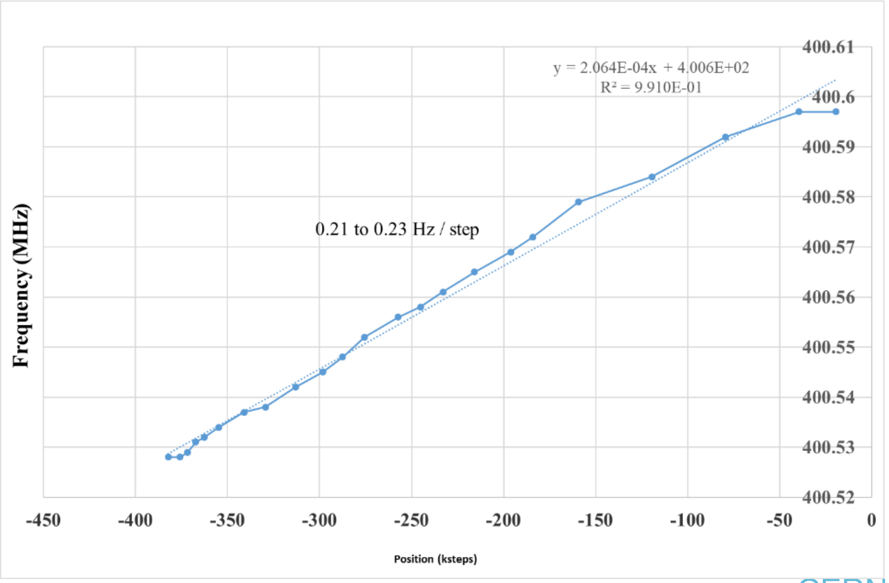
Until….

2 and 3 October, Cavity 1

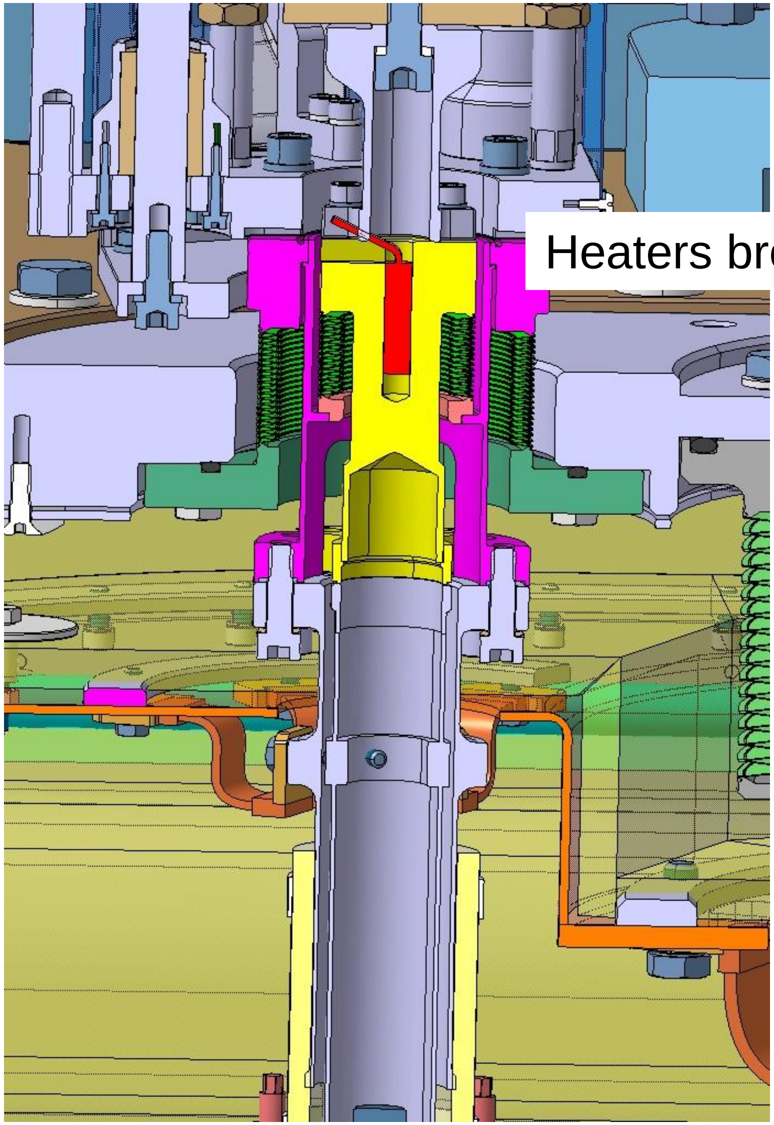
- Sudden increase of stiffness
- Limited by force interlock
- Still the same tuning sensitivity (motion transferred)
- Also cavity 2 some days later but less stiff

- The motor-gear coupling started slipping 19/10
- Cavity 2 motor-gear coupling did not slip



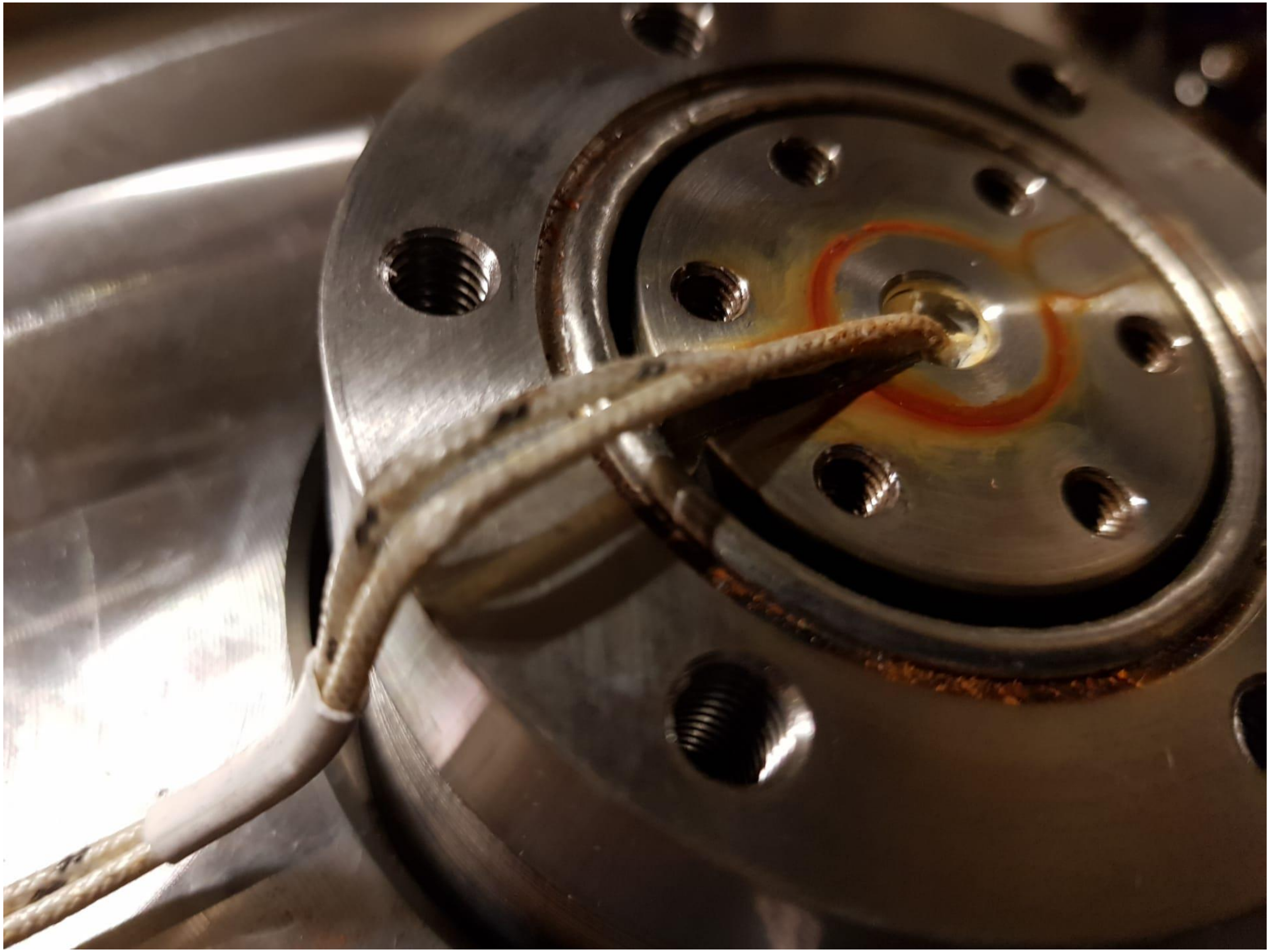


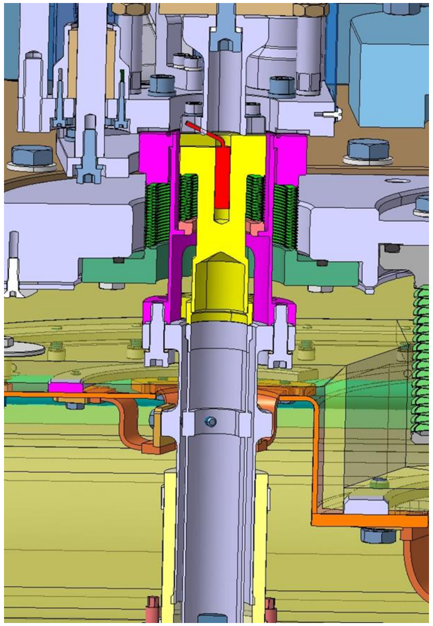
Possible causes blockage



Cavity 1

Cavity 2

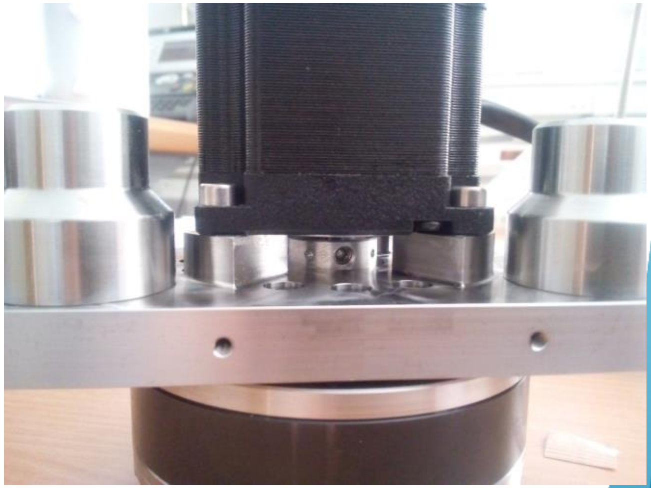




Cable creates bending moment, wrongly measured by load cell?
Or moment is strong enough to block bearing?
The coupling slipping indicates higher force.

Other possible cause: small clearances inside cryomodule, component shifted?

New design slip-free coupling that respects alignment tolerances is ready

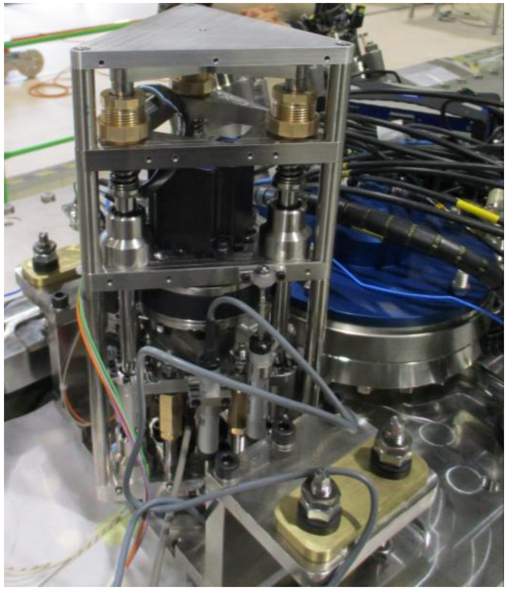


To be installed on SPS DQW TESTS and tested (at warm ?)

Status design components for RFD SPS TESTS and DQW and RFD HL-LHC:

Frame	design OK
Flexural guides	design OK
Double tuning tube, tuning bellows	Being redesigned, integration , clearances + make stronger
Linear actuator	Needs redesign, space and accesibility problem, reliability, instrumentation

Build a prototype for reliability testing



HL-LHC

Tuner actuator

Procurement of the actuator components strategy:

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

Test stand with tuner motorisation:

- Lifecycle
- Fatigue
- Radiation resistance

Conclusions

- The frequency reached at 2 K was exactly where we wanted, but we used a good part of the pre tuner range.
- The tuning at cold worked very well, but not for long enough. We were for sure very lucky (2 times).
- We «fine tune» or redo the design for RFD SPS TESTS and HL LHC

HiLumi
HL-LHC PROJECT

Thank you for your attention!

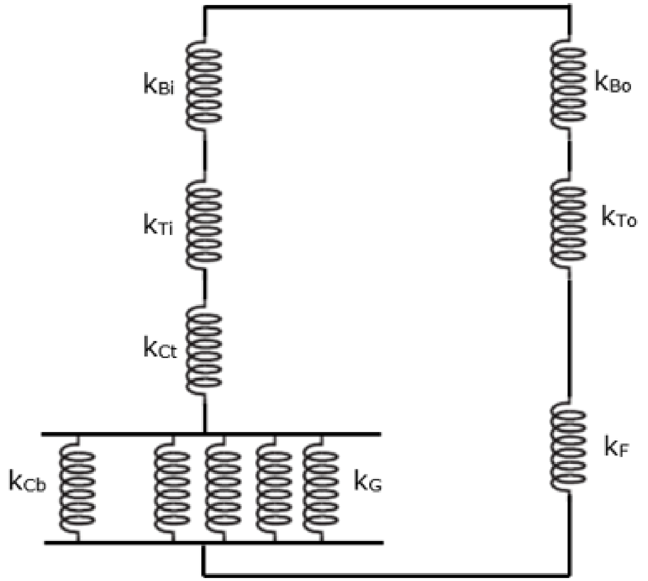
Time line tuner problems:

5th september: MD at 400.79 MHz
11th september: ~ 600 ksteps to neutral position (push) before small thermal cycle, both cavities

Thermal cycle
No mouvements between 11th and 27th september indicated
27th september: cav 2 -480 ksteps , cav 1 -400 ksteps to 400.528 , no problem.

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**