S1-Global
Tuner Performance Study

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on behalf of INFN Milan team

Tuning systems

- Main performances goals for tuning systems:
  - **Static or *Slow* tuning:**
    - Suitable tuning range according to cavity production frequency scatter. Typically 600 kHz for TESLA cavities.
    - Hz/step level frequency tuning resolution, with low hysteresis and mechanical backlash.
  - **Dynamic or *Fast* Tuning:**
    - Compensation of Lorentz Force induced Detuning or LFD during the flat-top or eventually during the full RF pulse

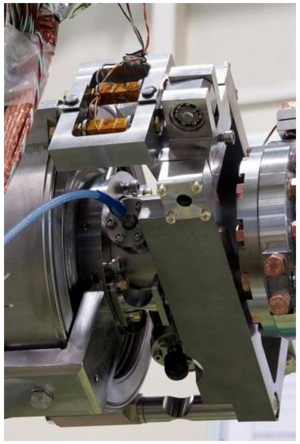
By design, S1-Global modules are rich in consolidated solutions as well as technical novelties and challenging issues.

This is true also for tuning systems: apart from the well established DESY/Saclay tuner, the others, the Blade from INFN/FNAL and the ones from KEK, are here installed on a string for the very first time.

S1-Global Cryomodule

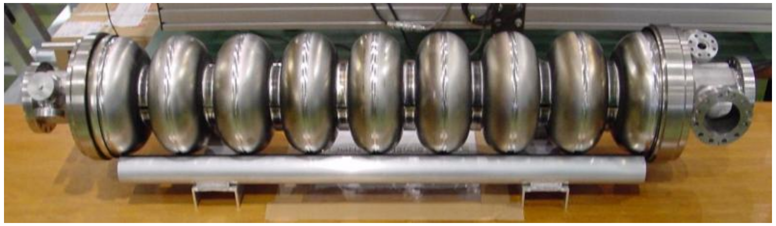
TESLA Cavity (DESY/FNAL)

Blade Tuner (INFN/FNAL)

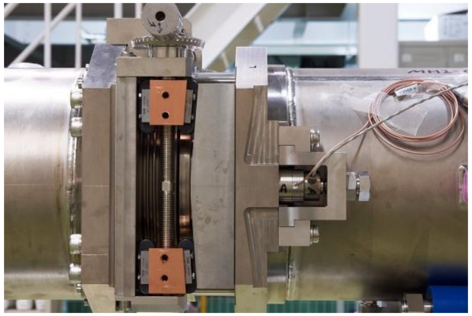


Saclay type Tuner (DESY)

TTF-III Coupler (DESY/FNAL)



Tesla-like (KEK)



Slide-Jack Tuner (KEK)

STF-II Coupler (KEK)

Tuning systems in details

- Cavities C1 and C2:
  - **Accel and AES TESLA cavities from FNAL**
  - **Helium tank from FNAL, specific design for coaxial tuner**
  - **Blade Tuner coaxial unit from INFN, revised ILC model**
  - **Motor drive unit with Phytron stepper motor and Harmonic Drive gear from FNAL**
  - **2 Noliac LV multilayer actuators from INFN**
- Cavities C3 and C4:
  - **"standard" DESY/FLASH TESLA cavity and helium tank system, fabricated by EZ**
  - **Lateral tuner with joint DESY/Saclay design**
  - **Motor drive unit composed by Phytron stepper motor and Harmonic Drive gear from DESY**
  - **2 Noliac LV multilayer actuators from DESY, packed in one single holder**
- Cavities A1 and A2:
  - **KEK TESLA-like cavities**
  - **KEK helium tank design for coaxial tuner**
  - **Slide Jack coaxial tuner mechanics from KEK**
  - **No drive unit installed. Tuner is manually driven from outside through a shaft.**
  - **One HV piezo from KEK**
- Cavities A3 and A4:
  - **The same than A1 and A2 cavity packages but with lateral tuner helium tank**
  - **KEK lateral Slide Jack tuner installed**

Overview

- A joint team from KEK, INFN and FNAL operated at S1-Global site:
  - **Module C tuners installation on February 2010, 2 Blade units and 2 DESY-Saclay units.**
  - **Low Power, CW, cold test of module C and A tuning systems on July 2010**

Room temperature measurement

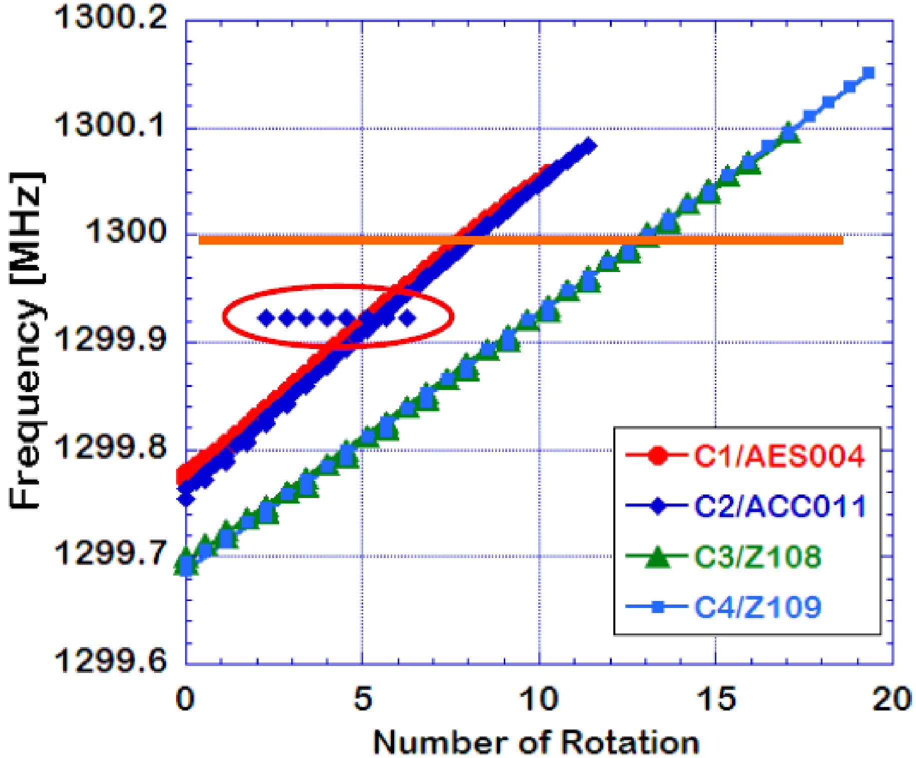
- Once tuner systems have been installed on mod. C, they have been subjected to a basic functionality check:
  - **Important cross-check prior to cold mass enclosing**
  - **2 failing piezo actuators in cavities C3 and C4 (DESY-Saclay tuners) discovered:**
    - Discharge observed at a voltage lower than nominal.
    - The issue has been identified as **superficial discharge due to impurities** and solved through an accurate acetone cleaning of piezo ceramic surfaces.
  - **Finally, all 4 tuning systems performed as expected:**
    - The frequency shifts induced by both motor drive units and piezo actuators (static, 2 piezos) have been measured.

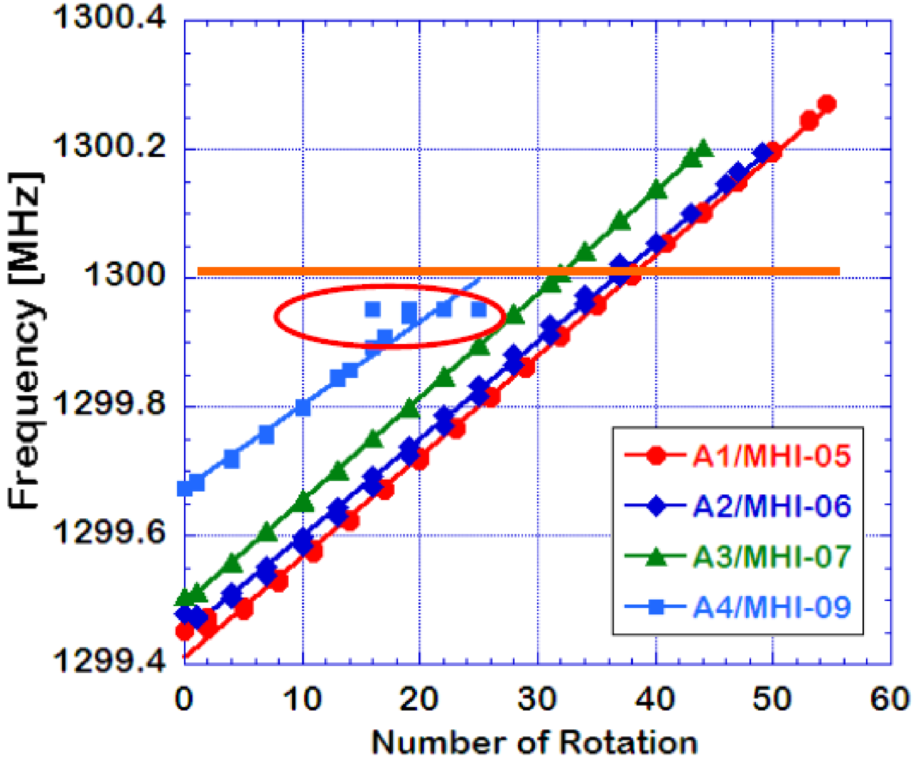
	C1 – Blade	C2 – Blade	C3 – Saclay	C4 - Saclay
Motor $\Delta\nu$/turn [kHz]	31	26	17	20
Piezo $\Delta\nu$/200V [kHz]	15	18	4	4

Static tuning range at cold

Cryomodule - C

Cryomodule - A





Trouble of two motor tuners occurred in C2/ACC011 (Blade) and A4/MHI-09 (Slide-Jack/end) !!

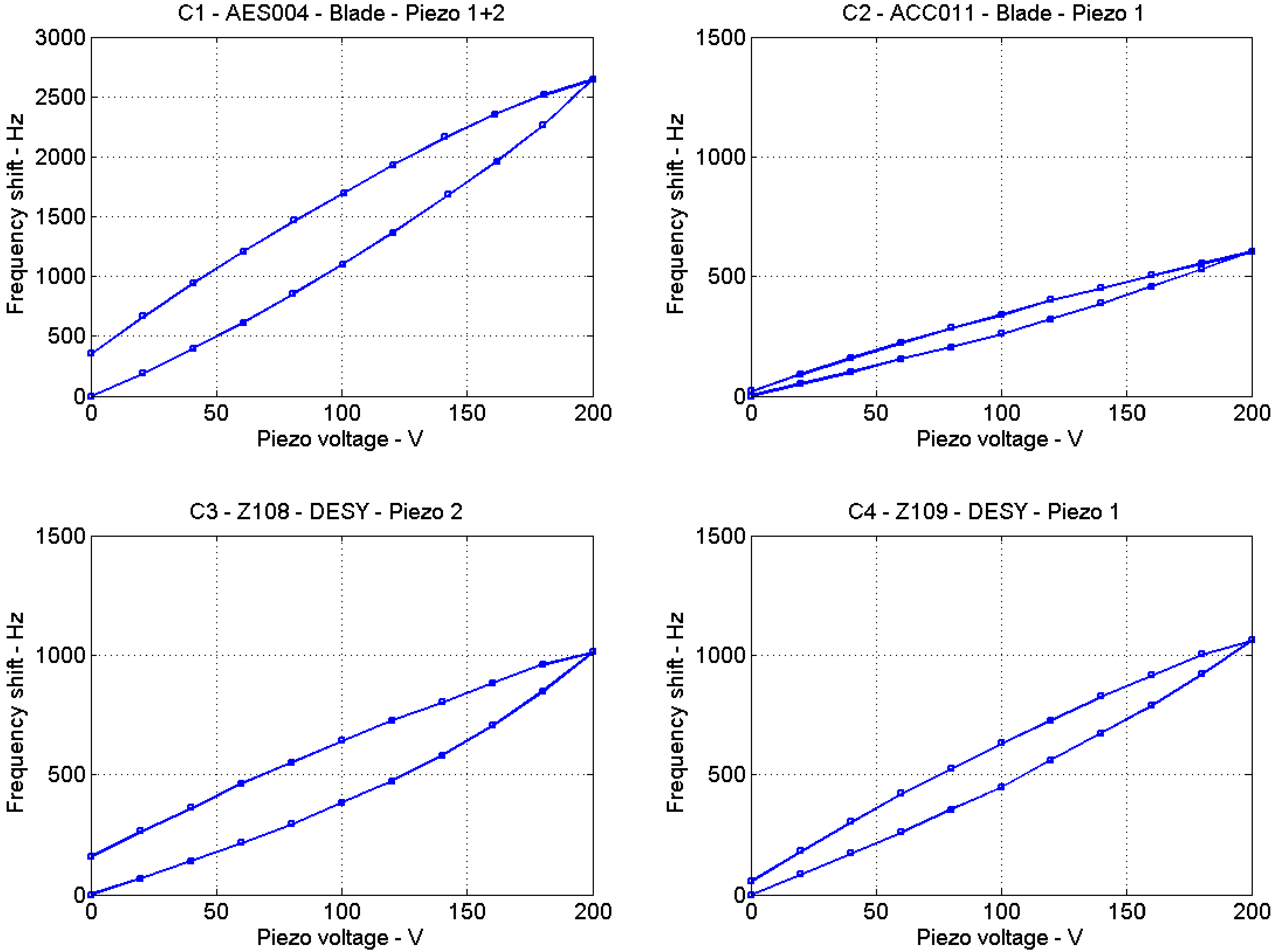
Static tuning range at cold

- For 6 out of 8 tuning systems installed the static tuning was confirmed in terms of range, hysteresis and capability to drive the cavity to operating frequency.
- Issue with Blade Tuner package in cavity C2:
  - **Correctly performed a first tuning cycle around 1.3 GHz**
  - **Still unknown failure happened during the second cycle and frequency resulted to be stacked at about 1299.92 MHz.**
- Issue with Slide Jack Tuner in A4:
  - **Initially moved toward higher frequencies**
  - **Failure occurred in the driving shaft joint and frequency resulted to be stacked at 1299.95 MHz.**

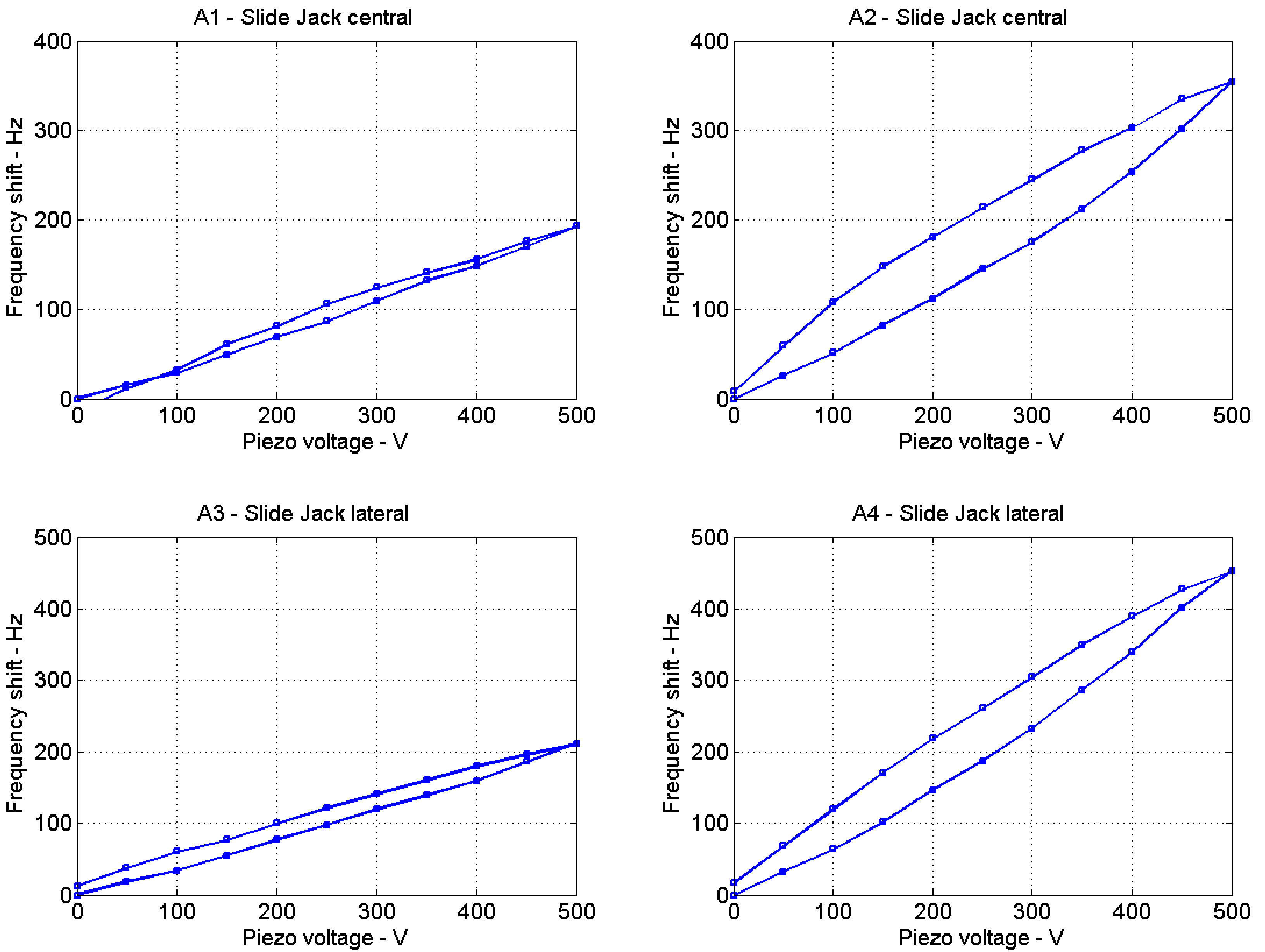
Piezo tuning range at cold

- Two main onset of measurements have been performed with fast actuators:
  - **DC piezo stroke, in different configurations. The cavity frequency shift is recorded as a function of the piezo DC driving voltage.**
    - This measurement allows for a direct evaluation of piezo integrity as well as the efficiency of their mechanical coupling to the cavity
  - **Pulsed piezo stroke. The dynamic frequency shift induced by a standard piezo pulse for LFD compensation is recorded.**
    - The pulse is a half-SIN waveform, 2.5 ms time width.
    - In this case the cavity intrinsic mechanical dynamic comes into the game, it's a meaningful evaluation of tuner LFD compensation capabilities.
- Measurements are performed with the cavity locked within a phase locked loop (PLL) with a 1kHz/V FM modulation factor:
  - **The modulation input signal is acquired, higher resolution and reproducibility is achieved if compared to direct NA measurements.**

Piezo DC response – module C



Piezo DC response – module A

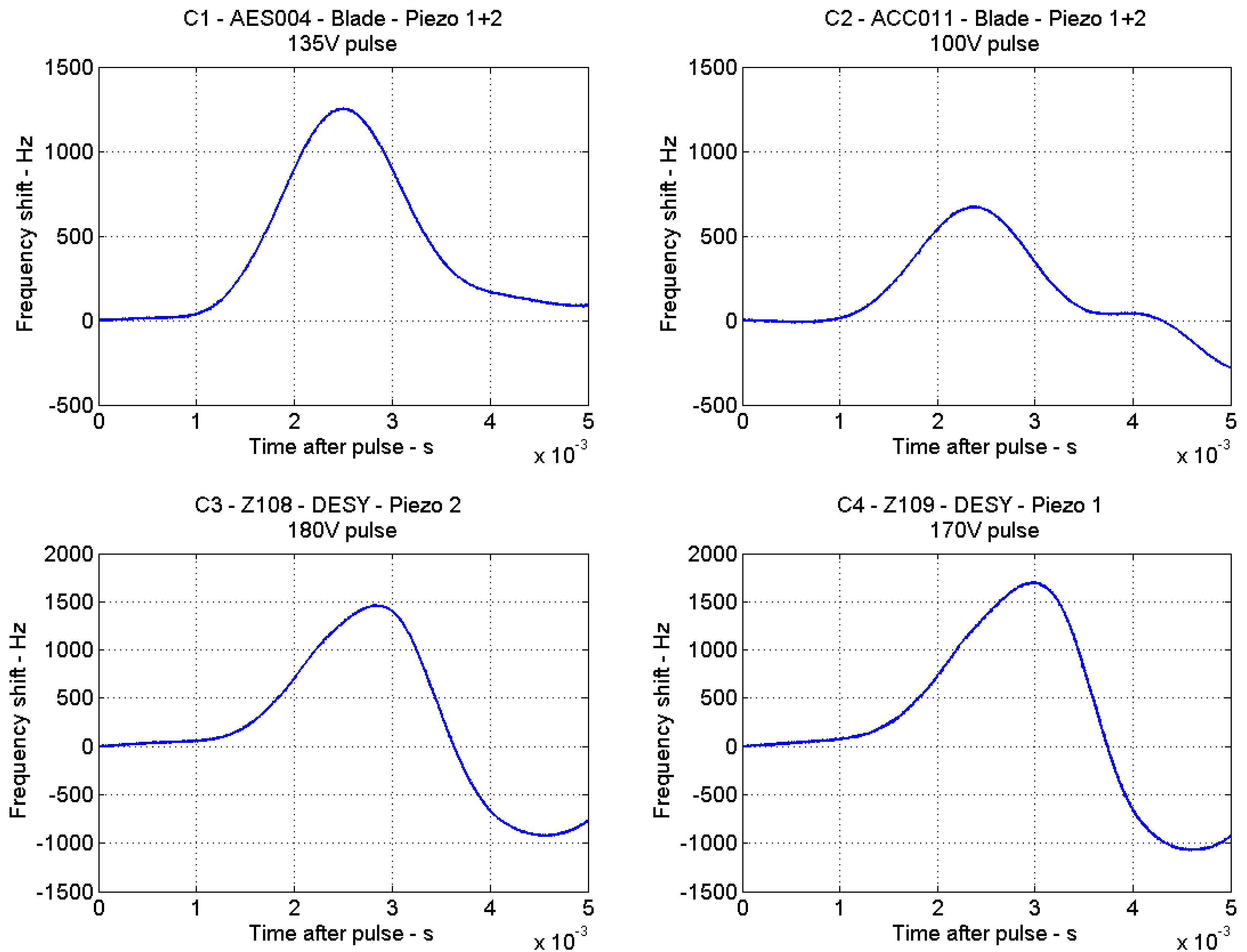


DC response analyses results

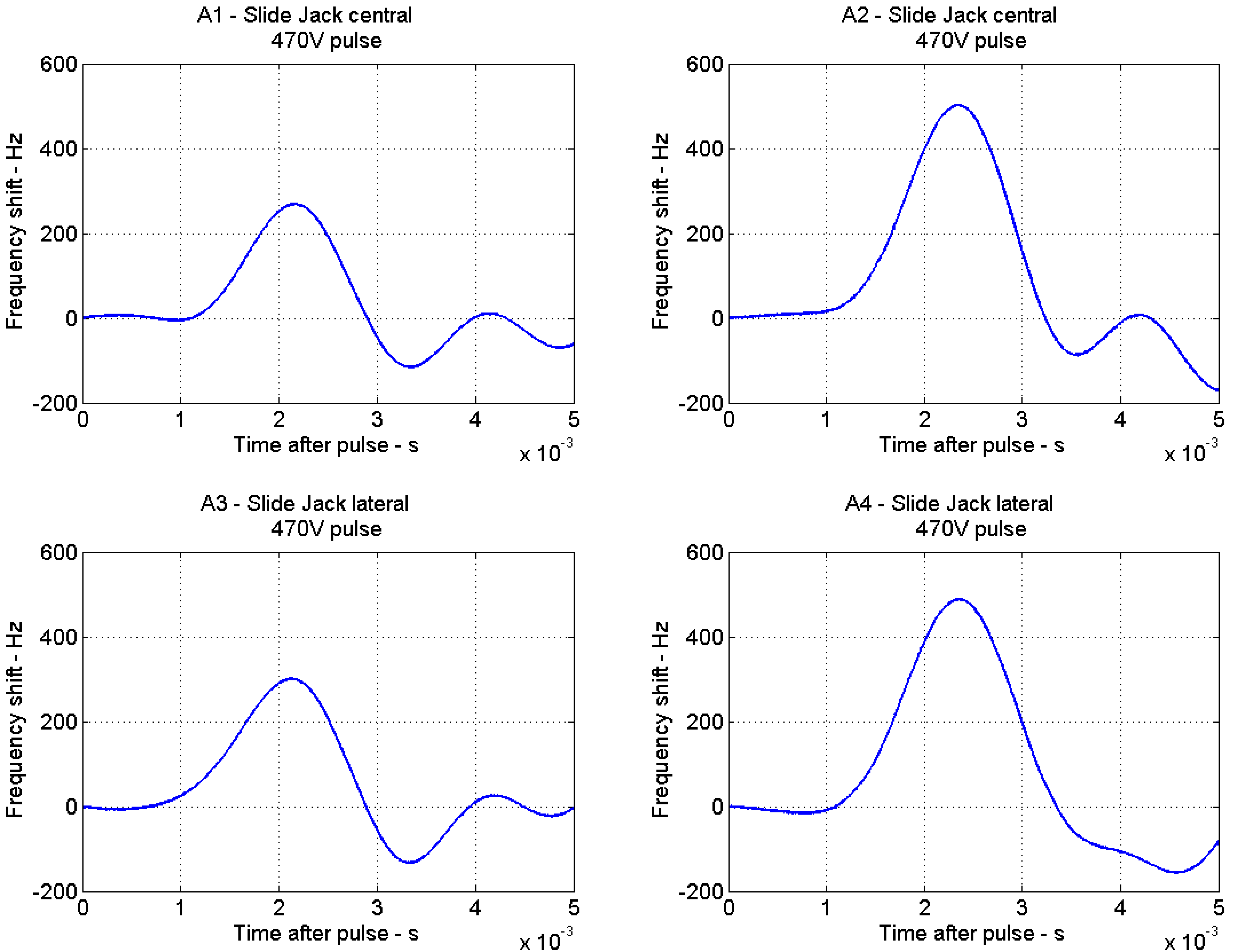
Table resumes piezo DC tuning results, the best piezo configuration is considered for module C cavities:

Cavity	Tuner	Maximum nominal piezo voltage [V]	Piezo configuration	Max applied voltage [V]	Frequency shift [Hz]
C1 – FNAL	Blade	200	1+2	200	2650
C2 – FNAL	Blade	200	1	200	610
C3 – DESY	DESY/Saclay	200	2	200	1010
C4 – DESY	DESY/Saclay	200	1	200	1060
A1 – KEK	Slide Jack cent.	500	-	500	190
A2 – KEK	Slide Jack cent.	500	-	500	350
A3 – KEK	Slide Jack lat.	500	-	500	210
A4 – KEK	Slide Jack lat.	500	-	500	450

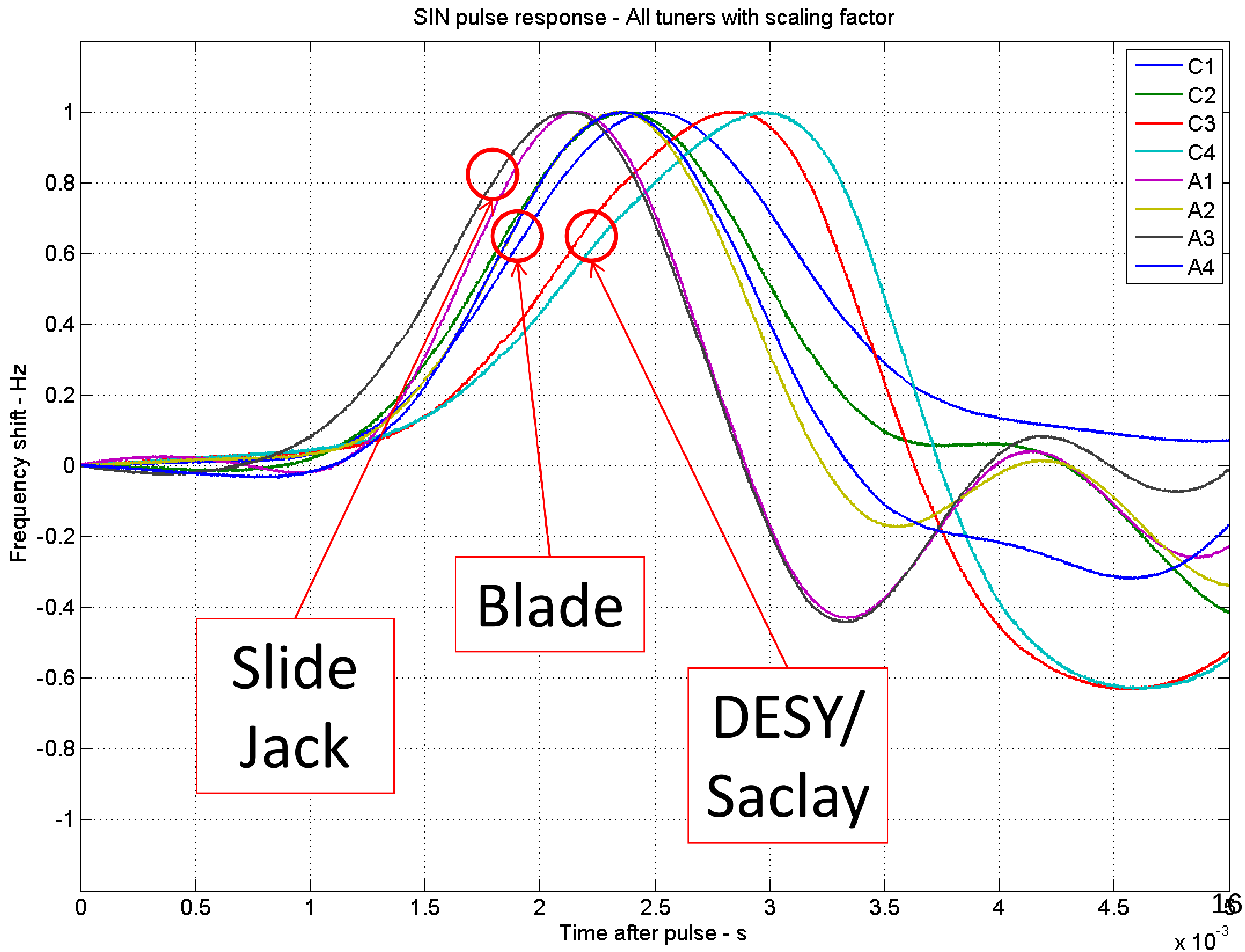
SIN pulse response – module C



SIN pulse response – module A



SIN pulse response – All

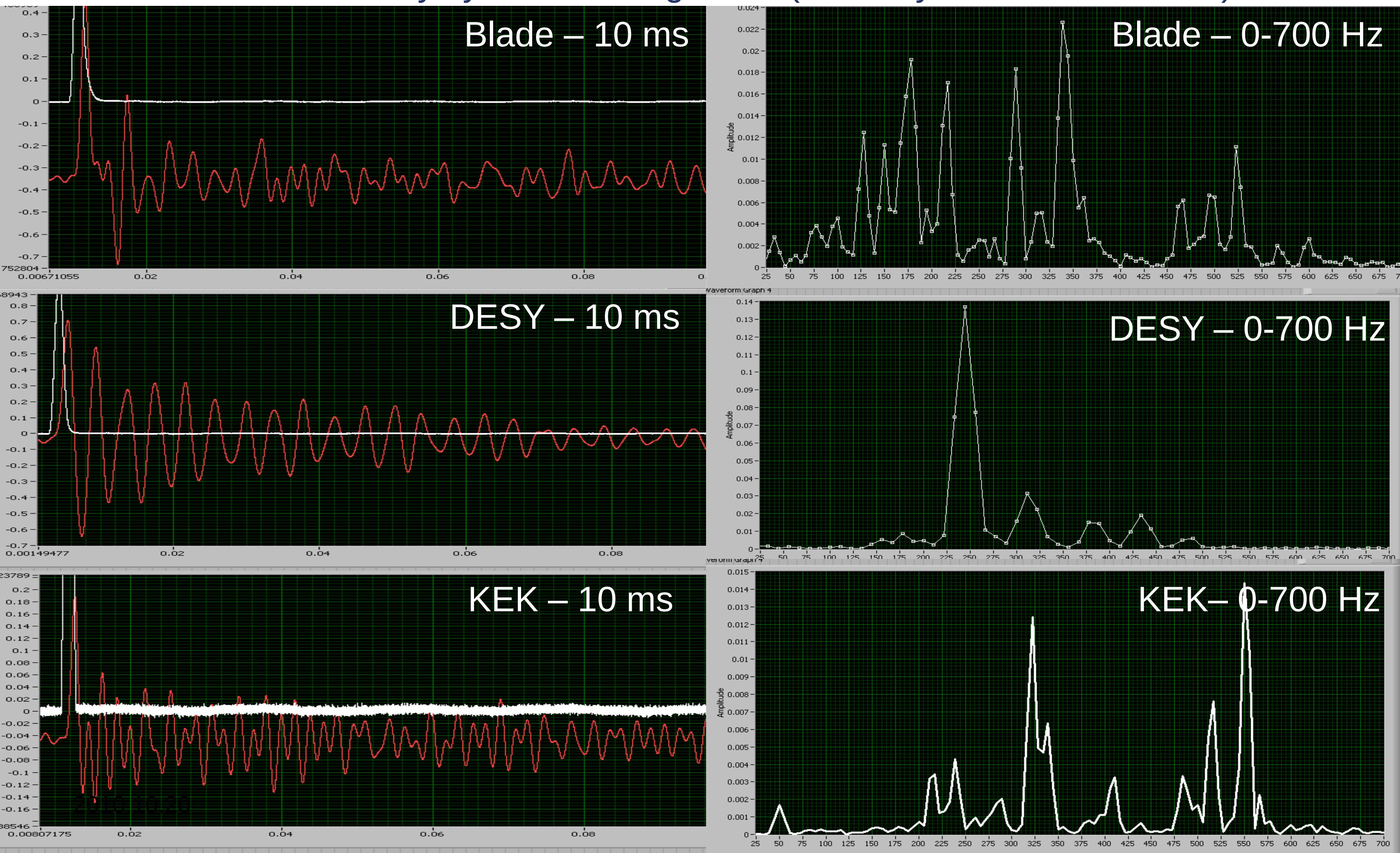


SIN pulse analyses results

Cavity - Tuner	Maximum piezo voltage [V]	Load C at 2 K [μF]	Piezo conf.	SIN pulse amp. [V]	Max. Freq. shift in 1 ms [Hz]	Best lead time from pulse start [ms]	Dynamic / Static detuning ratio
C1-FNAL Blade	200	4.1	1+2	135	1040	1.31	0.6
C2-FNAL Blade	200	3.9	1+2	100	590	1.24	1
C3-DESY DESY/Saclay	200	2.0	2	180	1100	1.58	1.2
C4-DESY DESY/Saclay	200	1.9	1	170	1170	1.64	1.3
A1-KEK S. Jack cent.	500	0.19	-	470	270	1.10	1.5
A2-KEK S. Jack cent.	500	0.21	-	470	450	1.26	1.4
A3-KEK S. Jack lat.	500	0.20	-	470	270	1.03	1.3
A4-KEK S. Jack lat.	500	0.21	-	470	450	1.22	1.1

Additional dynamic analyses

On a larger time scale, piezo response analyses reveal details of intrinsic dynamics of different cavity systems through FFT (courtesy of Y. Pischalnikov):



Dynamic analyses comments - 1

- Plain piezo issues in C2 (still unexplained):
  - **Severe lack of mechanical coupling on both piezo**
  - **Piezo 2 discharging at lower voltage, not seen at RT.**
  - **Puzzling scenario: possibly correlated to static tuning failure?**
- Assuming DESY design as a reference, the other two systems rely on two different design concepts. These could be named as:
  - **"*Small external stiffness guideline*" for the Blade Tuner:**
    - Simple and light cavity constraints, and therefore the same for the tuner
    - achieve a large LFD compensation capability as required
  - **"*High external stiffness guideline*" for the Slide Jack Tuner:**
    - Strong and stiff cavity constraints, and therefore the same for the tuner
    - Minimize the amount of LFD to be compensated

Dynamic analyses comments - 2

- Collected data set is fully consistent with the scenario previously described:
  - **Very large DC stroke for the Blade Tuner piezo system (C1) if directly compared to module A tuners. Accordingly larger LFD expected (and measured, see next talk by Y. Pischalnikov).**
  - **"Soft" Blade (and DESY actually) units systems act as low-bandwidth systems, with dominant modes placed at lower frequency and therefore longer rise-time.**
  - **"Stiff" KEK units act as high-bandwidth systems, with dominant modes at higher frequency and shorter rise-time.**
- Some other peculiarities emerged:
  - **Blade Tuner large DC tuning capabilities do not lead to equivalently high dynamic tuning capabilities. Both DESY and KEK systems took advantage in terms of static-to-dynamic detuning ratio:**
    - In DESY tuners case this is due to the purely harmonic response exhibited, sign of a clearly mechanically resonating cavity. This leads to a large dynamic overshoot when pulsing with piezo.
    - In KEK tuners case this is a direct effect of the system's higher bandwidth

Conclusions

- Globally speaking, all the four different tuning system design seemed to be able to accomplish their main goals:
  - **Statically tune the cavity with proper resolution**
  - **Ensure a dynamic piezo stroke sufficient to compensate the expected amount of LFD for that cavity, even in top-performance cavities**
- Severe failures emerged in some key components:
  - **Since motors, drives or piezo are well-known and (quite) affordable, the lack of experience with these brand new cavity systems could have played a major role.**
- High-power, pulsed RF test will clear the picture.
  - **See next talk from Y. Pischalnikov**