Test of the Cryomodule

Vitaliy Goryashko
E-mail:vitaliy.goryashko@physics.uu.se

Spoke section of the ESS linac

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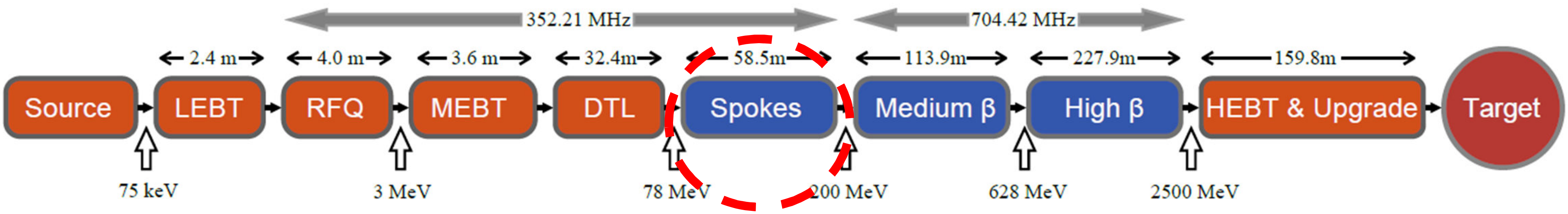
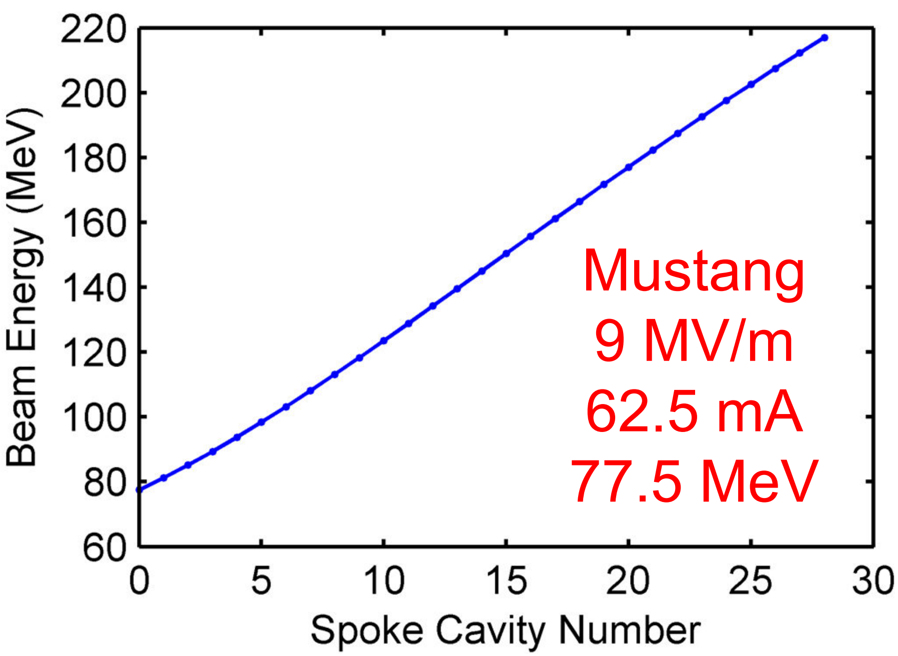
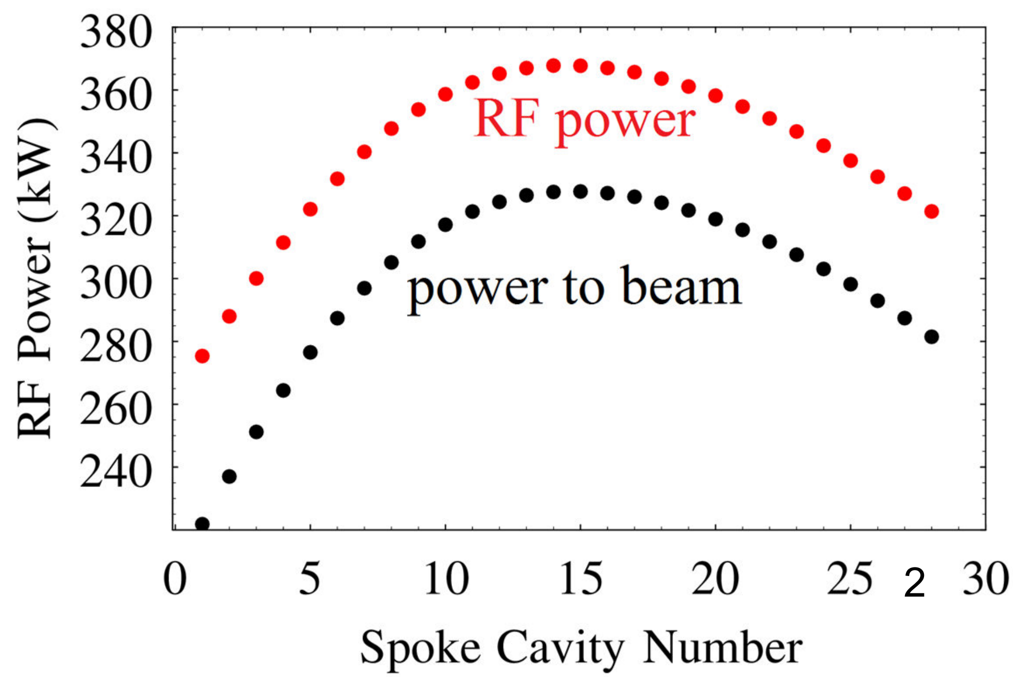


Section	Number of modules	Frequency [MHz]	Input energy [MeV]	Cavities per module	Cavities per sector	Module length [m]	Sector length [m]
Spoke	14	352.21	79	2	28	2.9	58.5





Test program of the cryomodule

1. Test of the cavity coupler:
- re-conditioning of the coupler: 400 kW, full pulse length
- RF properties of the coupler: external Q-factor, impedance
- thermal dynamics of the coupler: static and dynamic heat losses

2. Basic RF test of cavities
- Maximum accelerating gradient
- X-ray emission
- Dynamic RF losses
- Cavity quality factor

3. Lorentz detuning of a single cavity:
- static Lorentz detuning coefficient
- transfer function of the dynamic Lorentz detuning

4. Lorentz detuning compensation system:
- action of the piezo tuner on the cavity: adjustment of the cavity frequency and excitation of mechanical modes
- feed-forward system for compensation of the Lorentz detuning

5 Minimization of the RF power overhead

6. Reliability test of the tuner, stress test.

EMITTED POWER MEASUREMENT

THE REFERENCE MEASUREMENT FOR STRONGLY OVER COUPLED CAVITIES

Consider what happens when you suddenly remove the incident RF power from a cavity that has the stored energy U. This stored energy leaves the system through dissipation due to wall losses, i.e. Q_0 losses, and as RF power that is emitted from all of the RF ports in the system. Since $Q_L << Q_{FP}$ and $Q_L << Q_0$ in a strongly over coupled superconducting cavity the stored energy can be calculated as:

$$U = \int_{t_0}^{\infty} P_{emitted}(t)dt \approx \int_{t_0}^{\infty} P_{reflected}(t)dt$$

Historically value of U was measured using a gating circuit and an RMS power meter. In a sampled system, such as can be done with a Boonton 4532 pulsed power meter, the stored energy can be approximated by:

$$U \approx \sum_{m}^{N} \left(P_{reflected}\right)_i \Delta t$$

Where m is the sample point where the incident power is removed and N is the total number of sample points. In addition to the errors associated with the power measurement, there are errors in this measurement which are introduced by the sampling system that can be reduced by proper choice of system parameters.

Slide is adopted from Tom Power' presentation at SRF Workshop 2005

FIELD PROBE CALIBRATION

Once the stored energy has been determined the gradient can be calculated by using the following:

$$E_{Emitted} = \sqrt{2\pi f_0 * U * \frac{r/Q}{L}}$$

Where the emitted subscript is just an indicator of method used to determine the value. The filed probe coupling factor, Q_{FP} can the be calculated using:

$$Q_{FP} = \frac{E^2_{Emitted}}{(P_{Transmitted})_{m-1}} * \frac{L}{r/Q}$$

Where $P_{Transmitted}$ is sampled just prior to removal of the incident power signal. Normally an average of several points just prior to m is used for this value.

With good calibrations and proper sample rates the gradient, E, can be measured with an accuracy of 5% to 7% and Q of the field probe to about 10% to 12%.

Slide is adopted from Tom Power' presentation at SRF Workshop 2005

Cavity Voltage without Beam

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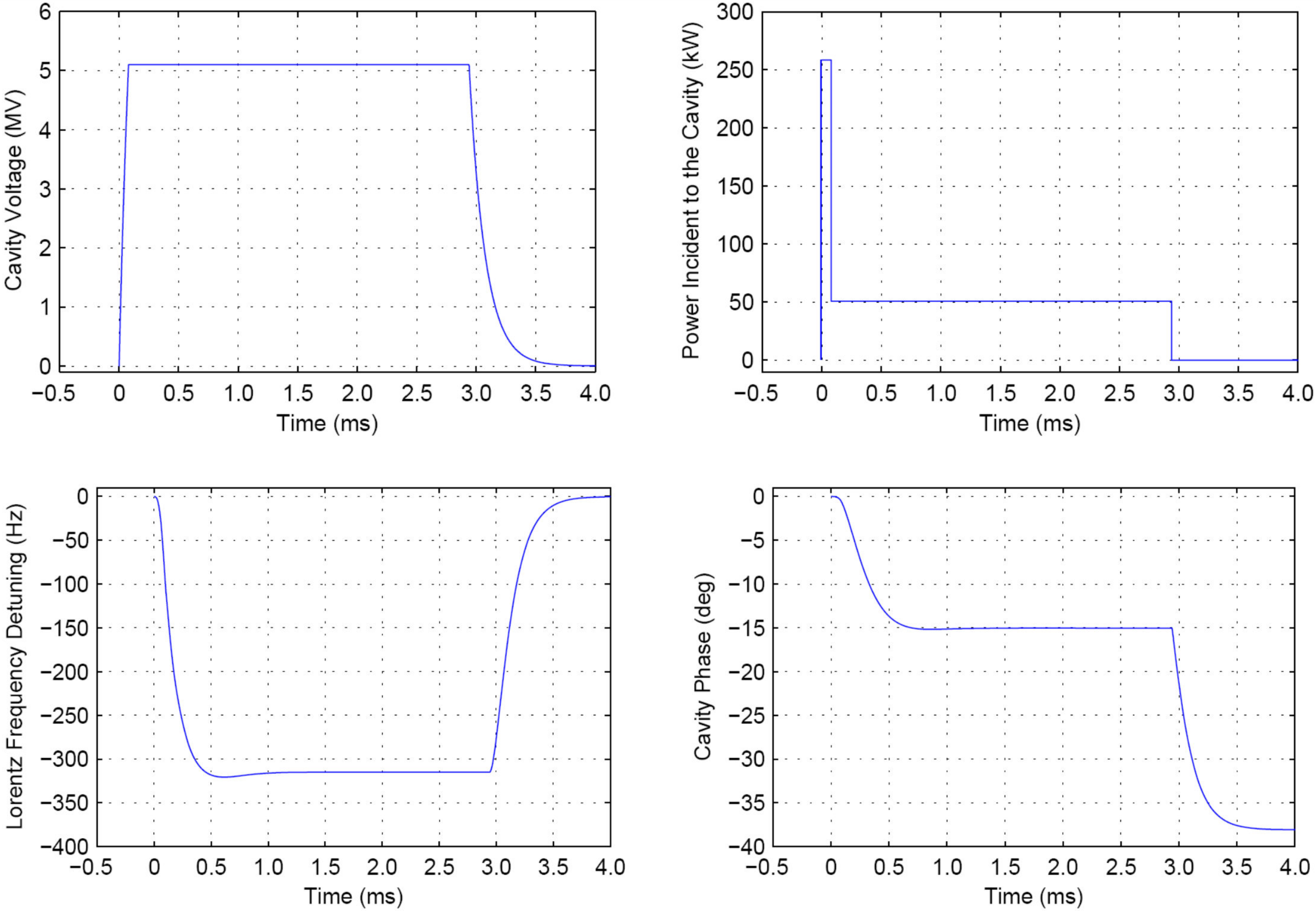


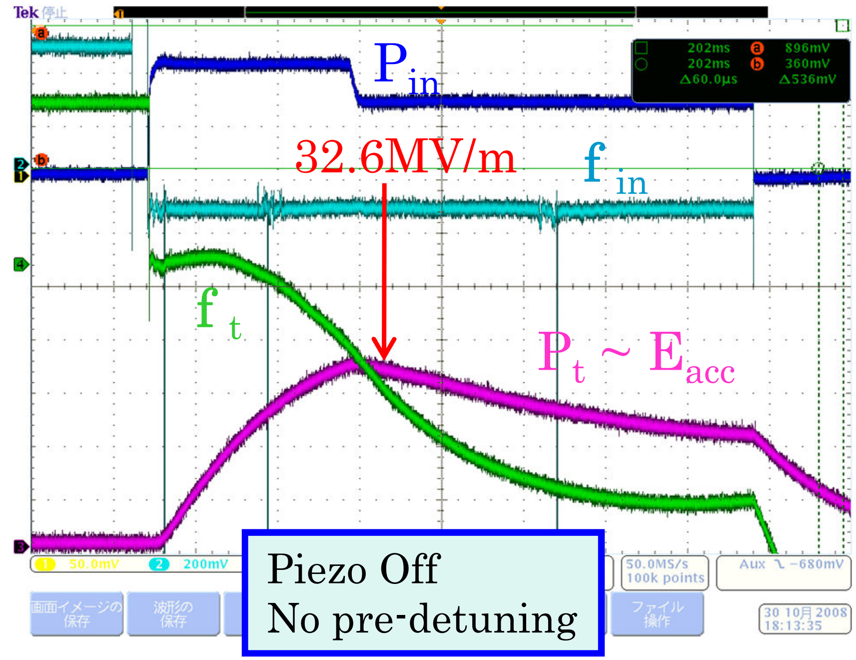
Standard feedforward with piezo tuners for TESLA

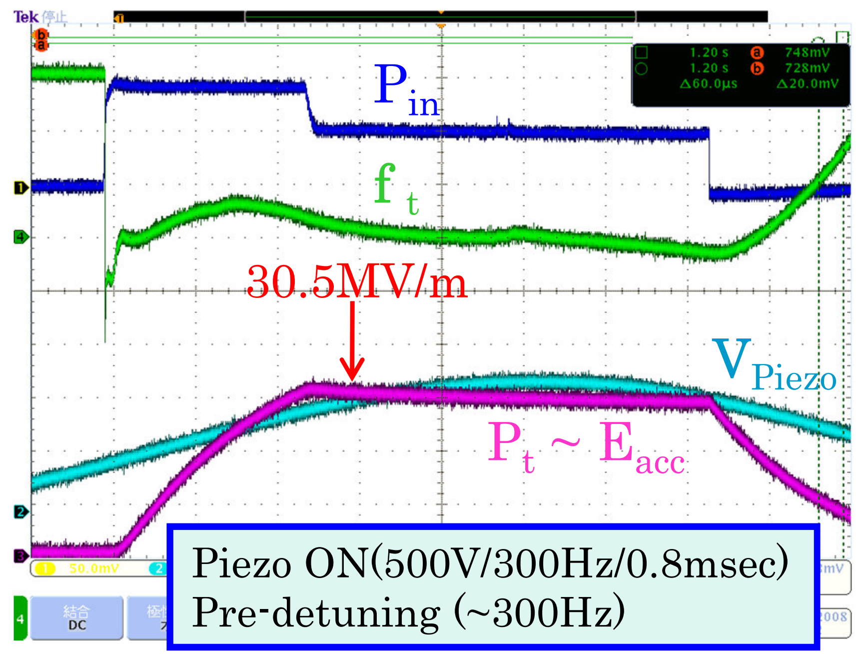
DESY approach uses a half-sine impulse

- rather simple wavefront of a piezo pulse
- good stabilization of the cavity frequency

BUT

- there is no optimization strategy to determine pulse parameters
- pulse parameters have to be re-adjusted for different operating conditions





H. Hayano, LCWS10

FERMI Lab feedforward with piezo tuners

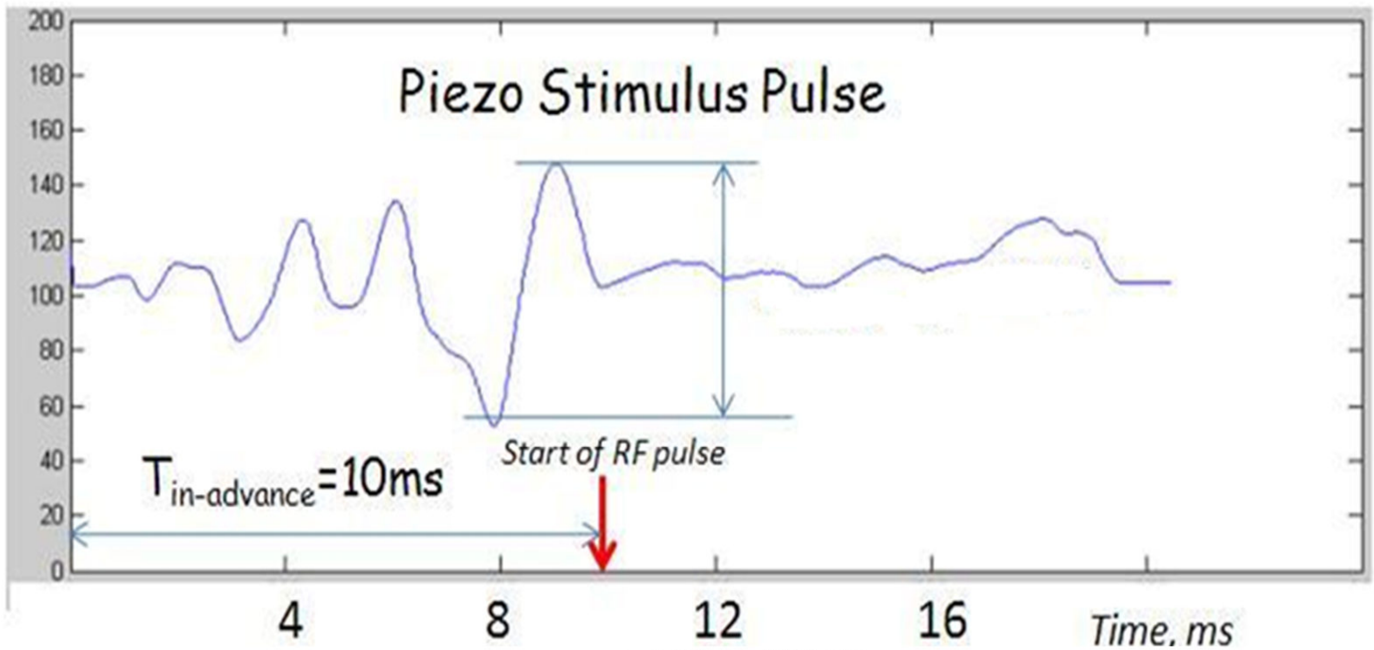
Optimized wavefront of a piezo pulse has a nontrivial oscillatory profile
BUT
gives very good result.

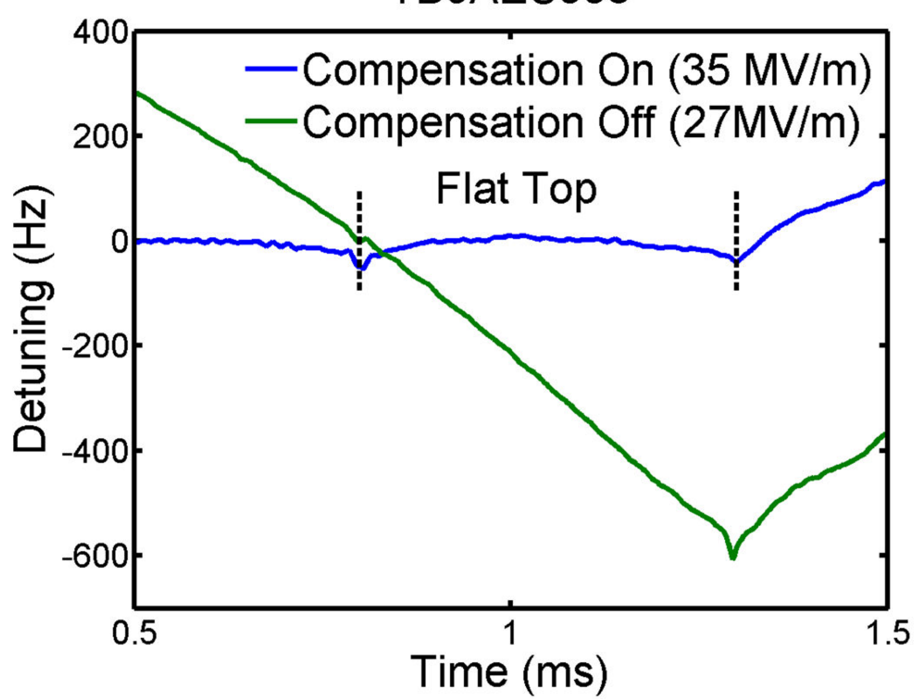
Will Fermilab approach give a good result also for the ESS spoke cavities?

What will this mean for the electroacoustic stability of two cavities?

To what extent can we minimize RF power consumption?

What is the optimum way of charging the cavity?





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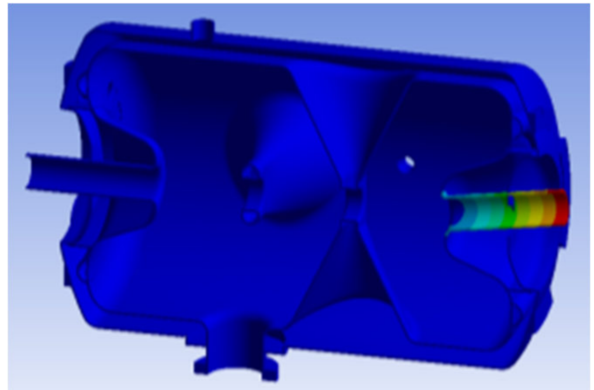
Mechanical modes of the spoke

FREIA

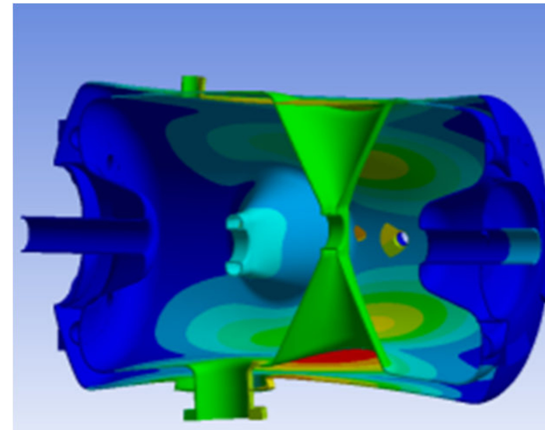
G. Olry, SHLIPP-13

N°	Frequency	Mode
1 & 2	212Hz	Beam tube on CTS side
3 & 4	**265Hz & 275Hz**	**Spoke bar/Helium vessel**
5 & 6	**285Hz**	**Coupled mode Cavity/Helium vessel**
7	313Hz	Helium vessel
8 to 11	**315Hz to 365Hz**	**Coupled mode Cavity/Helium vessel**
12	**396Hz**	**beam tubes**

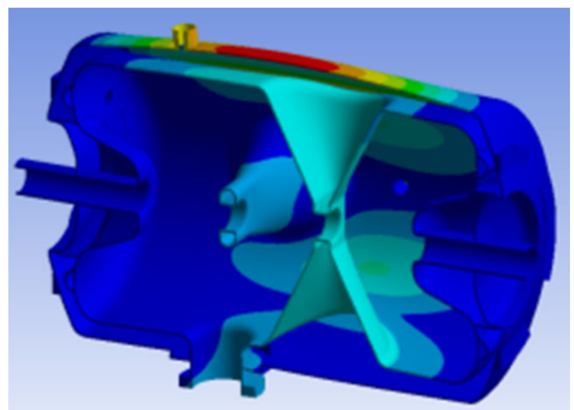
Mode 1: 212 Hz



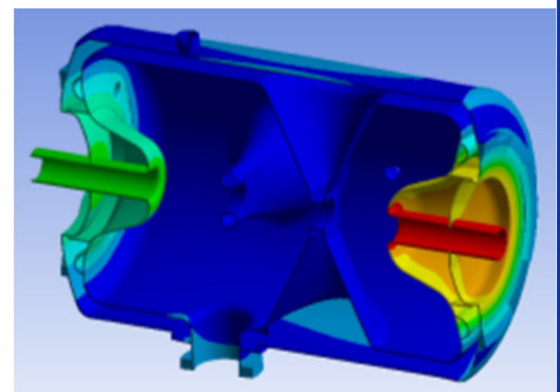
Mode 3: 265



Mode 5:



Mode 12: 396Hz

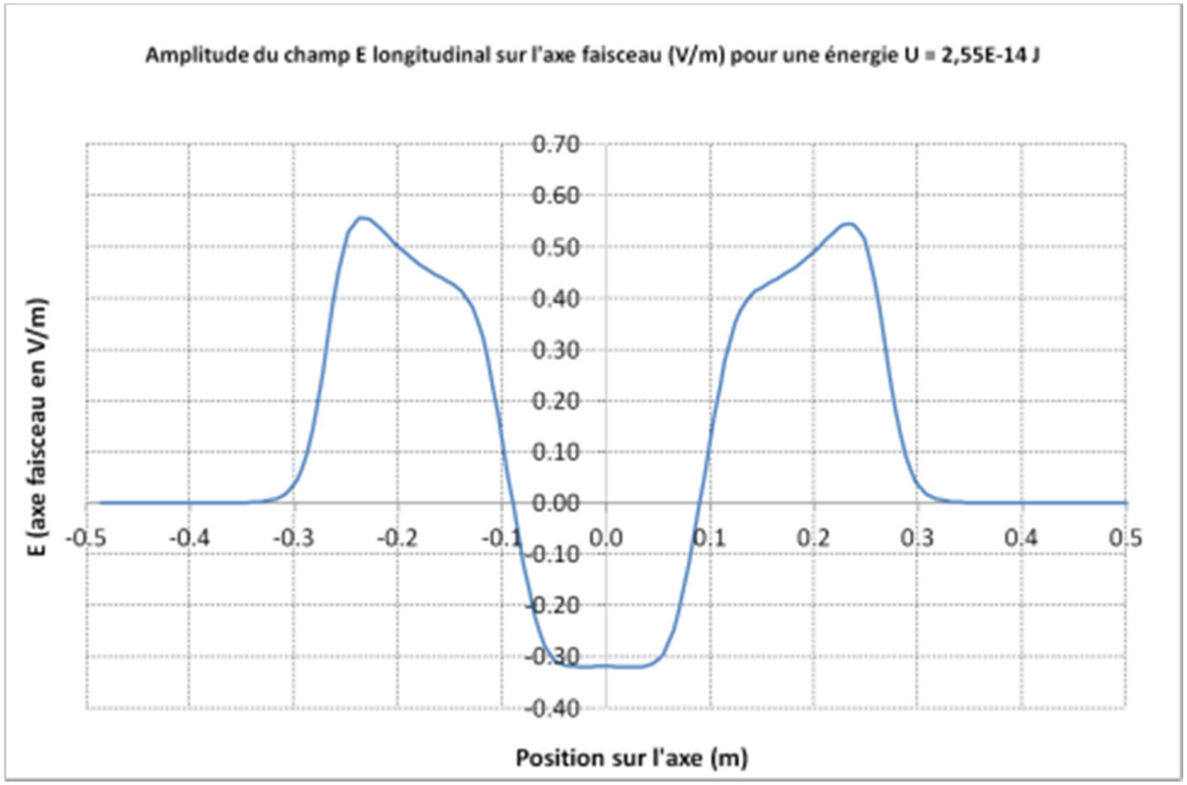


Harmonics of 14 Hz	15	19	20	22	28
Values in Hz	210	266	280	308	392

Electroacoustic oscillations of the spoke

G. Olry, SHLIPP-13

Parameters	ANSYS
Frequency [MHz]	351,76
Beta	0.5
B_{pk}/E_{acc} [mT/(MV/m)]	6,84
E_{pk}/E_{acc}	4.33
G [Ohm]	127
r/Q [Ohms]	424
$L_{acc} = N_{gap}.\beta.\lambda/2$ [m]	0.639
Temperature (K)	2
Q_0 Cu@ 300K	26469
Q_0 Nb@ 2K	$1.19*10^{10}$

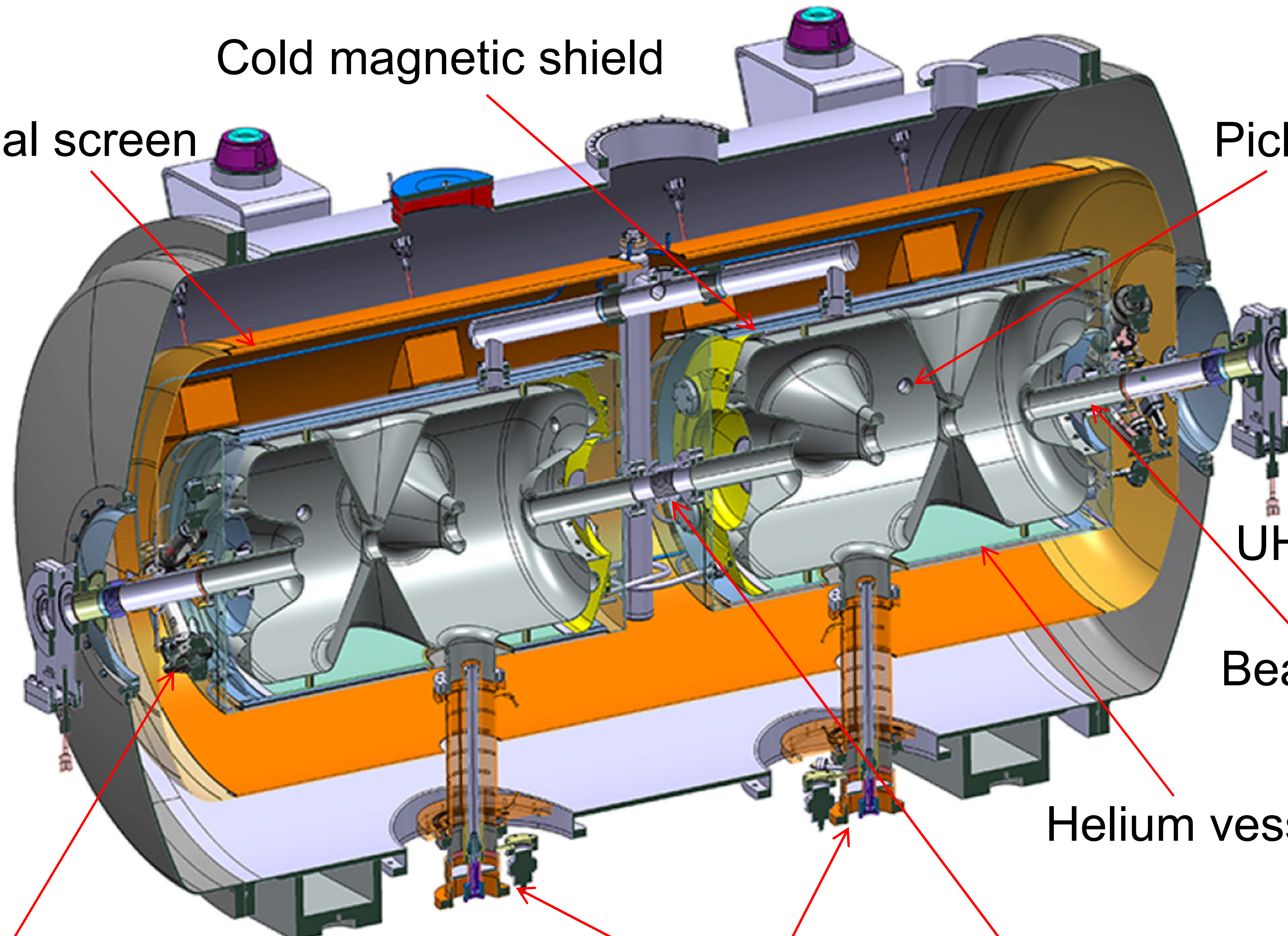


The field deviation is around 1V/m

Electroacoustic oscillations are not a problem for a single spoke BUT

- the eigen mechanical frequencies for the cryomodule will be different and may be a low harmonic of 14 Hz;
- feedforward with the piezo tuner will also excite mechanical modes.

ESS cryomodule. What else should be studied???



Ponderomotive instabilities and microphonics

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$$U=\frac{1}{2}\sum_{\mu}c_{\mu}q_{\mu}^{2},\quad T=\frac{1}{2}\sum_{\mu}c_{\mu}\frac{\dot{q}_{\mu}^{2}}{\Omega_{\mu}^{2}},\quad \Phi=\sum_{\mu}\frac{c_{\mu}}{\tau_{\mu}}\frac{\dot{q}_{\mu}^{2}}{\Omega_{\mu}^{2}}$$

$$\frac{d}{dt}\frac{\partial L}{\partial\dot{q}_{\mu}}-\frac{\partial L}{\partial q_{\mu}}+\frac{\partial\Phi}{\partial\dot{q}_{\mu}}=F_{\mu}$$

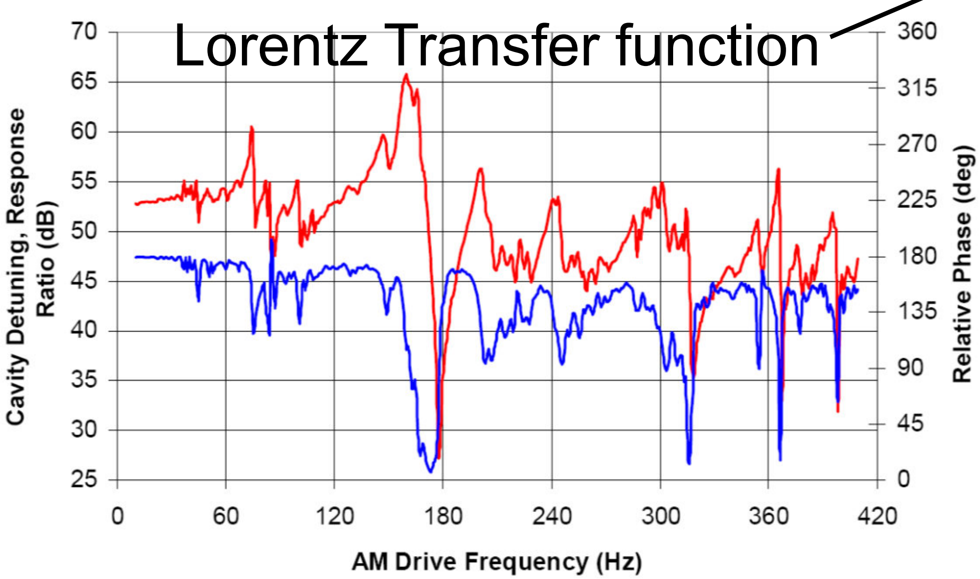
$$\ddot{q}_{\mu}+\frac{2}{\tau_{\mu}}\dot{q}_{\mu}+\Omega_{\mu}^{2}q_{\mu}=\frac{\Omega_{\mu}^{2}}{c_{\mu}}F_{\mu}$$

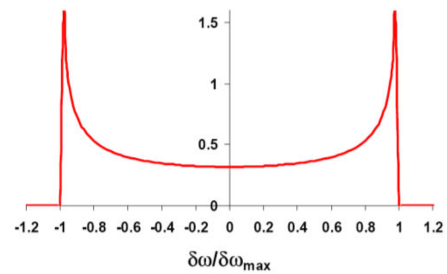
$$\Delta\ddot{\omega}_{\mu}+\frac{2}{\tau_{\mu}}\Delta\dot{\omega}_{\mu}+\Omega_{\mu}^{2}\Delta\omega_{\mu}=-k_{\mu}\Omega_{\mu}^{2}V^{2}+n(t)$$

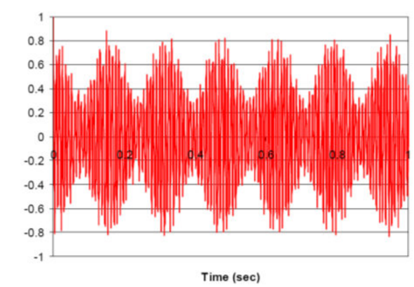
$$\delta\ddot{\omega}_{\mu}+\frac{2}{\tau_{\mu}}\delta\dot{\omega}_{\mu}+\Omega_{\mu}^{2}\delta\omega_{\mu}=-2\Omega_{\mu}^{2}k_{\mu}V_{0}^{2}\delta v+n(t)$$

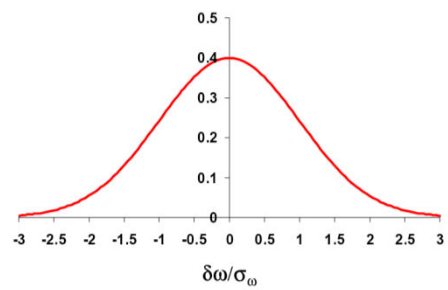
where $\Delta\omega_{\mu}=\Delta\omega_{\mu0}+\delta\omega_{\mu}$ and $V=V_{0}(1+\delta v)$.

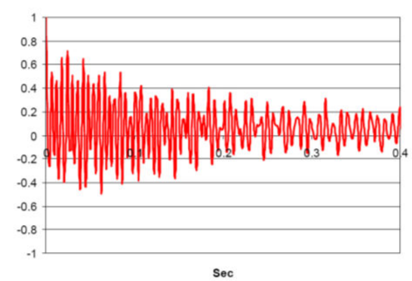
$$\frac{\delta\omega_{\mu}(\omega)}{\delta v(\omega)}=\frac{-2\Omega_{\mu}^{2}k_{\mu}V_{0}^{2}}{\left(\Omega_{\mu}^{2}-\omega^{2}\right)+\frac{2}{\tau_{\mu}}i\omega}=G_{\mu}(\omega)$$











Time Statistics 1

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• will be improved for next CHECHIA test

– demonstrate active detuning compensation using piezos

Some statistics on the test

- Test running 7.3.2003 – 14.8.2003
  - test took about 160 days (exact 3848 hours)
  - Scheduled cryo shutdown about 600 hours
  - warm-ups: 2x300 K, 4-5 times around 100 K
- Processing took about 165 hours
  - coupler 130 hours
  - cavity 35 hours
- RF operation of the coupler
  - cavity off-resonance and not at 2 K
  - power between 150 – 600 kW
  - 5 Hz operation very smooth
  - 10 Hz causes heating of the warm ceramics
  - **Total time RF on ~ 2400 hours**
- RF operation of the cavity
  - **1100 hours at around 35 +/-1 MV/m**
    - **~110 hours without interruption**
    - **57 hours at 36 MV/m +**
  - most of this is feed-forward operation
- Piezo compensation
  - **about 700 hours**

Time Statistics 2

- LINAC shutdown related (work on cooling water, etc.)
- automated operation, no shifts for cryo or CHECHIA operation
- Piezo tuner setup

LLRF

- About 160 hours were used for LLRF setup/commissioning including feedback
- a part of the operation at 15-30 MV/m was also used for LLRF
- a few hours at 35 MV/m (<100) were operated at ~35 MV/m
- very old DSP system, different from the one used in the machine, exchange for LINAC system did not cure noise problem but improved operability
- large noise on the cavity signals for the DSP
  - the gain of the feedback loop was insufficient to compensate drifts in Klystron output power
  - one source of noise was identified (switching power supply) and will be removed for the next CHECHIA test

Distribution of RF test