Initial ESS prototype High Beta cavity piezo based characterization and first LFD compensation experiences

Wojciech Cichalewski (LUT-DMCS), Grzegorz Jablonski (LUT-DMCS), Andrzej Napieralski (LUT-DMCS), Dariusz Makowski (LUT-DMCS), Aleksander Mielczarek (LUT-DMCS), Piotr Perek (LUT-DMCS), Aleksander Szubert (LUT-DMCS), Pawel Plewinski (LUT-DMCS), Adam Abramowicz(WUT-ISE),Krzysztof Czuba (WUT-ISE), Maciej Grzegrzolka (WUT-ISE), Igor Rutkowski (WUT-ISE), Jaroslaw Szewinski (NCBJ), Marcin Gosk (NCBJ), Dominik Rybka (NCBJ),

Outlook

1. ESS principles,
2. Piezo based cavity characterization in FREIA,
3. Initial LFD detuning compensation study,
4. Summary

ESS principles

European **S**pallation **S**ource – **E**uropean **R**esarch **I**nfrastructure **C**onsortium

Parameter	Units	Value
Energy	GeV	2.0
Current	mA	62.5
Pulse length	ms	2.86
Pulse repetition frequency	Hz	14
Average power	MW	5
Power during pulse	MW	125

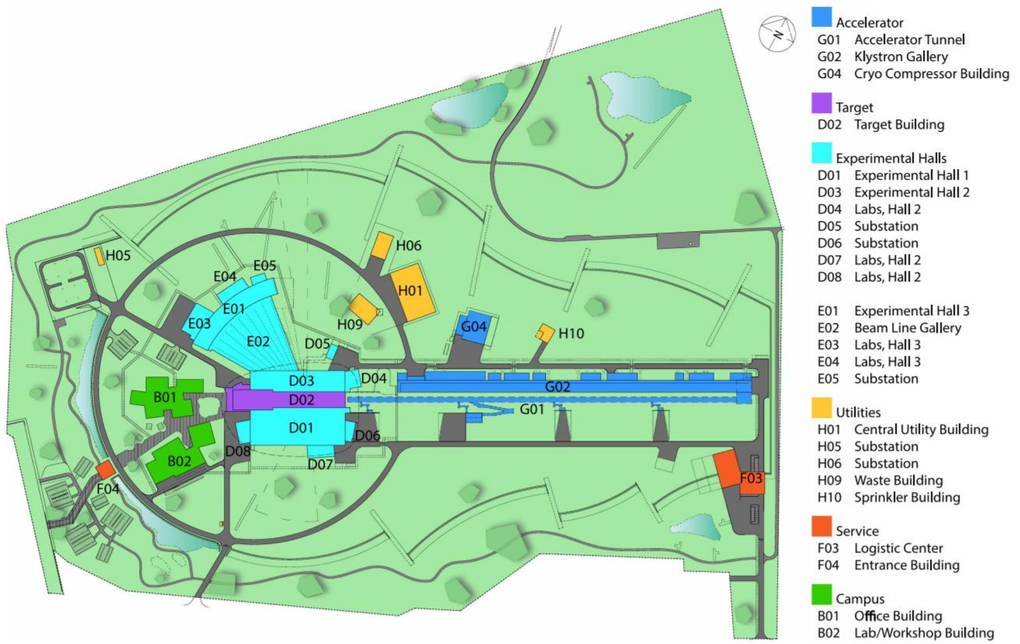


Figure 1. Layout of the ESS facility.

The European Spallation Source Design
Roland Garoby et al 2018 Phys. Scr. 93 014001

ESS principles - ACC collaboration

Institution	Main deliverables
Aarhus Univ (DK)	Rastering system
Atomki (HU)	RF local protection system
Bergen University (NO)	Seconded staff
CEA Saclay (FR)	RFQ, elliptical cavities and cryomodules, diagnostics
DESY (DE)	Diagnostics
Elettra (IT)	Spoke RF sources, magnets, power converters, diagnostics
ESS-Bilbao (ES)	MEBT, warm linac RF, diagnostics
Huddersfield Univ (UK)	RF distribution, radiation protection
IFJ PAN (PL)	Manpower for installation
INFN Catania (IT)	Ion source, LEBT
INFN Legnaro (IT)	Drift tube linac
INFN Milan (IT)	Medium-beta elliptical cavities
IPN Orsay (FR)	Spoke cavities, cryo distribution
Lodz Univ of Techn (PL)	Low-level RF
Lund Univ (SE)	Low-level RF
NCBJ (PL)	Low-level RF, gamma blockers
Oslo Univ (NO)	Diagnostics
STFC Daresbury (UK)	High-beta elliptical cavities, vacuum
Tallinn Univ of Techn (EE)	IOT modulator development
Uppsala Univ (SE)	Tests of spoke cavities and cryomodules
Warsaw Univ of Techn (PL)	Phase-reference line, low-level RF
Wroclaw Univ of Techn (PL)	Cryogenic distribution

The European Spallation Source Design
Roland Garoby et al 2018 Phys. Scr. 93 014001

ESS principles - Linac

European **S**pallation **S**ource – **E**uropean **R**esarch **I**nfrastructure **C**onsortium

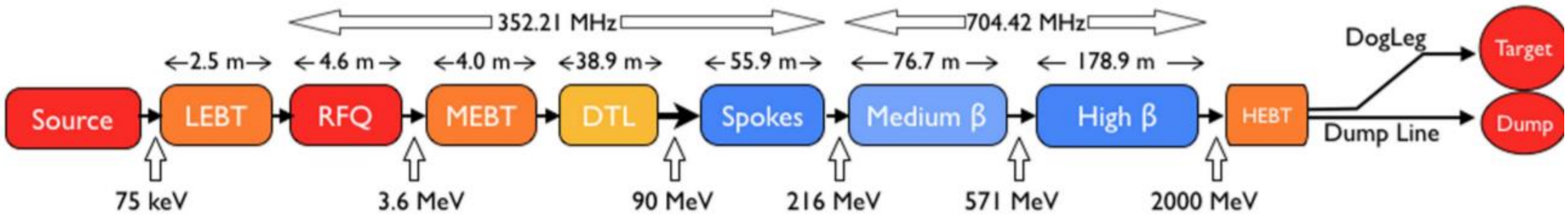


Table 19. Number of cavities, frequency and peak power level.

Linac section	Energy (MeV)	Freq. (MHz)	Number of cavities	Cavities per cryo-module	Geometric β	Temp. (K)	Max. RF power (kW)
Source	0.075	—	0	—	—	300	—
LEBT	0.075	—	0	—	—	300	—
RFQ	3.6	352.21	1	—	—	300	1600
MEBT	3.6	352.21	3	—	—	300	20
DTL	90	352.21	5	—	—	300	2200
Spoke	220	352.21	6	2	0.5 β_{opt}	2	330
Medium-β	570	704.42	36	4	0.67	2	870
High-β	2000	704.42	84	4	0.86	2	1100
HEBT	2000	—	0	—	—	300	—

The European Spallation Source Design
Roland Garoby et al 2018 Phys. Scr. 93 014001

ESS principles – H-beta cavity

Figure 1: High beta 704.42 MHz undressed cavity.

Requirement	High-beta
Frequency (MHz)	704.42
Beta	0.86
E_{acc} (MV/m)	19.9
E_{pk} (MV/m)	45
B_{pk}/E_{acc} (mT MV/m)	4.3
E_{pk}/E_{acc}	2.2
Iris diameter (mm)	120
RF peak power (kW)	1100
G/Omega	241
Maximum R/Q (Ohms)	477
Q_{ext}	7.6×10^5
Minimum Q_u	5×10^9

ESS HIGH-BETA CAVITY TEST PREPARATIONS AT DARESBURY LABORATORY, P.A Smith et all., SRF2017

Parameter	Unit	Value
K_L fixed ends	Hz $(\mathrm{MV\ m^{-1}})^{-2}$	−0.36
K_L free ends	Hz $(\mathrm{MV\ m^{-1}})^{-2}$	−8.9
Stiffness	kN $\mathrm{mm^{-1}}$	2.59
Df/Dz	kHz $\mathrm{mm^{-1}}$	197
max VM stress per 1 mm elongation	MPa	25
K_p fixed ends	Hz $\mathrm{mbar^{-1}}$	4.85
K_p free ends	Hz $\mathrm{mbar^{-1}}$	−150
max VM stress per 1 bar fixed	MPa	12
max VM stress per 1 bar free	MPa	15

The European Spallation Source Design
Roland Garoby et al 2018 Phys. Scr. 93 014001

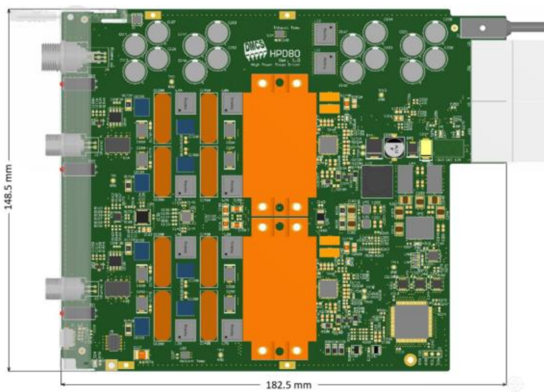
Piezo based cavity characterization

- Main goals:

1. Piezo driver (MTCA.4 version) evaluation,
2. Cavity parameters determination for cavity simulator configuration

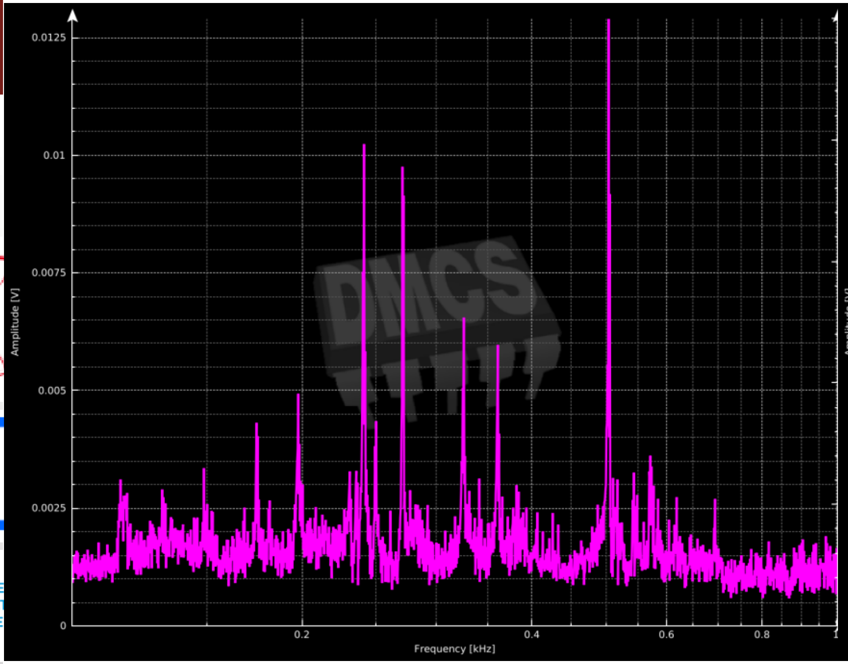
- Tests scope

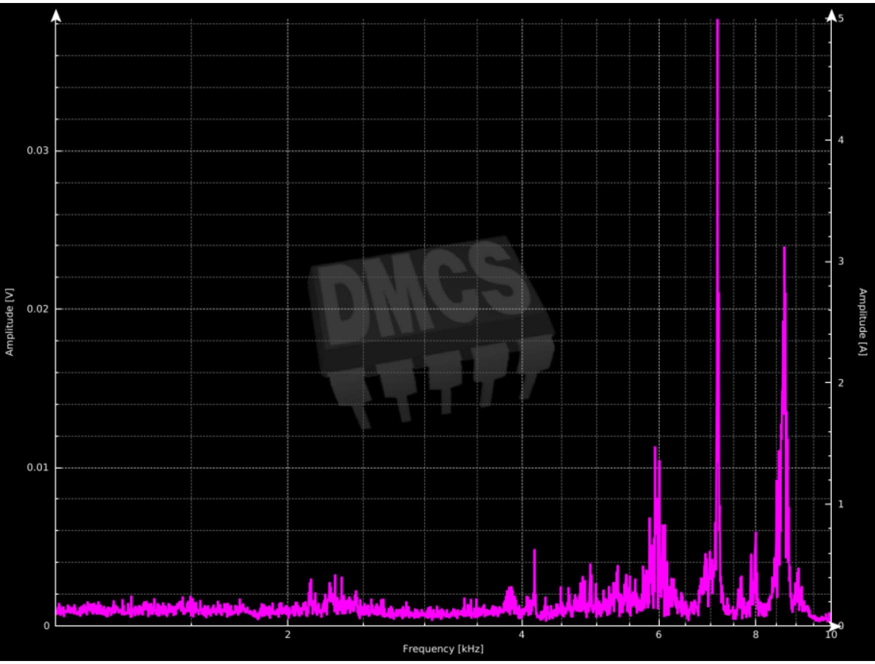
  - (G1) Maximum piezo DC excitation,
  - (G1) Different piezo configurations tests (actuator/actuator, acturator/sensor, sensor/sensor),
  - (G1) Sensor signal acquisition system verification,
  - (G1) Actuator operation with different excitation (continuous sin wave, arbitrary waveform, defined periods qunatity/freq sin wave, etc.),
  - (G2) Single (and both) piezo frequency scan,
  - (G2) Lorentz Force Detuning coefficient determination.



Frequency sweep tests

Single piezo excitation. Sin wave amplitude ~0.1 V





Frequency sweep range 1Hz – 1kHz:

- Different freq. identified 197, 240, 249, 270, 326, 360, 504 Hz,
- Probable mechanical modes 240Hz, 504 Hz

Frequency sweep range 1kHz – 10kHz:

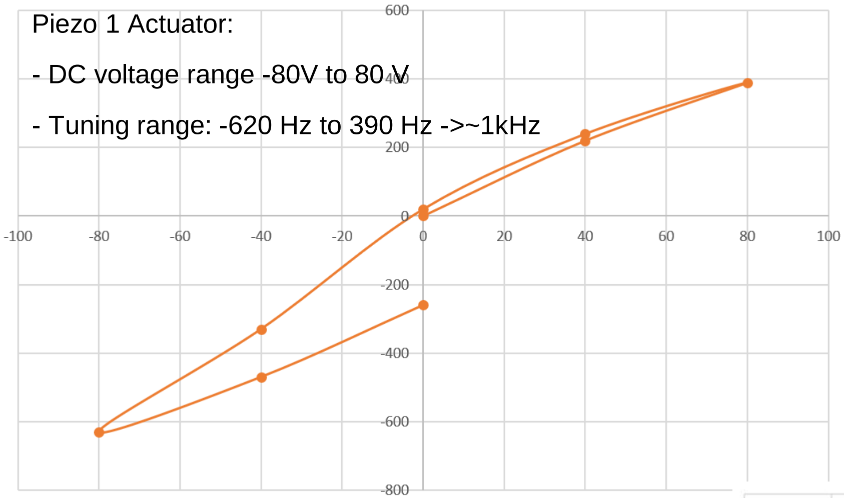
- Detected resonances rather not related to the cavity modes (fixture modes?),
- ~7kHz resonance can be dangerous for the setup,
- one need to be cautious about initial testing (low voltage can show resonances but will not damage the system).

Wojtek Cichalewski et. al, *wcichal@dmcs.pl*

Piezo tuning range study

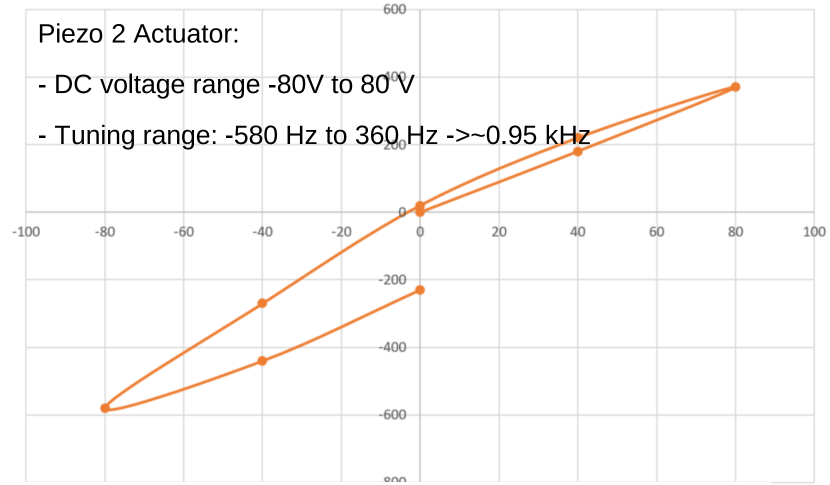
Piezo 1 Actuator:

- DC voltage range -80V to 80 V
- Tuning range: -620 Hz to 390 Hz ->~1kHz



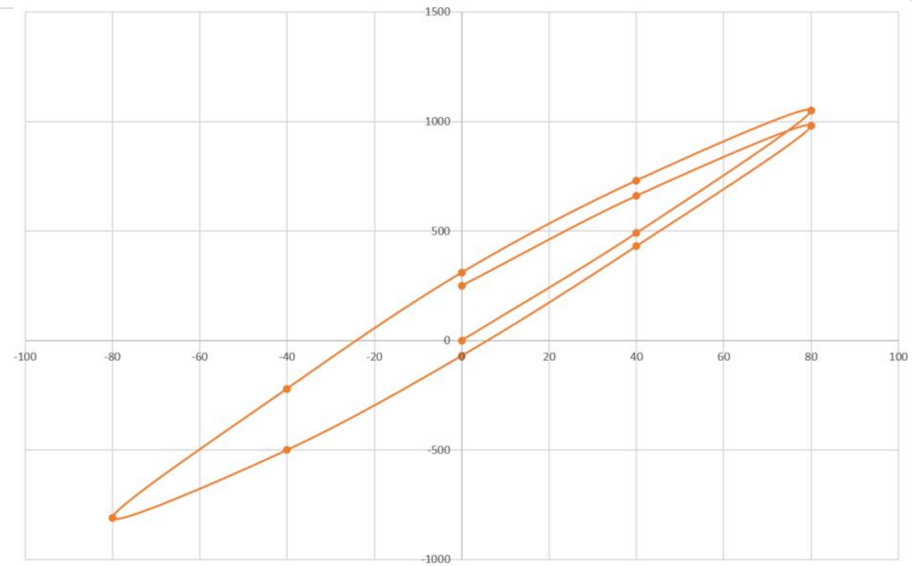
Piezo 2 Actuator:

- DC voltage range -80V to 80 V
- Tuning range: -580 Hz to 360 Hz ->~0.95 kHz



Piezo 1 & 2 :

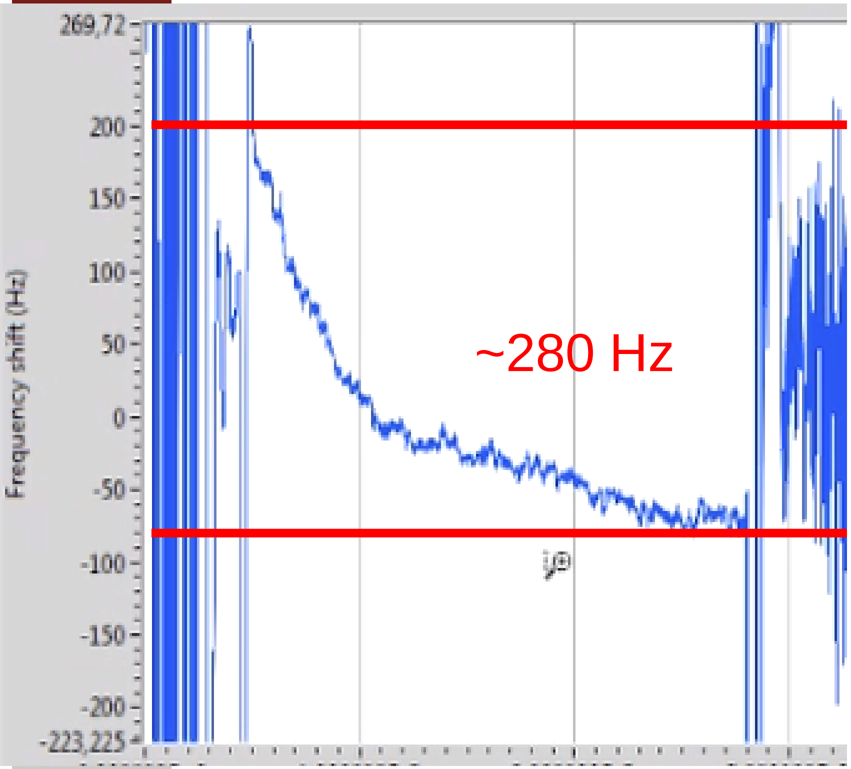
- DC voltage range -80V to 80 V (each piezo)
- Tuning range: -850 Hz to 1100 Hz ->~1,9kHz
- Range doubled in comparison to single piezo operation,
- Significant hysteresis (backlash) visible (not sure what is the source, to be verifed in future).



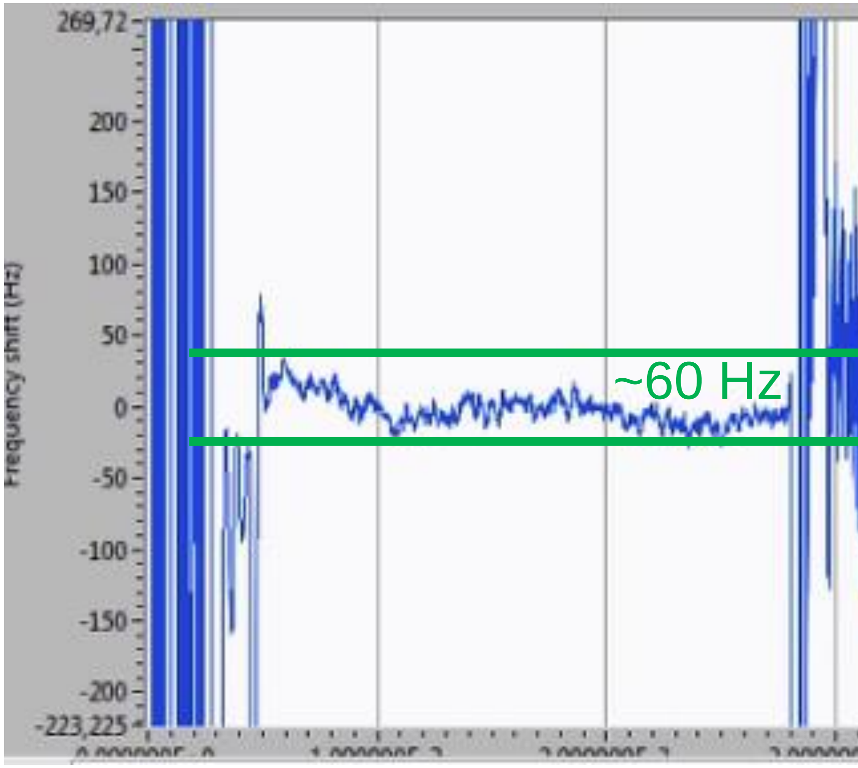
Initial LFD compensation study

Cavity operation parameters:

- GDR mode,
- Pulse length close to nominal,
- Gradient conditions ~15 MV/m.



No piezo compensation



With piezo compensation

(single period with 100Hz freq and Amp. ~60V)

Summary

- Main goals achieved:
  1. Succesful piezo driver (MTCA.4 version) evaluation,
  2. Cavity parameters have been determined (and measured during other tests),
- Performed frequency sweeps revelated possible candidates for mechanical modes,
- Achieved piezo regulation range (and linearity) to be confirmed during further studies (in ESS/Lund),
- Prove of principle concerning LFD compensation with installed piezos,
- Good starting point for furhter work towards fine frequency regulation – just beginig.