Renewal and upgrade of the fast beam-based feedback system at FLASH.

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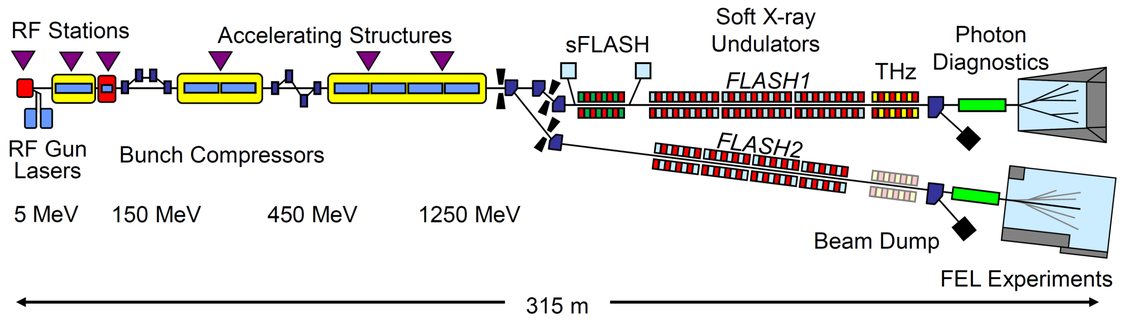
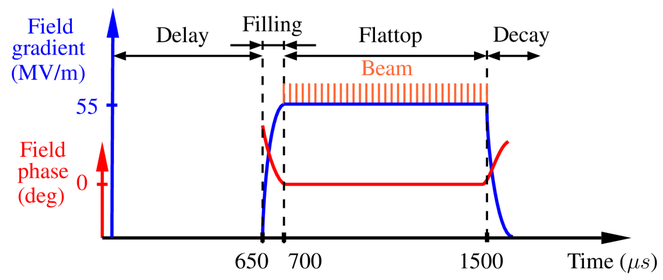
Abstract

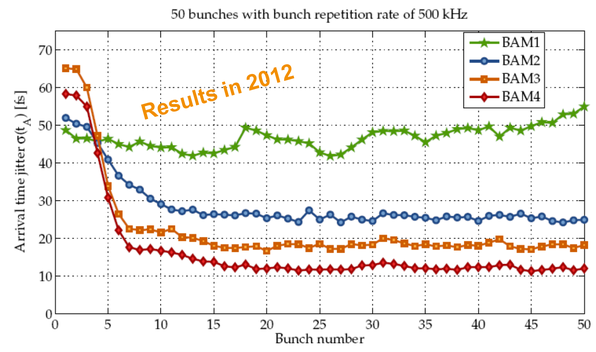
Linear accelerator facilities require femtosecond precision synchronization between external laser systems and the electron beam. Such high precision is required for the electron bunch injection into a plasma bubble for laser plasma acceleration or for pump-probe experiments. A renewal and upgrade of the fast intra-train beam-based feedback system is planned at the Free Electron Laser in Hamburg (FLASH). This linear accelerator is based on superconducting (SRF) technology operating with pulse trains of maximum 3 MHz bunch repetition rate. Arrival time fluctuations of the electron beam are correctable by introducing small energy modulations prior to the magnetic bunch compressor. This contribution focuses on the design and the characterization of an ultra-fast normal-conducting RF (NRF) cavity with large bandwidth, mandatory to correct fast arrival time fluctuations. Additional high frequency components needed for cavity operation and its digital low-level radio frequency regulation system were characterized to reach arrival time stabilization towards one femtosecond range. The tunnel installation in January 2018 and the integration with the currently used beam-based feedback system will be outlined.

Free Electron Laser in Hamburg (FLASH)



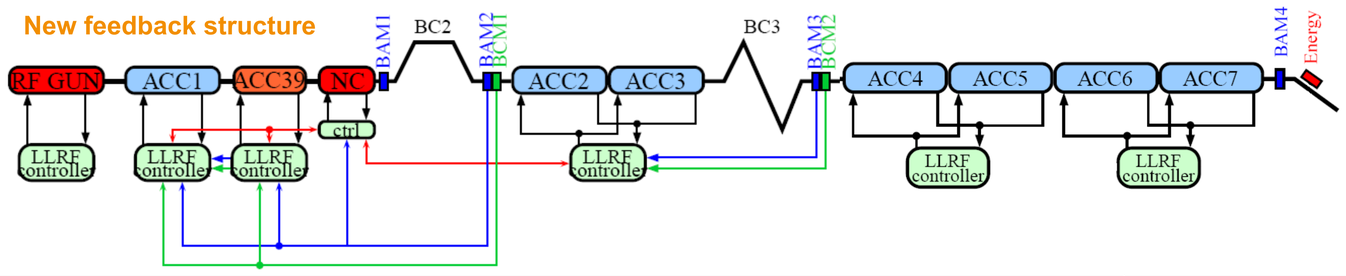
RF pulse structure and beam-based feedback





Upgrade to achieve ~1 fs arrival time stability

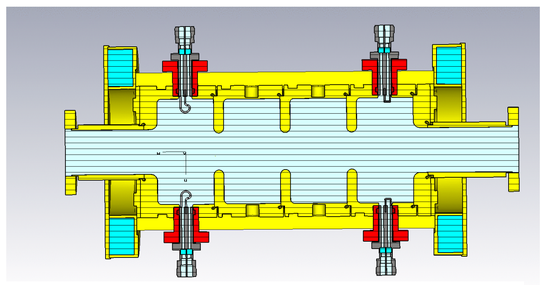
New feedback structure

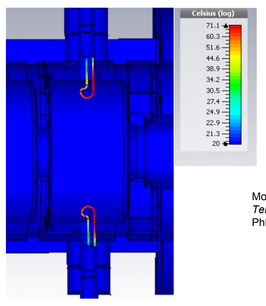


Requirements

- Fast energy corrector cavity with adjustable bandwidth
- Cavity operating frequency 2.9972 GHz
- Max. energy gain of ±40 keV for corrector cavity
- Low-latency feedback loop for RF field and beam-based signal
- ACC23 regulation $\Delta E/E \leq 1.125 \cdot 10^{-5}$
- Magnet power supply stability BC3 $\Delta I/I \leq 0.85 \cdot 10^{-5}$

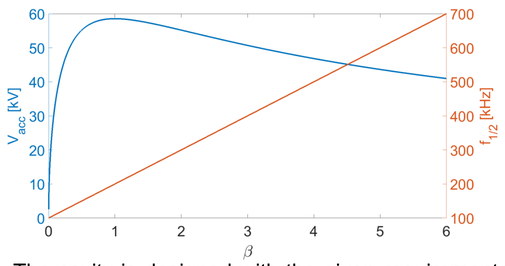
(1) Cavity design by simulations (2D/3D) and special input coupler design

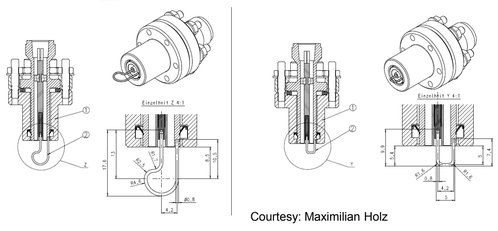




Thermal simulation of the input loop.

Moein Fakhari, *Design of radio-frequency cavities and Tera-Hertz electron injectors for advanced applications*, PhD thesis ,2016.



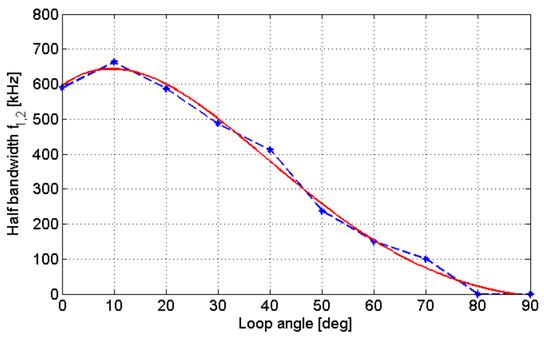


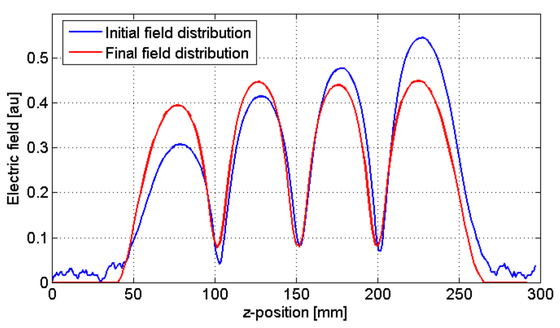
Courtesy: Maximilian Holz

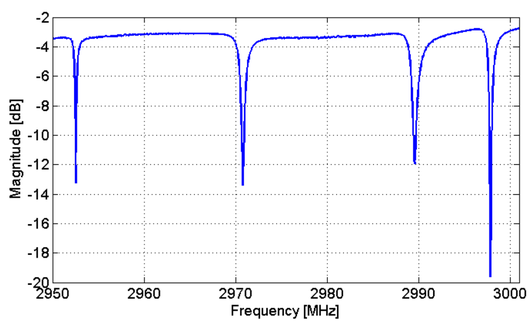
The cavity is designed with the given requirements. Additional passband modes for 4-cell cavity structure were placed away from the operating cavity frequency; achieved by an adjustment of the cavity cell dimensions. The power input is designed as magnetic loop. Thermal simulations show that single loop lead to loop temperature increase by 200 K for max. driving power.

(2) Cavity production and tuning

- Internal inspection after production
- Vacuum leakage test
- Measurements using network analyzer
- Bead-pull measurements
- Input coupler measurements
- Final tuning

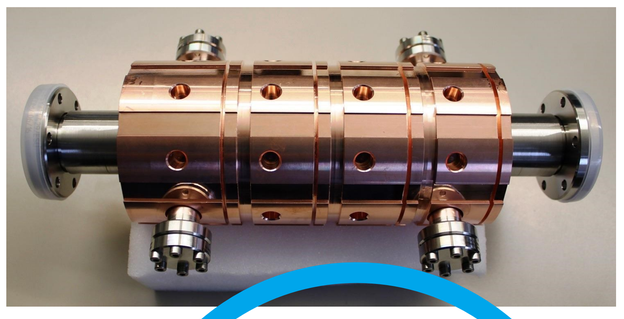




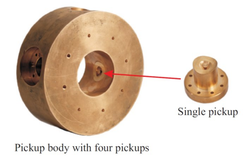


Both input loops were adjusted in parallel, where the combined coupling factor for both loops is the summation of the individual ones. The pickup loops were adjusted for coupling of -50 dBm to get about 1mW output power for the digitizer boards. The location of the operating mode has been adjusted to f_π = 2997.88 MHz at room temperature; operating cavity temperature about 38 deg. C. The measured frequency difference from π-mode to the other modes is 8.3 MHz, 27.1 MHz and 45.3 MHz, respectively.

Normal-conducting cavity



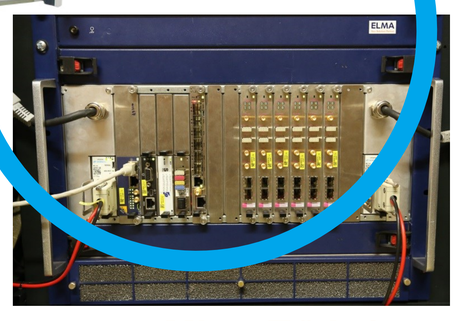
New 40 GHz bunch arrival monitor



A. Angelovski et al., "Pickup signal improvement for high bandwidth BAMs for FLASH and European-XFEL," in *IBIC*, 2013.

1kW power amplifier

RF field loop

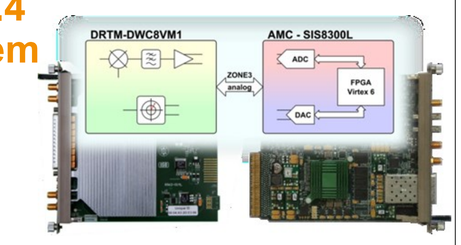


Beam-based signals

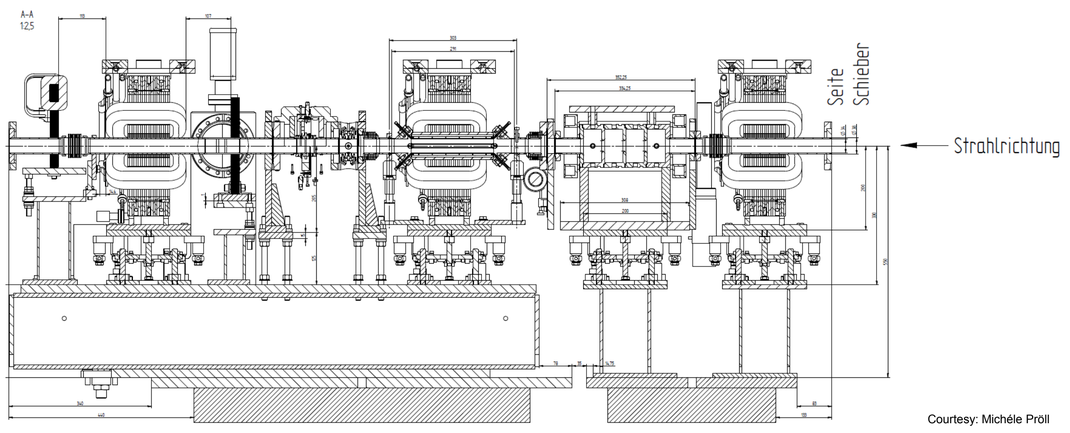
MicroTCA.4 LLRF system

Low-latency single cavity regulation scheme

Signal path	Delay [ns]	Comment
LLRF controller to VM output	344	Measured at REGAE including ADC sampling etc.
Cable VM output to Amplifier (≈8m)	40	Estimated cable length
VM output to Amplifier output	37	Measured with HV amplifier
Amplifier output to cavity (≈3m)	15	Estimated cable length
Cavity pick-up to LLRF system (≈11m)	55	Estimated cable length
Total for RF loop only	**491**	**Processing latency for one signal turn**
BAM sensor to LLRF system	~600	Including bunch time of flight, signal processing and signal transfer to LLRF system



Technical drawing for installation in 01/2018



Courtesy: Michéle Pröll

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