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STATUS UPDATE OF THE FAST ENERGY CORRECTOR CAVITY AT FLASH*

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Abstract

Linear accelerator facilities driving a free-electron laser require femtosecond precision synchronization between external laser systems and the electron beam. Such high precision is required for pump-probe experiments and also for example for the electron bunch injection into a plasma bubble for laser plasma acceleration. An upgrade of the fast intra-train beam-based feedback system is planned at the Free-Electron Laser FLASH in Hamburg, Germany. This linear accelerator is based on superconducting (SRF) technology operating with pulse trains of maximum 1 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 a normal-conducting RF (NRF) cavity with large bandwidth, mandatory to correct fast arrival time fluctuations. The cavity has recently been installed in the FLASH beamline. First measurements with the new cavity will be presented.

INTRODUCTION

The Free Electron LASer at Hamburg (FLASH) is a facility for research with tunable laser light in the X-ray range [1]. It delivers to its users a pulsed light with tunable wavelength down to 4.2 nm generated by SASE processes. Electron bunch trains of variable length and frequency with a repetition rate of 10 Hz are accelerated to a maximum energy of 1.2 GeV. Each pulse is enabled for about 1.4 ms while up to 800 bunches with a repetition rate of 1 MHz are injected. Providing stable and reproducible photon pulses needs a precise acceleration field control. During the last years additional control strategies were developed and included in the LLRF controller. This includes RF-field control and its superposition with beam-based information using the bunch arrival time and bunch compression information, [2–4]. By this the stability of the bunch arrival time at the end of the main accelerator could be improved, highly important e.g. for the precise synchronization between an external laser system and the electron beam [5]. To further improve the arrival time a fast energy corrector cavity prior to the bunch compressor is needed. This corrector cavity should be operated in the upper kHz bandwidth. The technical design and specifications for the fast corrector cavity named BACCA (Bunch Arrival Corrector CAvity) are given in [6].

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DESIGN OF THE CAVITY

The basis for the design was the buncher cavity at the *Relativistic Electron Gun for Atomic Exploration* (REGAE) accelerator facility [7]. The main difference is the power coupling to the cavity. Due to longitudinal space constraints for the installation at FLASH this is realized by magnetic coupling, i.e. coupling loop instead of coaxial coupler. Figure 1 shows the first 3D drawing of the cavity with the beamline connection and the feedthroughs hosting the loops for magnetic coupling.

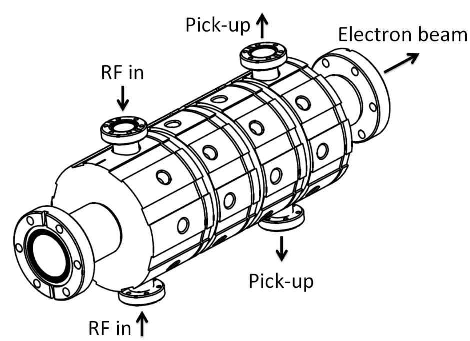

Figure 1: Technical design of the 4-cell fast corrector cavity with the 2 beamline flanges and the 4 feedthroughs for RF input and output loops/pickup.

The main design requirements are given as maximum energy correction of about 50 keV, a maximum feedback loop latency of 700 ns and a corrector cavity half bandwidth of 500 kHz. Furthermore, longitudinal and transverse wakefields as well as orbit changes for multi bunch operation should not occur during operation.

There is a trade-off between the accelerating voltage and the bandwidth of the corrector cavity as a function of the coupling constant [8]. The thermal stress to the input loop has been simulated justifying the power distribution with 2 input loops, [9]. Two output loops, i.e. the probe pickups, are used for symmetry reasons. The NRF cavity cells were produced at the Hansa Press- und Maschinenbau GmbH in Hamburg, Germany. Its assembly and the soldering of all parts were done at DESY. The assembled corrector cavity is shown in Fig. 2 with its 4 feedthroughs; 2 for in-coupling and 2 for the pick-up antennas.

CHARACTERIZATION OF THE CAVITY

The corrector cavity has been characterized and tuned for resonance after production. First we were driving the cavity with a test signal from the network analyzer via the input loop

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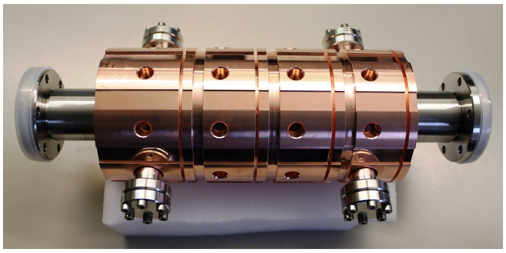

Figure 2: Assembled cavity after cell production, complete soldering and initial cleaning. The input and output loops are not connected.

of the cavity. For our set-up we used the S_{11} measurement of the network analyzer, i.e. the frequency dependent reflection coefficient. The frequencies where the S_{11} magnitude significantly reduces represent the resonance frequencies of the cavity. A change of the resonance frequency was observed while adjusting the magnetic coupling by rotating the input loop to the cavity [10]. Here 0 deg. means full magnetic coupling and 90 deg. no magnetic coupling of the cavity. Finally, both input loops were adjusted to a loop angle of 50 deg. which has been measured with half bandwidth of 500 kHz and a coupling factor of about 2.5. Each input loop has been adjusted to a half bandwidth of about 250 kHz and a coupling factor of about 1, i.e. critical coupling. In total 4 resonant peaks are visible, i.e., the operating π-mode frequency of about 2.998 GHz and the 3 remaining modes which are natural for a 4-cell cavity. The other modes are separated in the technical design and also in the measurements by more than 8 MHz from the operating mode. The electrical field flatness for the cavity was measured and corrected using the bead-pull method [11]. The cavity and all attached components like input loops were cleaned after the characterization of the cavity at air. This cleaning is required for installation into the FLASH beamline and its operation under vacuum. The input loops and pickup antennas were mounted and remeasured in a clean-room at DESY.

INSTALLATION

The tunnel installation took place in January 2018. The section after the third harmonic module ACC39 and before the first bunch compressor BC2 was renewed completely. During the removal of all components a damage of the first bunch compressor magnet was observed. The damaged magnet has been exchanged delaying the originally installation schedule by 2 days. Finally, the new cavity, 3 new quadrupoles and a new bunch arrival time monitor (BAM) body were installed together with the old horizontal and vertical steerer, strip-line bunch position monitor (BPM), charge monitor and vacuum pump, see Fig. 3. The picture was taken before end of installation, but before placement of the shielding wall.

At the end of the shutdown all main components, like vacuum pump, steerer, diagnostic and the three new quadrupoles were operable again. The installation of the power amplifier for the cavity together with the MicroTCA.4 system for LLRF regulation and the cable installation has been completed. The common forward and reflected signal as well as both probe signals were initially calibrated. The frequency generation module, converting the main 1.3 GHz frequency to the cavity operating and intermediate frequencies for signal detection (in-phase and quadrature) has been installed and commissioned, [6]. A commercially available cooler from TermoTek GmbH [12], in our case a modified version allowing heating, has been installed to bring the cavity to its resonance which is at about 40 deg. Celsius. Three temperature sensors for cavity body and cavity input loop supervision were installed.

FIRST BACCA MEASUREMENTS

The first measurements were done without RF and with beam loading only. Hereby the cavity can be used as charge detector by analyzing bunch transients. Figure 4 shows the peak amplitude of the beam transient measured with one probe antenna of the cavity and the charge monitor information. The cavity probe signals were finally calibrated using the bunch arrival time monitor (BAM) behind BC2. The calibrated gradient of the first accelerating module ACC1 has been used as reference. The gradient of ACC1 has been varied leading to a change in beam energy and arrival time behind the bunch compressor BC2. This resulting calibration factor was used to calibrate the BACCA probes. The BACCA energy gain was switched from maximum deceleration to maximum acceleration by imposing a 180 deg. RF phase change. The common forward and reflected signals were finally calibrated using a resonant circle scan with variation in drive frequency. First energy modulations with maximum possible energy change lead to no orbit variations. Furthermore, multi bunch effect were not observed for the maximum bunch repetition rate of 1 MHz at FLASH.

CONCLUSION AND FUTURE WORK

The cavity and the main components in the FLASH BC2 section were changed during the winter shutdown in 2018. The cavity together with additional modules providing e.g. the operating frequency and the MicroTCA.4 based LLRF system has been installed and commissioned. First RF measurements without and with beam were performed. The first measurements in multi bunch operation look promising. The next step is the interconnection with the BAM such that bunch arrival information can be used within a train of electron bunches for fast arrival time feedback.

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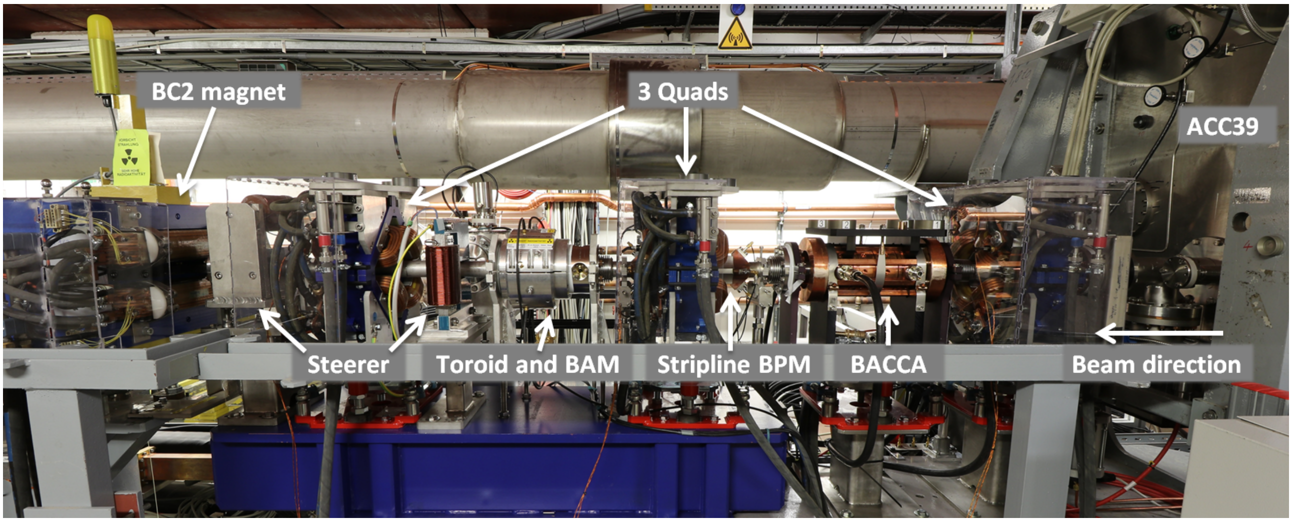

Figure 3: Picture from the installation during shutdown in January 2018. Beam direction is from right to left, with third harmonic RF module (ACC39) to the right and the entrance of the first bunch compressor (BC2) to the left.

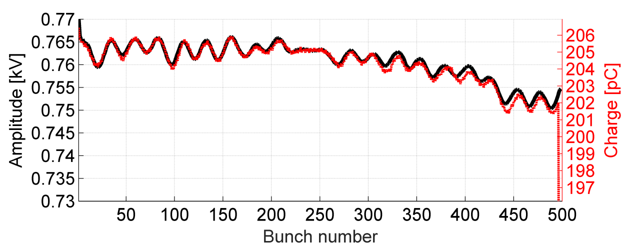

Figure 4: Maximum bunch transient amplitude in comparison to the charge measurement in the BC2 section. The black curve shows the maximum peak voltage and the red dashed line the charge readout for each bunch.

given by Klaus Flöttmann and Markus Hüning has been a great help in designing and tuning of the NRF cavity. Special thanks to Katja Honkavaara and Siegfried Schreiber for their driving support for this work at a time of other dominant projects such as the European XFEL. Furthermore, I would like to thank the following groups at DESY for their assistance and support: D3, MCS, MDI, MEA, MIN, MKK, MPS, MPY, MSK, MSL, MVS and ZM1. Without their help it wouldn't be possible to redesign the BC2 section at FLASH for the later installation of the NRF cavity.

REFERENCES

[1] FLASH, "Free-electron laser FLASH," 2016, [Online]. Available: `http://flash.desy.de/`

[2] M. Viti *et al.*, "Recent Upgrades of the Bunch Arrival Time Monitors at FLASH and European XFEL,", in *8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 695–698. `https://doi.org/10.18429/JACoW-IPAC2017-MOPIK072`

[3] C. Behrens *et al.*, "Upgrade and Evaluation of the Bunch Compression Monitor at the Free-Electron Laser in Hamburg (FLASH)," in *1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, pp. 912–914.

[4] S. Pfeiffer, "Symmetric Grey Box Identification and Distributed Beam-Based Controller Design for Free-Electron Lasers," PhD thesis, Hamburg University of Technology, Germany, 2014.

[5] S. Schulz *et al.*, "Femtosecond all-optical synchronization of an X-ray free-electron laser," in *Nature Communications*, vol. 6, pp. 5938–5949, 2015. `https://doi.org/10.1038/ncomms6938`

[6] S. Pfeiffer, "Technical design report on ultra-fast longitudinal feedback for FLASH," EuCARD2, Deliverable 13.1, 2014, [Online]. Available: `http://eucard2.web.cern.ch/science/deliverables`

[7] REGAE, "Relativistic Electron Gun for Atomic Exploration," 2016, [Online]. Available: `https://regae.desy.de/`

[8] M. Fakhari, "Design of Radio-Frequency Cavities and Tera-Hertz Electron Injectors for Advanced Applications," PhD thesis, Universität Hamburg, Germany, 2016.

[9] M. Fakhari *et al.*, "Thermal Simulation of an Energy Feedback Normal Conducting RF Cavity," in *7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 396–398. `https://doi.org/10.18429/JACoW-IPAC2016-MOPMW003`

[10] S. Pfeiffer, "FLASH NRF cavity and FB system," EuCARD2, Deliverable 13.5, 2017, [Online]. Available: `http://eucard2.web.cern.ch/science/deliverables`

[11] L. C. Maier Jr. and J. C. Slater, "Field Strength Measurements in Resonant Cavities," in *Journal of Applied Physics*, vol. 23, pp. 68-77, 1952. `http://dx.doi.org/10.1063/1.1701980`

[12] Termotek GmbH, [Online]. Available: `http://www.termotek-ag.com/de/`