Progress on the multi bunch FEL Performance at FLASH.

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Introduction

The Free-Electron Laser in Hamburg (FLASH) is a high-gain FEL user facility operating in the soft x-ray regime [1, 2]. The current layout of FLASH is shown in Figure 1. Acceleration of the electron bunches is achieved by using 56 superconducting TESLA-type [3] cavities in seven modules (ACC1-7). Due to the high achievable duty cycle, a long radio frequency (RF) pulse structure can be provided, which allows to operate the machine with long bunch trains. At high beam energy the FEL saturation length at FLASH is close to the total length of the undulator. Small perturbations, for example betatron oscillations or energy variations, will limit the beam power of the amplification process. It has been shown [4] that RF-induced intra-bunch-train trajectory variations are substantially decreasing the multi bunch FEL performance and must be considered as the dominant source of intra-bunch-train variations of the SASE intensity. This work aims to explore the possibilities of limiting trajectory variations by reducing the variation of RF parameters within one bunch train with the current level of LLRF control at FLASH. Special consideration will be given to the role of the static and dynamic detuning of the cavities.

Mitigation of RF variations

In this section we present a detailed evaluation of the RF setup at multi-bunch operation at FLASH. A total amount of user runs with 400 bunches has been investigated (cf. Fig. 2) and are compared to dedicated measurements. We will show that the current level of LLRF control is capable of significantly reducing intra-bunch-train RF variations, if the machine is set up accurately.

Figure 3 shows the simulated accelerating gradients (top) and detuning (bottom) of eight cavities for three scenarios: 1) detuned cavities with LFD, 2) tuned cavities with LFD and 3) tuned cavities with decreased LFD. The latter results from the operation of fast pace timers. Comparison between the left and center column reveals that by decreasing the coarse detuning of the cavities from 97 Hz to 17 Hz, the variation of the accelerating gradient gets reduced. Additional limitations of the LFD from 101 Hz to 10 Hz decreases the gradient variation in a fifth of the initial range.

The coarse detuning of the cavities is determined mainly by the Lorentz forces. Especially for ACC6/7, where the gradient has to be changed frequently to reach different beam energies, the coarse detuning is poorly adjusted in regular operation (rms value in ACC6/7: $\Delta f_{\text{rms}} = 980$ Hz) as can be seen in Figure 4. Consequently, the gradient variation is particularly large in these cavities (rms value in ACC4/5: $\Delta f_{\text{rms}} = 803$ kHz).

Impact on trajectories and SASE performance

The red plot marks in Figure 2 show the impact of the tuning procedure on the rms offset variation in the undulator and the variation of SASE intensity within one bunch train. For the highlighted example (arrows), the reduction in the horizontal and vertical plane is 128nm and 25 nm, respectively, while the SASE intensity variation gets reduced by 49%. The mean SASE intensity within the bunch train is thereby increased from 74% to 91% with respect to the bunch with maximum variation.

Results indicate that the multi-bunch FEL performance can be improved significantly, if the RF setup receives more attention during the machine setup. Besides, the pace timer are important for limiting crucial horizontal trajectory variations in the undulator and their reliable operation should be of priority.

Furthermore the reproducibility of machine settings can be positively influenced by permanently maintaining the tuning setup. This requires automated processes which monitor and adjust the detuning, which is foreseen and receives more attention during the machine setup.

The impact of different RF parameters on trajectory variations and SASE performance is shown in the Table 1.

References