FEMTOSECOND LEVEL ELECTRON BUNCH DIAGNOSTIC AT QUASI – CW SRF ACCELERATORS: TEST FACILITY ELBE

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Abstract

Superconducting radiofrequency (SRF) accelerator technology allows to accelerate electron bunches not only in considerably longer bunch trains than is possible by normal conducting accelerator technology, but also in principle enables a mode of operation that can circumvent any macropulse scheme and provides relativistic electron bunches with real repetition rates scaling from the kHz to GHz regime [1, 2, 3, 4]. In this proceedings we discuss different approaches foreseen for online electron bunch diagnostic at the new femtosecond electron beamline of the superconducting cw RF accelerator ELBE [1]. In medium term we believe the concepts tested at the femtosecond beamline at ELBE are of great importance for various energy recovery linac accelerators (ERL) coming online in the next few years [2, 4] as well as facilities like the European X-FEL [5] and FLASH [6] when operated in long bunch train mode of operation.

INTRODUCTION

The quasi-cw mode of operation enabled by SRF accelerator technology receives recently increasing attention. This is partially driven by the user communities of 4th generation X-ray and THz light sources [6, 7, 8, 9] which are requesting a higher average brilliance for e.g. spectroscopic experiments on condensed matter or liquid samples. At the same time the concept of energy recovery linacs have matured to a point where several prototype facilities are in the process of construction. A presently unsolved question is how such facilities, aiming at the same time for repetition rates up to the GHz regime, few femtosecond bunch durations and few pico coulombs (pC) electron bunch charges can be controlled and stabilized robustly during operation. At the HGF research center Dresden-Rossendorf (HZDR) the existing SRF accelerator ELBE [1] is currently upgraded with an additional electron beamline and a novel SRF electron gun that will allow to compress and accelerate electron bunches with a charge of 1 nC, a duration in the few 100 femtosecond (fs) regime at scalable repetition rates between 1 and 500 kHz. Additionally electron bunches generated by the existing thermionic gun with a bunch charge of few ten pC can be accelerated to repetition rates up to 13 MHz. This unique range of parameters makes ELBE an ideal testbed for electron bunch diagnostic at future quasi-cw accelerator facilities (see Figure 2). In the following two different conceptual approaches are discussed: (i) an upgrade of existing single shot techniques of arrival time [10, 11, 12] and bunch form [13, 14] to few 100 kHz to MHz repetition rates and (ii) new concepts based on phase sensitive detection [15] that omit the quest for analysing individual bunches for a much increased sensitivity for average bunch properties (see Figure 1). The latter approach bears much promise at quasi-cw facilities and may allow for online measurements and feedbacks on electron bunches with charges down to the few hundred femto coulomb (fC) regime. Both concepts are pursued at ELBE as a multi institutional collaboration within the frame of the accelerator research and development (ARD) program of the HGF. Besides dedicated space in the accelerator for testing various novel electron bunch monitor concepts two THz beamlines guide coherent THz radiation from a coherent transition/diffraction screen and a THz undulator into a THz laboratory (see Figure 2). This new lab, coined THz facility at ELBE (TELBE), is acclimatized, equipped with various spectrometers and femtosecond lasers. It can therefore serve as an ideal testbed for novel concepts of THz based electron bunch diagnostic.

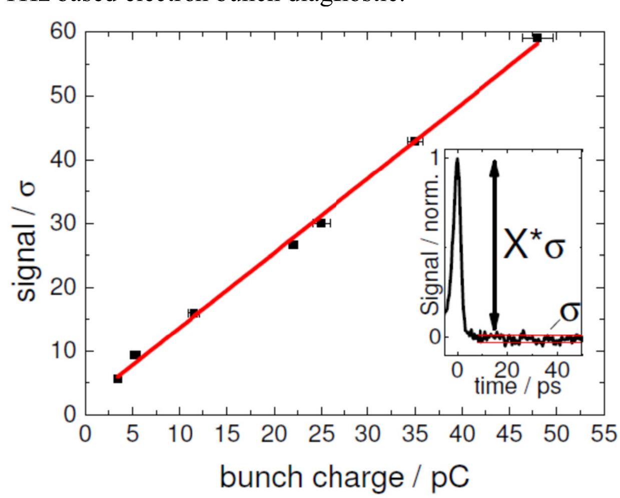

Figure 1: Electro-optically sampled electron bunch forms in the existing picosecond (ps) electron beamline at ELBE (for technical details see [15]). Phase sensitive detection allows scanning an average electron bunch form within few seconds. Integration time at individual time delays was 100 milliseconds (ms) in all measurements.

SINGLE SHOT CONCEPTS

Electron bunch diagnostic on highly charged, ultra short electron bunch diagnostic has made a tremendous progress over the past 10 years. In particular at FLASH, as the world's wide first soft X-ray FEL user facility, a large number of techniques have been realized, tested and even implemented for online feedbacks of the accelerator [10, 13, 14]. The quest at a quasi-cw accelerator like ELBE is to find ways to improve the read-out frequency of these techniques from the few hundred Hz to the kHz or even MHz regime. On one side the hope lies here on the progress in the development of fast read out detectors (see e.g. supplementary information in ref. [11]). A second approach is working with existing technology but aims at a fast readout and processing of the essential information (e.g. peak position of an electro-optically measured electron bunch profile) [16]. However, besides these efforts it is clear that the presently existing single shot techniques struggle to reach the sensitivity required for analysis of electron bunches with lower bunch charges in the few ten pC regime or smaller. This poses a severe problem for the high repetition rate mode at the fs electron beamline at ELBE (77 pC/13 MHz). The technological challenge will be even larger at future ERL facilities, where typically few pC charges are accelerated at GHz repetition rates [2, 4]. At ELBE the established single shot diagnostic techniques will therefore be combined with diagnostic based on a second approach that makes use of the quasi-cw mode of operation and is based on the principle of phase sensitive detection.

PHASE SENSITIVE DETECTION

The quasi-cw mode of operation opens up the opportunity to achieve a much higher sensitivity when employing so called "phase sensitive detection" techniques.

The fundamental idea is to employ devices called lock-in amplifiers that allow to considerably reduce noise in the measurement by narrowing down the actually amplified frequency band around a known modulation frequency of the signal. Of additional importance is the opportunity to omit signals that have the right frequency but wrong phase. In the case of electron bunch diagnostic in a quasi-cw accelerator we intend to use the repetition rate of the electron bunches as modulation frequency to which the lock-in amplifiers would be locked [15]. Any noise with frequencies different to the repetition rate or similar to repetition rate but at wrong phase is filtered. As we could show recently, this enormous improvement of sensitivity then enables for instance to determine electron bunch profiles down to charges of only few pC [15] already at relatively low repetition rates of 100 kHz and integration times of few 100 ms (see Figure 1). Furthermore, the opportunity arises to design robust online monitor concepts that provide suitable error signals for slow feedbacks in quasi-cw SRF accelerators working in low charge mode of operation (for one example see Ref. [15]).

SUMMARY AND OULOOK

To summarize, at ELBE two different approaches for diagnostic on the fs electron bunches will be pursued. The existing, matured single shot techniques for femtosecond electron bunch diagnostic, mainly developed at the FLASH and LCLS linacs, will be adapted to the requirements of the ELBE accelerator. Main focus will here be on increasing the read out frequency and the sensitivity. Secondly, phase sensitive detection techniques will be developed. The short term intention is here to provide online diagnostic for low charges at ELBE. In medium term it shall be investigated whether these concepts can be upgraded and scaled for use at future ERL facilities, FLASH and the E-XFEL when operated with long bunch trains.

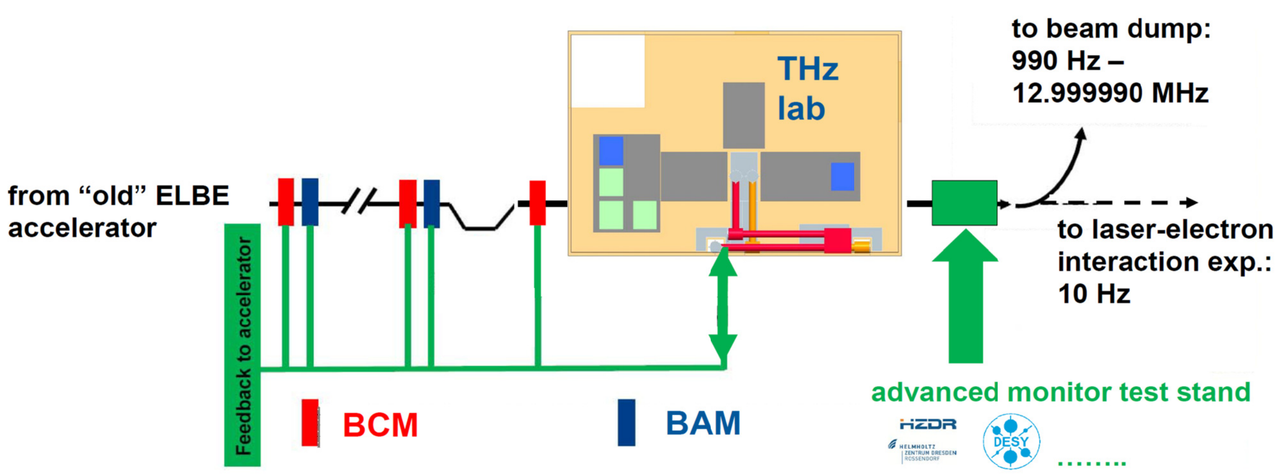

Figure 2: Vision of the electron bunch diagnostic in the new fs electron beamline at ELBE. Bunch compression monitors (BCM) [17] and bunch arrival time monitors (BAM) [10] are adapted from FLASH/DESY. The THz lab is situated on top of the accelerator. Two beamlines guide THz radiation from a coherent transition/diffraction source and from a THz undulator. The lab is acclimatized and equipped with FT-IR spectrometers and fs laser systems and space for permanent THz based electron bunch diagnostic set-ups has been reserved. Downstream space in the accelerator is reserved for a testing advanced electron bunch monitor concepts. Further downstream laser-electron interaction experiments (e.g. Thomson scattering) are foreseen at a repetition rate of 10 Hz [18].

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