BUNCH COMPRESSION DEPENDENT JITTER ANALYSIS WITH LARGE SPECTRAL RANGE

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Abstract

At the superconducting continuous wave (CW) accelerator ELBE electron bunch diagnostics have been installed, enabling the investigation of bunch arrival-time jitter for varying bunch compression states [1]. Using these diagnostic systems a comprehensive investigation has been performed that reveals the influence of the bunch compression to spectral noise components up to a frequency of 100 kHz. The contribution describes the measurement results taken for both electron injectors (DC-Gun, SRF-Gun) at the ELBE facility and will give an interpretation of different noise components. Arrival time jitter of the electron bunches is directly transferred into jitter of the secondary radiation generated by the ELBE beam.

INTRODUCTION

Pulse Compression Scheme

The ELBE Accelerator uses two magnetic chicanes to compress the picosecond bunches to the 100 fs regime. The correlated energy spread after the first accelerating module leads in combination with the first chicane to a temporal stretch of the electron bunches. The cavities installed in the second module are operated far off-crest to introduce a large chirp, i.e. a linear correlation between particle energy and longitudinal coordinate. Together with the transport matrix element R56 an energy dependent path deviation in the chicane leads to a longitudinal bunch compression. Figure 1 shows the ELBE accelerators' layout with the two electron injectors and two accelerating modules and illustrates the bunch compression scheme.

Bunch Arrival Time Monitor (BAM)

The bunch arrival time monitor takes advantage of an optical synchronization system that has been installed at ELBE [2]. The stabilized laser pulses provided by that system are used as a timing reference in the BAM. A probe of the electron's electric field passing by is extracted using a broadband electric pickup [3]. The signals are combined in an electro-optic modulator (EOM) which leads to an intensity modulation of single laser pulses according to the phase relation between the reference and pickup signal. Using this technique timing variations are mapped into amplitude modulations of the laser pulses.

The BAM-System installed at ELBE is capable to operate at MHz repetition rates in CW operation and enables arrival time measurements for individual electron bunches with a high resolution [3].

Bunch Compression Monitor (BCM)

The bunch compression monitor uses coherent diffraction radiation or coherent transition radiation generated by the electron pulses passing a boundary of a silicon screen. The intensity of the emitted coherent radiation pulse is dependent on the electron bunch duration [4] and can be used as a qualitative measure for the bunch compression state at the screen position. The shorter the electron bunches the higher the intensity of the coherent radiation pulse. At ELBE the BCMs are used to optimize the compression state of the electron bunches while tuning up the machine. Their application for an active beam-based feedback in order to stabilize the bunch compression state on the target position is currently being evaluated.

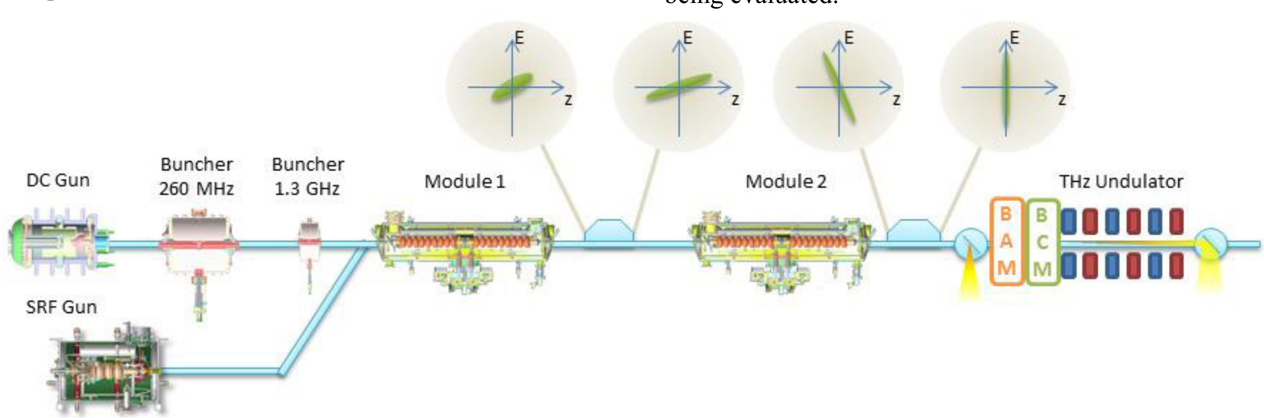

Figure 1: ELBE layout and bunch compression scheme for short pulse operation.

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MEASUREMENT RESULTS

The diagnostic systems have been used to characterize the behavior of the electron bunches at varying compression states. The investigation was mainly focusing on changes of arrival time of the electron bunches which have direct impact on time resolved experiments with secondary radiation at ELBE.

In order to compress the electron bunches a magnetic chicane after the second accelerating module (LA2) is used. For optimization of the bunch compression process, the R56 of the chicane is kept constant and the phase of LA2 is tuned, while the nominal energy of the electron bunches is maintained by adjusting the accelerating field amplitude. By introducing a very large chirp the over-compression regime is entered where the pulses become longer again.

Thermionic Injector

The user operation at ELBE is mainly served with the thermionic injector. The electrons are accelerated in a DC field up to an energy of 235 keV. The subsequent normal conducting cavities compress the electron bunches from 500 ps RMS to 3 – 5 ps RMS before they enter the superconducting cavities of the main accelerator. The stability of the high voltage supply is a crucial element for the temporal and energy stability of the electron beam entering the main accelerator [5].

Figure 2 shows the normalized output signal of a bunch compression monitor with respect to the phase of LA2. The maximum signal amplitude marks the minimum bunch length. The minimum bunch length can be observed at 156 degree for this specific setting.

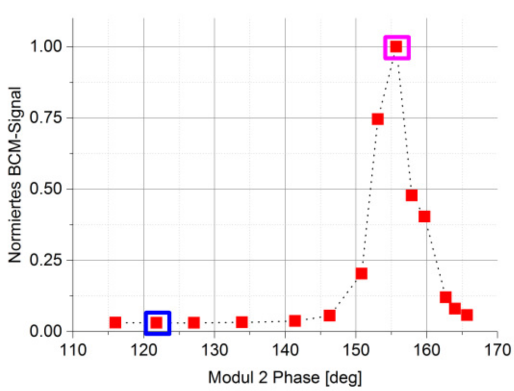

Figure 2: Normalized BCM signal for the thermionic injector changing the bunch compression by adjusting the phase of the 2nd module.

Figure 3 shows the power spectral density of the arrival time measurement and the integrated RMS-jitter for the thermionic injector. For low compression states (blue) the high frequency noise components are more dominant while the low frequency noise components are lower compared to the high compression state (red). The total jitter in the spectral range from 10 Hz to 50 kHz has changed from 750 fs RMS to 1 ps RMS. For all the measurements performed the 50 Hz line frequency and its harmonics are the most dominant noise sources.

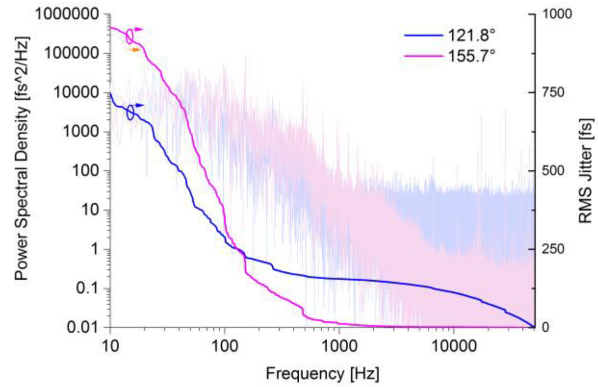

Figure 3: Power Spectral Density of the arrival time measurement and the integrated RMS-jitter at the thermionic injector.

Superconducting RF Injector

A superconducting RF photo injector is currently under development at HZDR [6]. It will provide high average current at low emittance in CW for the ELBE accelerator. For the predecessor of the currently installed cavity the same examination as for the thermionic injector has been performed. That means the chirp and thereby the bunch compression has been varied and the bunch arrival time has been measured.

Figure 4 shows the compression response on the variation of the phase of the second superconducting accelerating module. In this case the maximum compression is achieved at 97 degree phase shift.

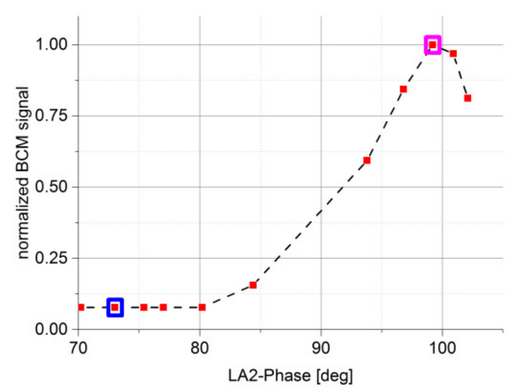

Figure 4: Normalized BCM signal for the SRF injector changing the bunch compression by adjusting the phase of the 2nd module.

In Figure 5 the results of the arrival time measurement are presented. For low compression the arrival time jitter is in the in the order of 100 fs RMS in the displayed spectral range. For high compression, the low frequency components become more dominant and lead to a jitter of 220 fs RMS. At the same time the high frequency noise is reduced. The general behavior is very similar to the beam injected by the DC gun but the absolute jitter is by a factor of five lower. The measurement shows that the 50 Hz line frequency is a major jitter contributor.

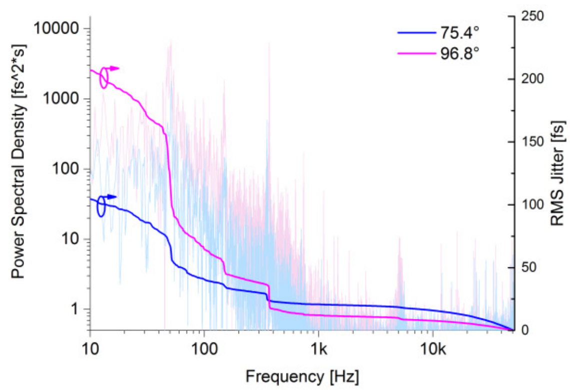

Figure 5: Power Spectral Density of the arrival time measurement and the integrated RMS-jitter at the SRF injector.

CONCLUSION

The measurements performed revealed a strong dependence of the beam arrival time jitter on bunch compression for both injectors used at ELBE. The SRF Gun generates more stable bunches than the thermionic injector. The DC Gun is affected by instabilities from the high voltage and the buncher section [5].

The high frequency noise is believed to be generated by the injectors because it is reduced while increasing the bunch compression. According to [7] the arrival time jitter in front of LA2 is reduced by the bunch compression factor. In addition, the high quality factor of the superconducting cavities suppresses high frequency variations of the RF filed.

The low frequency noise is mainly introduced by the superconducting accelerating modules. The phase and amplitude is varying with the line frequency which is modulated on the electron beam energy. Together with the second chicane these variations appear as arrival time changes.

OUTLOOK

In order to eliminate the jitter components, further accelerator studies have to be performed. The investigation will focus on the high voltage power supply, the pulse generation on the electron gun and on the phase stability of the normal conducting buncher cavities operating at 260 MHz and 1.3 GHz.

In parallel, the RF generation has to be improved to suppress the line frequency noise and a beam based feedback will be installed to eliminate the residual jitter.

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