Measurement of the time jitter of coherent terahertz synchrotron radiation with a superconducting detector

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***Abstract*—We have applied an ultrafast superconducting $YBa_2Cu_3O_{7-\delta}$ (YBCO) detector to study the time jitter of the propagating electron bunches in a synchrotron. The jitter was determined from the coherent terahertz (THz) synchrotron radiation (CSR).**

I. INTRODUCTION AND BACKGROUND

CSR is a powerful tool for spectroscopy and beam diagnostics. First, the broadband emission makes CSR an excellent source for Fourier transform spectroscopy. The second application is beam diagnostics including characterization of the time structure of the electron bunch. This is necessary based on the fact that the CSR spectrum depends on the shape of the bunch [1]. The timing accuracy of the electron bunch depends on the operating conditions of the synchrotron and can be determined by ultrafast superconducting YBCO detectors [2].

II. EXPERIMENTAL SETUP

For the observation of the THz CSR a thin film detector made from high temperature superconducting YBCO was used. It was manufactured by means of electron-beam lithography from about 40 nm thick YBCO films. The critical temperature is T_c=86 K and the operation temperature is approximately 78 K. To cover the CSR spectral range from 0.1 – 2 THz, the detector was equipped with a broadband log-spiral planar antenna. Incident THz radiation was coupled to the detector by using an extended elliptical silicon lens. Mounted in a dedicated holder, the detector was attached to the rear side of the lens.

A continuous-flow cryostat, containing the detector holder, was used and cooled down to 64 K (cold finger temperature) by liquid helium. To connect the bias voltage supply to the detector an external bias-tee was used (operating point: 113 mV, 13.6 mA). The signal was coupled out via the bias tee and fed into a low noise amplifier with 8 GHz bandwidth. For data acquisition and the following signal analysis the output signal was fed into a 50 GHz sampling oscilloscope. It was triggered by the 500 MHz MLS rf system clock. The time resolution of the measurement was limited by the bandwidth of the readout electronics, in our case by the amplifier. All experiments were performed at the THz beamline of the Metrology Light Source (MLS) synchrotron facility of the Physikalisch-Technische Bundesanstalt (PTB) in Berlin [3]. It is the first electron storage ring with a dedicated electron optics for low-alpha operation and an optimized THz beamline. Both are necessary for the generation of stable high power THz CSR [4].

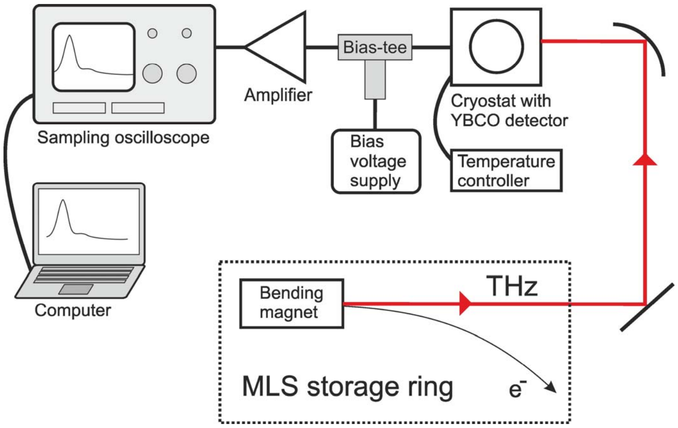

Fig. 1. Simplified scheme of the experimental setup.

III. DATA ANALYSIS AND RESULTS

The typical filling pattern of the MLS storage ring consists of 80 electron bunches. Due to the 500 MHz rf clock the distance between two adjacent bunches is 2 ns. The detector response to the incident THz pulse showed a pulse length of 80 ps FWHM which is limited by the bandwidth of the amplifier. To determine the time jitter of the electron bunch we measured the transients of the THz pulses and extracted the time variation Δt_{meas} at the rising edge of the pulse. To generate a histogram of the jitter the arrival time was measured for up to 2000 pulses. Ensuring that the steepest part of the rising edge was used the arrival time was determined at half the rising edge (see red rectangle in Fig. 2). To avoid additional jitter due to baseline fluctuations the first few picoseconds of the baseline were used to correct these fluctuations. The measurements were done using two different machine optics of the MLS (3 kHz and 5 kHz optic). Filled with 80 electron bunches, every single bunch was detected and the standard deviation was measured.

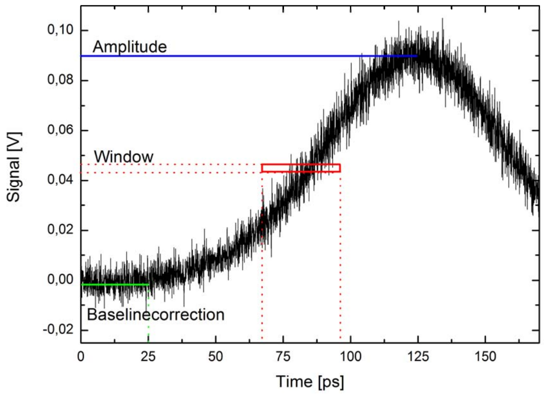

Fig. 2. Rising Part of a THz CSR pulse with illustration of the analysis method for determination of the total jitter of the CRS pulse.

As displayed in Figure 3 the jitter shows a Gaussian distribution. It has two contributions. First, the time jitter of the electron bunch due to the fluctuation of the arrival time as a consequence for example of a slightly unstable orbit or longitudinal oscillations. Second, the jitter due to the detector and its electronics (Δt_{electr} =2 ps; an estimation based on the fact that the trigger jitter is in the range of 1.5 ps). Assuming that all jitter contributions are independent we calculated the jitter Δt_{CSR} from Eq. (1).

$$\Delta t_{CSR} = \sqrt{\Delta t_{meas}{}^{2} - \Delta t_{electr}{}^{2}}\,. \qquad (1)$$

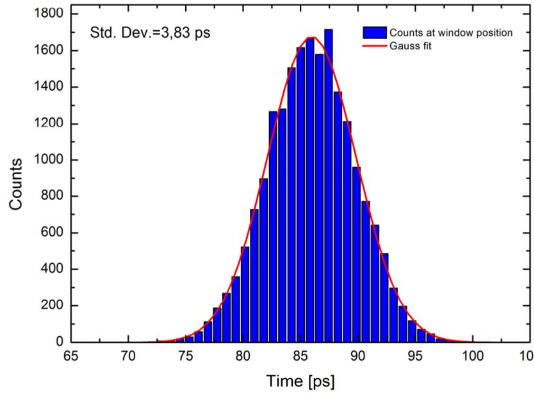

Fig. 3. Resultant jitter distribution. Usually it was well represented by a Gaussian function.

Jitter measurements using the two optics of the MLS are shown in Figure 4. The data are corrected for the electronic jitter. It can be seen that the CSR jitter as well as the rate of increase with rising beam current depends on the machine settings and is significant smaller with the 3 kHz optic than the 5 kHz optic, meaning that shorter bunches have shorter jitter. Also with increasing bunch length the jitter increases. Its FWHM is approximately 50 % of the bunch length measured with the streak camera (3 kHz optic, Fig. 4b).

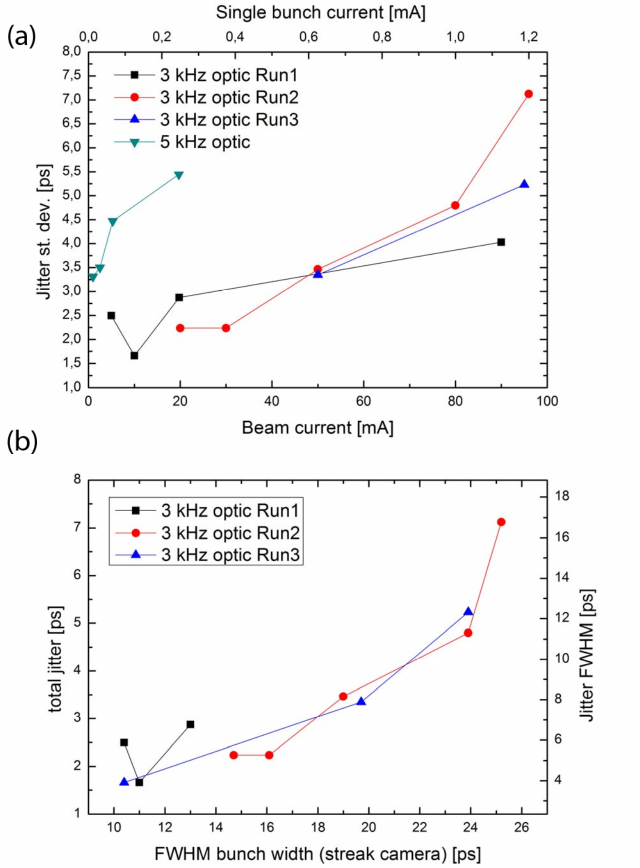

Fig. 4. (a) Increasing bunch jitter with increasing beam current (5 kHz optic: 480 kV rf Voltage / 6.94 kHz tune; 3 kHz optic, 477 kV rf Voltage / 4.16 kHz tune). (b) The time jitter also increases with increasing bunch length (FWHM, determined by a streak camera).

IV. CONCLUSION

We investigated the time jitter of CSR at the MLS of the PTB in Berlin by applying a superconducting YBCO detector. The time jitter has a Gaussian distribution and is in the range of a few picoseconds. The jitter increases with increasing bunch current and also with increasing bunch length. Comparing the two machine optics the 3 kHz optic showed better bunch stability then to the 5 kHz optic.

V. ACKNOWLEDGEMENT

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