COHERENT SYNCHROTRON RADIATION STUDIES AT THE ACCELERATOR TEST FACILITY*

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Abstract

Coherent Synchrotron Radiation has been the object of recent experiments and is a topic of great importance for several accelerators currently in their design phase (LCLS, ILC, CIRCE). We present the results of several experimental sessions performed at the Accelerator Test Facility - KEK (ATF). An infrared bolometer was used to detect the emitted synchrotron radiation in the 1 - 0.05 mm wavelength range as a function of several beam parameters (beam current, RF power, extraction timing, photoinjector laser phase). The beam energy spread was also recorded. We detected beam-generated synchrotron radiation from the bunch injection. After replacing the beamline in-vacuum window, for better IR transmission, we also measured a signal from circulating beam at the shorter end of our instrument sensitivity. This signal seems very weakly dependant on the beam current and the determination of its exact nature requires further experiments.

INTRODUCTION

In this paper we present the results of experimental measurements in the 1 mm to 50 μm wavelength range performed at the Accelerator Test Facility at KEK. The object of these experiments was to integrate the CSR studies carried out at the ALS and BESSY-2 [1-3]. These studies showed that Coherent Synchrotron Radiation (CSR), under certain conditions, induces a saw-tooth instability in the circulating bunches. The theoretical threshold of such instability has been calculated by J. Wu, et al. [4], as a function of the wavelength and of the wiggler impedance.

There is a two-fold interest in a better understanding of CSR generation in synchrotron rings, as this instability could possibly be used as a powerful source of synchrotron radiation in the presently neglected THz region, if we could control it in some fashion. On the other hand, the CSR instability constitutes a limit in the maximum bunch charge density, which is especially important in high-performance damping rings currently in their design phase (ILC, for one).

We describe our experimental set-up and show the data obtained during two experimental sessions in April and December 2005.

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MEASURING COHERENT SYNCHROTRON RADIATION

The theory of the generation and propagation of synchrotron radiation in a vacuum chamber has been well known for a long time [5]. Summarizing the results relevant to our measurements we can say that the power emitted by a bunch composed of N_b electrons, each of length σ_z is given by

$$P_b(\omega) = P_e(\omega)\left[N_b + N_b(N_b - 1)g(\omega,\sigma_z)\right] \quad (1)$$

where P_e is the power emitted by an individual electron. The second term in square brackets is the coherent term. The form factor g defines the "efficiency" of the coherent emission and depends on the actual bunch shape. For Gaussian bunches g is practically zero for wavelengths $\lambda<\pi\sigma$ and it obviously becomes closer to unity for $\lambda>>\sigma$.

On the other hand the so called waveguide cut-off condition, effectively shields all the wavelengths

$$\lambda > 2h^{3/2}\rho^{1/2} \quad (2)$$

where h is the vacuum chamber height and ρ is the electron trajectory curvature radius.

From Eqs.(1) and (2) we can see that it is possible to have emission in the CSR regime only for such wavelengths satisfying the following two sided inequality:

$$\pi\sigma > \lambda > 2h^{3/2}\rho^{1/2} \quad (3)$$

For many machines the rightmost side of Eq.(3) is actually larger than the leftmost, so that there never is coherent emission at any wavelength.

Figure 1: Infrared Laboratories 4.2 K Si bolometer.

EXPERIMENTAL SET-UP

In order to measure the beam generated infrared radiation we used an Infrared Laboratories [6] 4.2 K Si bolometer (Fig.1) with a 100/1000 cm^{-1} switchable cut-on windows.

The two filters allow measuring separately wavelengths from 1 mm to 100 μm and from 100 μm to 10 μm. The bolometer low-noise preamplifier can provide can be set to high and low gain (1000x and 200x) and the raw signal is also available. Our instrument was placed in the streak camera/interferometer diagnostic beamline (Fig.2).

The infrared bolometer is not DC coupled, so that it wouldn't measure a constant signal, and its response time is in the order of 1 ms.

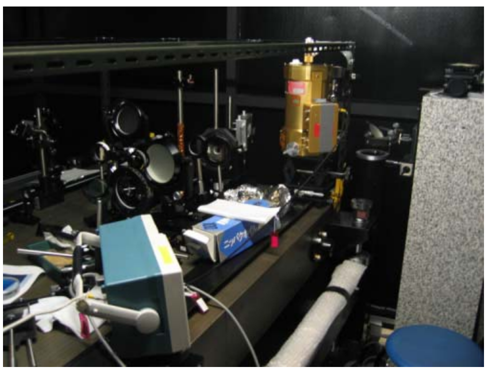

Figure 2: Expermental set-up at the ATF diagnostic beamline.

During the first measurements in April we saw that the beamline in-vacuum window optical glass (BK7) caused a very strong attenuation in the infrared signal, which was nonetheless detectable by setting the bolometer to maximum gain and the output oscilloscope into averaging mode.

During the summer we measured the attenuation in the region of interest of BK7 and water-free fused silica at the Advanced Light Source and decided to replace the in-vacuum window during the summer scheduled shutdown. The measurements results are shown in Fig.3.

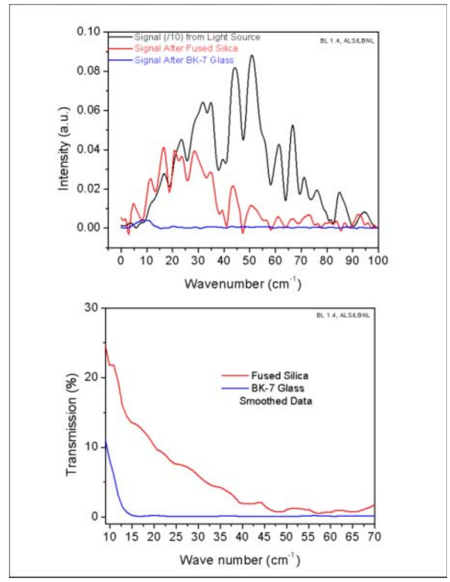

Figure 3: Experimental measurements of the attenuation in the near-infrared region from BK7 optical glass and water-free fused silica.

MEASUREMENTS RESULTS

Figure 4 shows a typical signal output from our bolometer, from two subsequent bunch injection/extraction cycles. As stated previously, the bolometer doesn't record DC signals, so that the only way to ascertain if this is the bolometer response to a constant IR emission, or a pulsed signal generated by the injection process would be using a light chopper and see if the bolometer detects any signal following the injection.

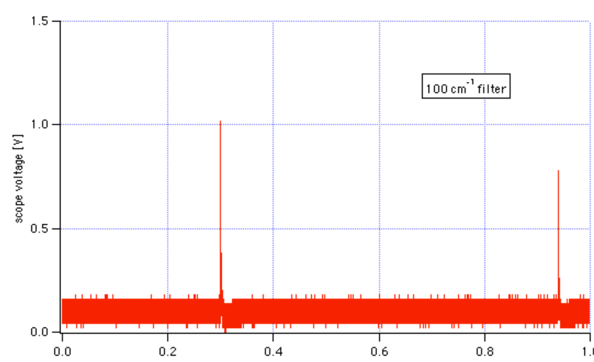

Figure 4: Typical bolometer signal from two successive bunch injections (100 cm^{-1} filter).

When we switched the bolometer filter to detect shorter wavelengths, we saw a definitely weaker signal (Fig.5. Quite surprisingly, we also detected a signal from the circulating bunch, together with the usual spike in correspondence of the bunch injection.

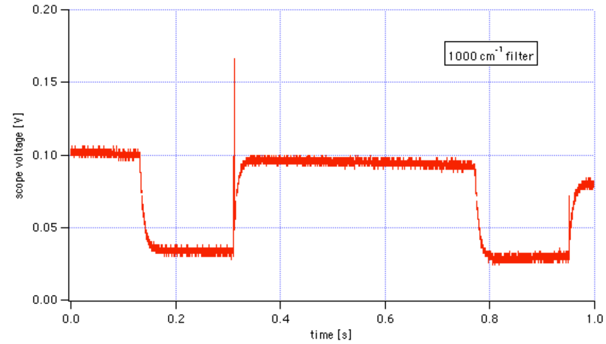

Figure 5: Typical bolometer signal (1000 cm^{-1} filter). Bunch is dumped 450 ms after injection. Injection period is 650 ms.

Because of the intrinsic DC rejection in the bolometer, this signal should originate from some ongoing dynamic process taking place in the circulating bunch. By using a primitive high-pass filter, we determined that this signal's wavelength is at the shorter end of the bolometer response. We also kept a bunch circulating in the machine for many thousands of turns, still detecting the same signal, so that it can be excluded this could be somehow related to the injection process, when the bunch is initially mismatched to the equilibrium phase space of the damping ring.

In Fig.6 we show a collection of many data points taken at different bunch charges. We have used both the damping ring and the injection line current monitors and the latter seems a better reference, as the injection spike level is better correlated to the injected current than to its average circulating value (after injection losses).

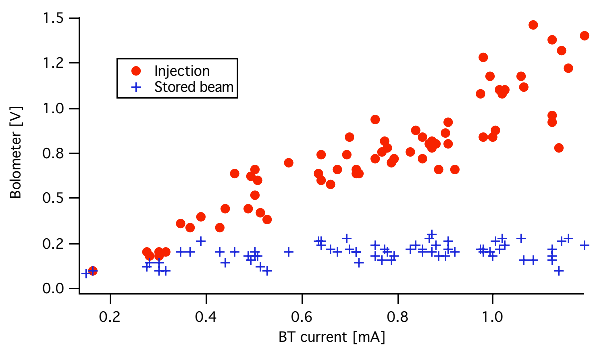

Figure 6: Bolometer signal from injection a stored beam as a function of the bunch current (injection transfer line current monitor).

Due to operational limitations we couldn't reach the theoretical threshold current for the CSR instability, which is around 3.5 mA for a 1 mm wavelength [4]. The injection signal level seems to be proportional to the bunch current, indicating that it consists of incoherent emission. The signal from the stored beam is instead almost not dependent on the bunch current and we have not yet determined its true nature and origin.

CONCLUSIONS

Using a 4.2 K Si Bolometer on the ATF streak camera diagnostic beamline we measured infrared beam signals in the 1 mm to 10 μm wavelength region. We recorded two distinct types of signals. The first type appears to be incoherent infrared emission from the bunch and is measured as a peak in the bolometer output voltage in correspondence of the bunch injection.

The second, weaker, signal instead appears only at the short wavelength end of the instrument's response. This signal is recorded at a constant level throughout the time a bunch is circulating in the machine and vanishes when the bunch is extracted. Its intensity seems weakly correlated to the bunch current. The second type of signal has never been observed in the experiments carried out at the ALS, using the same bolometer and comparable beam conditions, and its identification is still uncertain and would require further investigation.

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