OBSERVATION OF LONGITUDINAL MICROBUNCHING INSTABILITIES IN THE DIAMOND STORAGE RING

R. Bartolini1,[2], P.Karataev[3], G. Rehm[1]
[1]Diamond Light Source, Oxfordshire, UK, [2]John Adams Institute, University of Oxford, OX1 [3]RH, UK, [3]John Adams Institute, RHUL, Egham, TW20 0EX, UK

Abstract

Diamond is a third generation synchrotron light source built to generate infra-red, ultraviolet and X-ray synchrotron radiation (SR) of exceptional brightness. The operation of the Diamond storage ring with short electron bunches for generation of coherent THz radiation and short X-ray pulses for time-resolved experiments is limited by the onset of microbunching instabilities. We have started a project to investigate the longitudinal electron beam dynamics and microbunching instabilities in the Diamond storage ring which is based on the use and the development of ultra fast THz detectors. In this report we will present our first preliminary results and also discuss future plans.

INTRODUCTION

The Diamond Light Source has recently started an experimental programme for the generation of short radiation pulses in the storage ring. Dedicated low-alpha optics[1] have been developed and tested for users providing radiation pulses as short as 1 ps rms. Both X-ray time resolved experiments and THz users are expected to benefit from such operating mode.

It is well known that low-alpha optics can only operate with reduced current per bunch due to the onset of the so called microbunching instability[2]. The average current thresholds can be as low as several tens of µA per bunch[3-7] to operate below the instability threshold. The performance of the storage ring is therefore strongly reduced by this instability and it is essential to understand which operating conditions provide the users with short radiation pulses of the required intensity and stability. To this aim we started an experimental analysis of the microbunching instability with the final goal of developing strategies to control the instability or minimise their impact on the users' experiments. The main feature of this instability is the emission of strong THz bursts above a certain current threshold. The emission is stable for moderate current providing a stable THz source with good average flux level. However, increasing the current, the THz emission becomes less regular reaching a completely chaotic pattern at sufficiently high current. This might limit the possibility of using the ring as a stable source of THz radiation and X-ray pulses.

The availability of diagnostics capable of detecting the coherent THz bursts on a bunch by bunch basis provides a powerful tool for the understanding and the optimisation of the radiation source. With this aim we have installed in the storage ring an ultrafast THz detector that can measure the THz radiation generated by the bunch from a dipole beam port.

We report here the results of the measurement and the observations made using these new detectors at the Diamond Storage ring.

THZ DIAGNOSTICS

We have employed an ultrafast Schottky Barrier Diode (DXP-12 from MilliTech) with a standard gain horn antenna (SGH-12). The main characteristics of the detector are summarised in Table 2.

Table 2: Schottky Barrier Diode (DXP-12)

Frequency range	60 – 90 GHz
Wavelength range	3.33 – 5 mm
Sensitivity range (freq. dep.)	2740 – 1430 mV/mW
Horn Antenna Gain (freq. dep.)	22.50 – 23.69
Time response (FWHM)	~250ps

The detector was installed at B01 visible light port used at Diamond for diagnostics purposes. The detector was mounted on a long post facing an in-vacuum mirror through a fused silica viewport, which is capable of transmitting millimetre wavelength radiation (see Fig.1). A high quality RF cable (RG213) was used to transport the signal from the detector to an oscilloscope (Agilent DSO91304A).

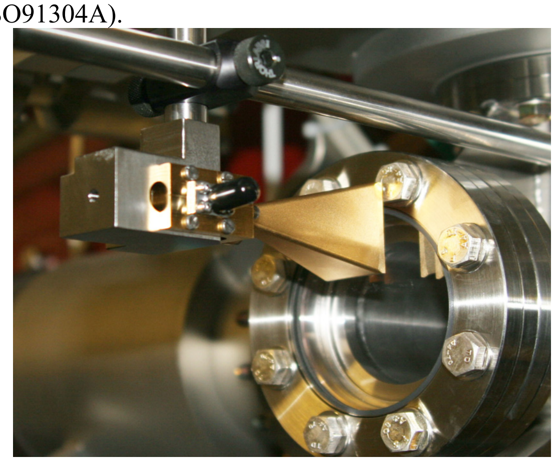

Figure 1: Experimental set up of the THz detector.

A typical signal observed from the detector is illustrated in Fig. 2. The average FWHM (Full Width at Half Maximum) pulse duration was about 250ps; however there was a tail (~2ns) which made the pulse somewhat longer. Nevertheless, as the distance between subsequent bunches at Diamond is 2ns, the DXP-12 allows us the measurement of the signals from each individual bunch.

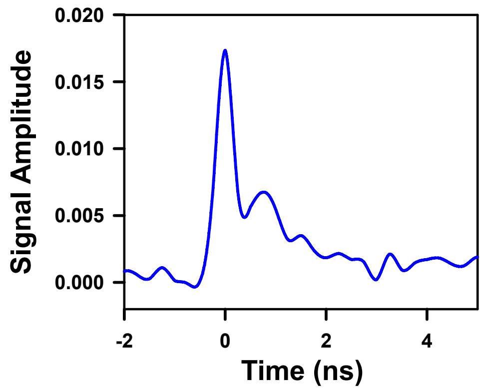

Figure 2: Typical signal from DXP-12 for the THz emission generated by a single bunch in the diamond storage ring. The signal amplitude is in Volts.

We also performed simultaneous measurement of the THz radiation and acquisition of streak camera images during the bursting process. This was possible by triggering the streak camera with a signal from the amplitudes at the THz burst. In this way the THZ emission process can be studied in conjunction with the longitudinal dynamics and the correlation between the two can be put in evidence.

OBSERVATION OF THZ EMISSION

The experimental observation of the THz radiation has been so far performed using the normal operating optics in the standard multibunch fill (2/3 fill with 1/3 gap), in the single bunch mode and in the so called hybrid mode where a single bunch with charge as high as 6 nC is injected in the gap of the standard multibunch mode.

This optics has a nominal zero current bunch length of 11ps rms, at the voltage of 3.0 MV. However, due to Potential Well Distortion and Microwave Instability, the bunch length grows rapidly with current and can reach more than 40 ps rms at 5 mA. With such bunches we expect a coherent THz emission from the whole electron bunch up to a the critical wavelength $c/2\pi\sigma_z$ reaching 7.5 cm (4 GHz) which cannot propagate above the vacuum pipe cut-off, estimated to be 54 GHz from the relation $2h\sqrt{(h/\rho)}$ with our total vertical aperture h = 38mm and the bending radius ρ=7.1m. However, it has been suggested that microwave and THz emission can be generated also by a density modulation of a portion of the bunch [5] which can occur at significantly shorter wavelength and indeed we could detect significant THz radiation even with such long bunches in the 3.3 – 5 mm wavelength range.

We first used the DXP-12 detector to observe THz emission from the beam in the usual operating mode of 300 mA in 600 bunches corresponding to an average current in single bunch of 0.5 mA. At this current level, the single bunch has already undergone a modest lengthening and the bunch length was measured to be 12ps rms. The coherent radiation must appear at the wavelength comparable to or longer than the bunch length and is therefore still below the vacuum pipe cut-off frequency. The electron beam is very stable in the user mode, and no signal was observed as expected. From this test we concluded that the detector is not sensitive enough to detect incoherent part of the emitted microwave radiation.

Subsequently we have investigated the behaviour of a single bunch mode as a function of the current. The fast response allowed the detection of the signal turn-by-turn, which gave us an opportunity to study the bursts' structure and evolution. In Fig. 3 we present oscilloscope traces of the THz bursts observed from storage ring. The scope was triggered by the signal itself.

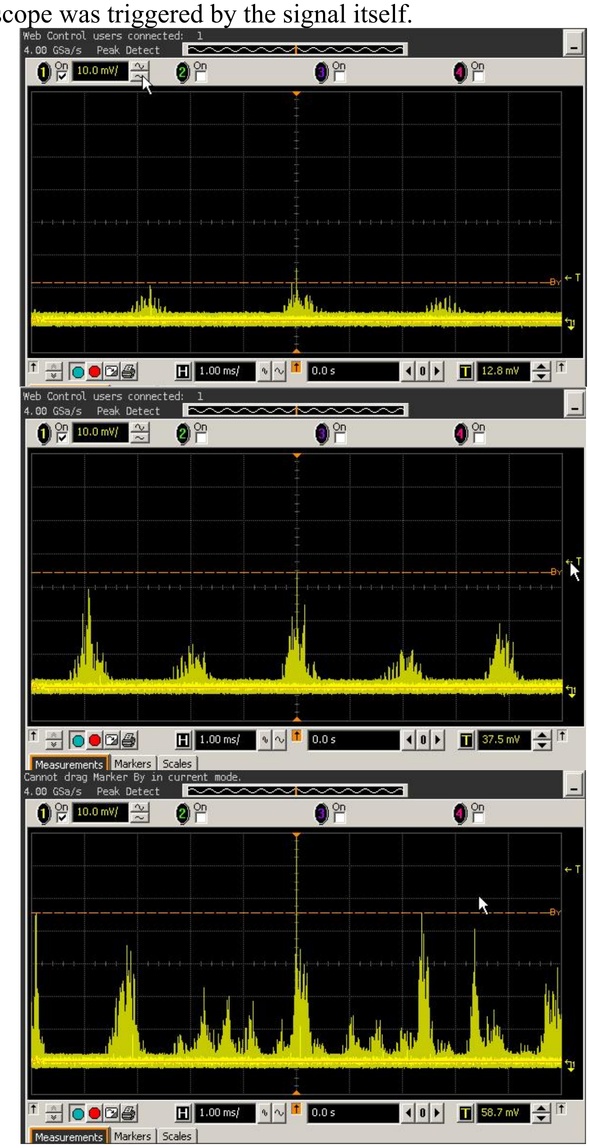

Fig. 3: Oscilloscope traces of the signal from the Schottky Diode showing the onset of the THz bursts at 1.9 mA (top), at 3 mA (middle) and a chaotic series of bursts at 5.2 mA (bottom).

When the single bunch current exceeded 1.9 mA we observed the sudden appearance of a set of quasi-periodic sub-THz bursts with period of about 2.5 ms. The top picture represents the bursts for the single bunch current reached 1.9mA, corresponding to a charge of 3.56nC. The threshold is typically very sharp. At the beam current of 1.88mA no THZ signal was detected and adding up 0.02mA was enough to trigger the instabilities. The middle picture in Fig. 3 represents the instabilities at 3mA, corresponding to a charge of 5.62nC. One may see that the intensity increases while the beam charge increased. Moreover the period of the bursts is reduced, i.e. the instabilities started appearing more frequently. This aspect suggests that the time required by the instabilities to build up is reduced. Finally, increasing further the current, the THz emission gets increasingly irregular as shown in bottom picture of Fig. 3.

In hybrid mode a very strong THz emission was detected from the high charge single bunch (6 nC corresponding to about 3 mA) as expected from the data previously discussed.

The THz emission pattern is strongly influenced by the value of the RF voltage. We observed in fact that the THz bursts structure can occur under very different time scales for different RF voltages. Quasi-periodic bursts of THz radiation of 100 μs period have been detected just above threshold for RF voltages within 3.2 and 3.3 MV. Increasing the current, this THz burst pattern exhibit a sharp transition toward a quasi-periodic burst pattern with much larger period (2.0 ms). In all cases investigated, however, it was not possible to detect a THz emission from the single bunch at each turn inside the ring, i.e. the THz emission is always appearing in bursts separated by many turns where the bunch seems to damp to an equilibrium condition and no THz emission is detected.

We finally investigated the behaviour of the single bunch instability with a streak camera acquiring THz signal and streak camera images with the same trigger. It was possible to establish a clear correlation between the emission of a THz burst and a modest but clearly detectable variation of the bunch length as shown in Fig. 4. Asymmetries detected in the bunch profile during the THz bursts are under investigation and seems to point to the presence of quadrupolar and higher order collective modes excited in the longitudinal phase space.

CONCLUSIONS AND FUTURE WORK

We have started the investigation of microbunching instability by means of an ultra fast THz detector. First measurements show that substantial THz radiation is generated in single bunch current with the nominal lattice. The phenomenology of this instability appears to be very rich and a full classification will be the object of forthcoming experiments.

The current dependence of the emission is under investigation and no firm conclusion can be drawn with our preliminary measurements about the coherent content of the emission and the scaling law with the number of electrons in the bunch.

In the future we plane to build a Michelson interferometer to measure the spectral content of the CSR radiation. This will enable us to study the longitudinal structure of the bunch and possibly the dimensions of the microbunch modulation. The interferometer will be installed on an optical table placed on the floor and the radiation will be deflected downwards by a periscope to minimize any background contributions, reduce the hardware radiation damage and increase the lifetime of the equipment (detectors, motion stages, etc.). Since the DXP detector is relatively narrow band, we intend to use a few such detectors setup on a moving stage to be able to change them and cover a longer wavelength range. We will also employ a broadband pyroelectric detector capable of detecting shorter wavelengths.

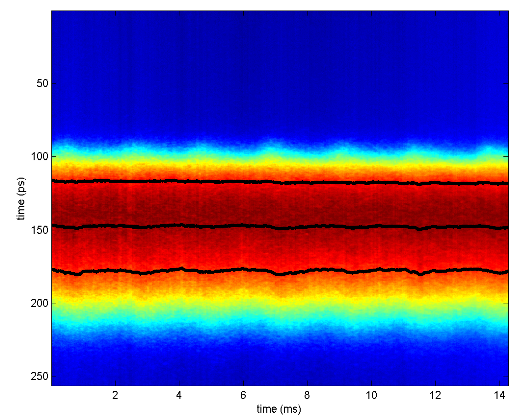

Figure 4: Streak camera image of single bunch longitudinal current distribution in correspondence of THz bursting.

The aim of these measurements is the optimisation of the THZ emission by an early detection of the onset of the instability and possibly by devising strategy to control or reducing the bursting nature of the process. At the same time we expect to develop a model for the longitudinal impedance and numerical tracking codes [8] of the longitudinal beam dynamics with the aim of gaining information about the machine impedance and further insight in the mechanisms of the instability.

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