Abstract

In the ANKA storage ring it is possible to store bunches with RMS lengths of the order of 1 ps using a dedicated optics with reduced momentum compaction factor. For short bunch operation a beam energy of 1.3 GeV is chosen as a tradeoff between low energy longitudinal instabilities and the increase in natural bunch length with energy. At this medium energy (the energy range of the ANKA storage ring is 0.5 to 2.5 GeV) steady state emission of coherent synchrotron radiation is observed at the ANKA-IR beamline below the threshold current defined by the micro-bunching instability. At lower beam energies where the natural bunch length is significantly shorter, coherent synchrotron radiation is detected in spite of the longitudinal oscillation. The far infrared spectrum is sensitive to the dynamics of the charge distribution generating the radiation. Measurements of the frequency spectrum of the infrared detector signal add information on bunch dynamics. This paper gives an overview of the studies performed at the ANKA storage ring.

INTRODUCTION

Since last year the ANKA storage ring offers beam time for users of a special operation mode with short bunches that emit coherent synchrotron radiation in the far infrared [1]. This THz radiation is detected at the ANKA–IR beamline [2], where the synchrotron light is produced in the fringe field of a bending magnet. This edge radiation has the advantage of being more collimated than constant field radiation. Edge radiation allows the observation of frequencies down to 30 GHz through a modest vertical aperture of 15 mrad, which would not be possible with classical constant field emission due to the increasing beam divergence with decreasing frequency. In order to provide coherent synchrotron edge radiation to the experiments, the storage ring is filled at 0.5 GeV. The desired beam current is then ramped to 1.3 GeV, since the ANKA storage ring suffers from longitudinal instabilities at energies below 1.3 GeV [3]. At the end energy, the bunch length is gradually decreased by an optics change in a so-called “low-α_c squeeze”. Measurements can be performed at any of the individual “squeeze states”, allowing to adjust the bunch length to user demand. To improve understanding and control of the low-α_c mode, beam studies have been performed that are described in the following.
The visible polarisation of the internal source indicates a residual polarisation of the detection system.

tune can be expressed by

\[ Q_s^2 = \left( \frac{\alpha_c h}{2 \pi E} \right) \sqrt{\frac{e^2 V_{RF}^2}{2} - U_0^2} \]  

(1)

where \( U_0 \) is the energy loss, \( V_{RF} \) the total accelerating voltage and \( h \) the harmonic number. A global fit of this function to the \( f_s \) measurements shown in Fig. 1 yields an effective momentum compaction factor for all energies of \( \alpha_c = (6.6 \pm 0.1) \cdot 10^{-3} \) which is reasonably close to the value determined at the beam energy for regular user operation of 2.5 GeV with resonant depolarisation of \( (7.39 \pm 0.01) \cdot 10^{-3} \) [4]. The hatched areas in Fig. 1 denote the error bands of the global fit. The RMS Bunch length as a function of beam energy derived from the measurements shown in Fig. 1 is displayed in Fig. 2. The hatched regions show the error bands of the calculated bunch length dependence on total accelerating voltage and beam energy as obtained by a full error Monte Carlo. The markers represent the bunch length derived from synchrotron frequency measurements during the “low \( \alpha_c \) squeeze” for different beam energies. The energy dependence of the resulting far infrared (FIR) spectrum due to the change in natural bunch length is clearly visible in Fig. 3: with increasing beam energy the spectrum shifts to lower frequencies, that is lower bunch lengths. The fact that the low frequency content is reduced for shorter bunches could hint at detector non-linearities. Since for small bunch currents the low energy instabilities are less pronounced, a scan of the stable/bursting threshold could be performed with a low-\( \alpha_c \) scan at 0.998 GeV. The transition to steady-state radiation was clearly seen. A comparative analysis of threshold scans at different beam energies is in progress.

**POLARISATION IN THE FIR**

The edge radiation observed at the ANKA–IR beamline is expected to show a radial polarisation. For very low frequencies, however, the annular structure is enlarged with respect to the mid-IR wherefore only a slice of the radiation in the orbit plane will be visible. The measured polarisation should be mostly linear. To test this, the FIR spectrum was detected in standard operating conditions (that is, at 1.3 GeV) for different orientations of a polarising grid. The dependence on the polariser orientation is clearly visible in Fig. 4 and confirms the expected linearity: the highest transmission was achieved for an orientation perpendicular to the orbit plane, the lowest for an orientation parallel to the orbit plane. The resulting degree of polarisation, \( A = (P_{\text{max}} - P_{\text{min}})/(P_{\text{max}} + P_{\text{min}}) \), is shown in Fig. 5 as a function of the frequency. A measurement with an internal source (Globar) also plotted in Fig. 5 indicates a residual polarisation of the detection system that needs to be included in an analysis of the polarisation degree. The observed “intrinsic” polarisation could be due to the placement of the polariser in the focal point inside the sample compartment of the spectrometer. This leads to a strong divergence at the polariser that can bias the results. The polarisation experiment therefore will be repeated with the polariser located at a position where the IR beam is parallel to suppress the influence of the divergence.
Measurements of the raw bolometer signal show a clear evolution in the time domain (for an example see [1]). For the following studies, the signal was subjected to a harmonic analysis using the method of Lomb Normalised Periodograms (LNP) [5]. To study the change of the frequency contents during the build-up of a burst, the signal around a burst was cut in slices and analysed separately. Figures 6 and 7 show such a sequence of Lomb Normalised Periodograms of the bolometer signal for bunch currents of 0.47 and 0.16 mA, respectively, and at 1.3 GeV. The maximum of the radiation burst is located at $t = 0$. The high current dataset clearly shows a double peak structure around the synchrotron frequency of 5.5 kHz that could be due to bunch length oscillations. For lower currents the structure around $f_s$ is no longer present and the maximum of the burst is more pronounced. The low frequency contents clearly shows a current dependent behaviour. Figure 9 shows the spectrogram for a constant current but a changing bunch length. The two changes in optics are denoted by the step-wise change in $f_s$. The onset of bursting emission for shorter bunches is obvious.

SUMMARY

Measurements at different beam energies confirm the possibility to generate steady-state coherent synchrotron edge radiation at ANKA. First polarisation studies show the expected linear behaviour but also systematic effects that need to be taken into account. The frequency spectrum of the IR signal displays a dependency on current and bunch length. Further work is needed to correlate the findings to theoretical predictions.

REFERENCES