BEAM SIZE AND BUNCH LENGTH MEASUREMENTS AT THE ANKA STORAGE RING

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Abstract

ANKA is an electron storage ring working at a nominal energy of 2.5 GeV. The beam is injected at 500 MeV into the storage ring and ramped to the final energy. The beam size and bunch length have been measured in the range from 500 MeV to 2.5 GeV. The beam size measurements were performed with two synchrotron light monitors, one in a dispersion region and the other in a zero dispersion one. The bunch length was measured using the bunch spectrum with an Annular Electrode and a spectrum analyser up to 8 GHz [1]. The bunch length as a function of the momentum compaction factor, the growth rate of a longitudinal instability as a function of beam current and the Intrabeam Scattering have been analysed.

INTRODUCTION

Bunch length and beam size have been measured between 500 MeV and 2.5 GeV; for different bunch currents. The filling pattern has been always the same, 25 bunches filled out of 184 possible.

From the analysis of the results we have seen that the bunch length is mainly determined by the presence of a longitudinal instability that increases the energy spread of the beam below 2.5 GeV.

The beam size measurements were not fully satisfactory since that longitudinal excitation at lower energies, which could not be avoided, is hiding any trace of Intrabeam Scattering or Microwave Instabilities.

BUNCH LENGTH

The bunch length has been measured using the bunch spectrum up to 8 GHz coming from an Annular Electrode [1]. The system has to be calibrated to a reference low current bunch length, which is assumed to be the natural bunch length. We have calibrated the system with 0.04 mA per bunch (1 mA in 25 bunches) at 2.5 GeV, where the beam is completely stable, the energy spread is the natural one and neither Intrabeam Scattering nor Microwave Instabilities are present.

Natural bunch length

With 1 mA in 25 bunches and a constant RF voltage, the synchrotron frequency has been measured as a function of the energy, it is shown in figure 1.

By fitting the curve to:

$$f_s = f_o \sqrt{\frac{\alpha\, h \cos\phi_s}{2\pi} \frac{eV_{RF}}{E}} \qquad (1)$$

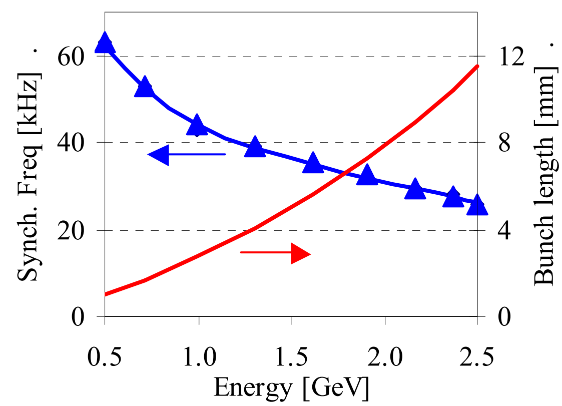

Figure 1: Synchrotron frequency (measurement: points, and fit: line) and bunch length calculation.

Where f_s is the synchrotron frequency, f_o the revolution frequency, α is the momentum compaction factor, ϕ_s is the synchrotron phase, V_{RF} the RF voltage and E the energy, the momentum compaction factor is found to be:

$$\alpha = 0.0070 \pm 0.0004$$

This is in good agreement with the optics model of the ANKA storage ring [2]. The natural bunch length can be then calculated:

$$\sigma_o = \frac{\alpha\, c}{2\pi f_s} \frac{\sigma_E}{E} \qquad (2)$$

Where σ_o is the natural bunch length, c is the light speed and σ_E is the energy spread.

The natural bunch length as a function of energy is shown as well in figure 1. The natural bunch length at 2.5 GeV is 11.5 mm.

Measurement method

The measurement is done by recording the RF frequency harmonics of the bunch spectrum, the Fourier transform of it is then related to the bunch length in the time domain. Assuming a Gaussian distribution, one only needs to evaluate the spectrum at two frequencies.

In order to get an absolute measurement it is necessary to have a reference or calibration point, for which a beam of 1 mA current at 2.5 GeV was used.

The procedure is, first measure the amplitude of two (or more, for statistics) harmonics of the RF frequency (f_n, f_1) at the reference point $(P_n\text{-}P_1)_0$ and use this measurement as a calibration factor. Then, measure the same set of frequencies in any other condition $(P_n\text{-}P_1)$, i.e. different bunch current, beam energy, RF voltage or the machine optics. We can then get the bunch length from the relative change as follows [1]:

$$\sigma_L = \sqrt{\frac{(P_n - P_1)_o - (P_n - P_1)}{171.4\ (f_n^2 - f_1^2)} + \sigma_o^2} \qquad (3)$$

Where P_n and P_1 are the amplitude of the spectrum in dBm at the frequencies f_n and f_1 in Hz. Subindex "o" means the values for the reference bunch length. Figure 2 shows a typical spectrum of the beam, with markers at the harmonics of the RF frequency.

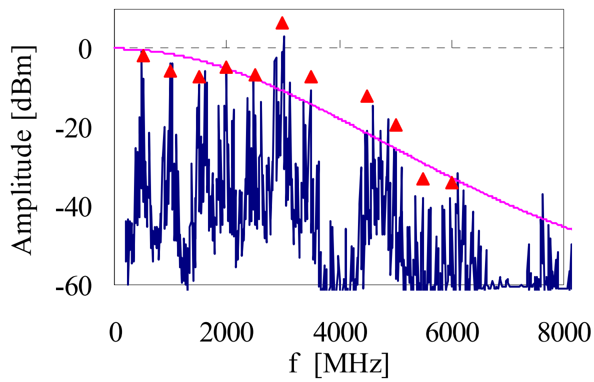

Figure 2: Beam spectrum. Markers point out the harmonics of the RF frequency.

As an example, figure 3 shows the bunch length as a function of the momentum compaction factor, for different optics with negative dispersion in the straight sections.

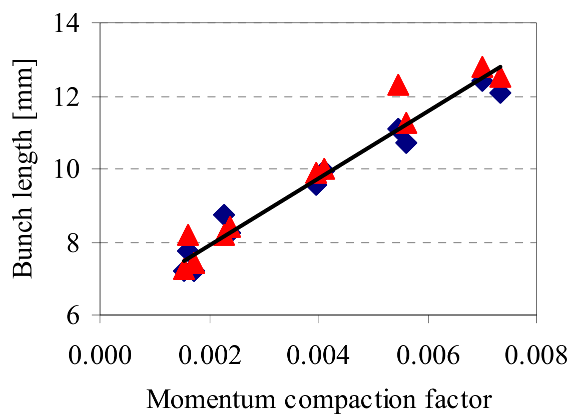

Figure 3: Bunch length as a function of the momentum compaction factor

In these measurement f_1 is 1 GHz and f_n is taken at 3.5 and 5.5 GHz (points). The bunch length is then calculated as an average of these values (line). The measurement was repeated twice with the same results.

Longitudinal instability

By measuring the bunch length as a function of the energy and the current we have determined the threshold of a longitudinal instability created by one high order mode in the RF cavities.

In figure 4, the bunch length as a function of the energy for a 1mA beam current is shown. One can observe that above 1 GeV the bunch length collapses to the theoretical prediction of the natural bunch length, i.e. the beam is longitudinally stable.

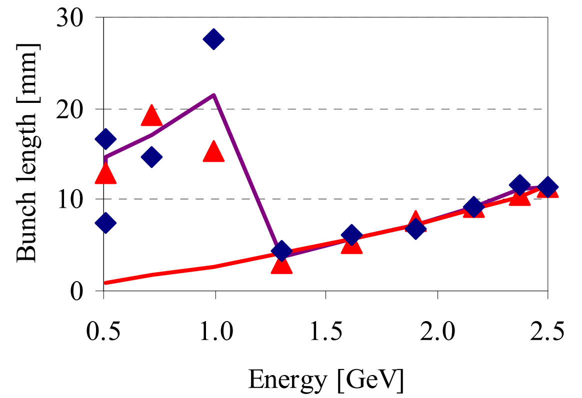

Figure 4: Bunch length as a function of beam energy for a 1 mA beam.

By increasing the beam current, the energy at which the bunch length collapses to the natural one increases, always following:

$$\alpha_{\text{HOM}} < \alpha_{\text{Damping}} \qquad (4)$$

Where α_{HOM} is the growth rate of the instability and α_{Damping} is the damping rate of the machine.

By calculating the damping rate for each energy, one can derive the growth rate of the instability as a function of the beam current, shown in figure 5.

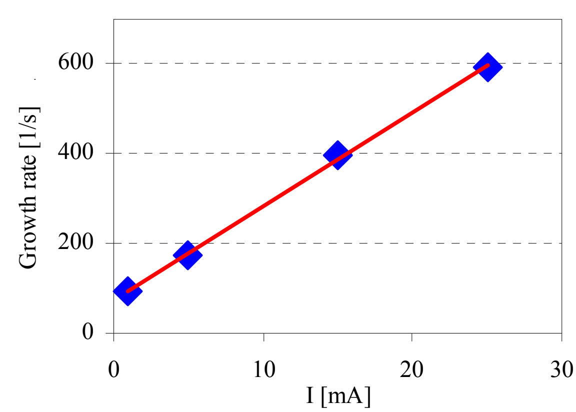

Figure 5: Growth rate of the longitudinal instability as a function of the beam current.

As can be seen the growth rate increases linearly with current, as expected. The extrapolation of the linear fit to zero current ($\alpha_{\text{HOM}} = 74.5\ s^{-1}$) also indicates that the beam would be unstable always at 500 MeV ($\alpha_{\text{Damping}} = 5.4\ s^{-1}$).

Another information extracted from the measurement of figure 4 is that at low energies, when the beam is longitudinal unstable, the values of the bunch length show a high spread. To analyse that, we have recorded the bunch length as a function of time by sitting on one RF harmonic with span zero and sweep time of 2 seconds. The extracted bunch length is shown in figure 6.

One can see that the bunch length is oscillating between 10 and 18 mm. The instability is "unstable", meaning that it does not reach an equilibrium. A similar effect has also been observed at the SPEAR ring [3].

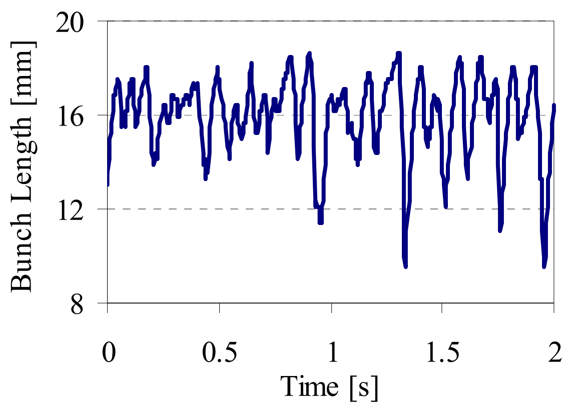

Figure 6: Bunch length vs. time of a 15 mA beam excited by a longitudinal mode at 500 MeV.

BEAM SIZE

An attempt to measure the beam size as a function of current and energy has been done in order to determine the role of the Intrabeam Scattering and the Microwave Instability at low energy.

Two beam line monitors using the visible part of the spectrum have been used. One is located in a not-dispersive section and the other in a dispersive one.

The measurements done with the monitor in the dispersive section are completely random and could not be fitted. This can be explained by the behaviour of the beam in the presence of the longitudinal instability. As shown in the figure 6, the bunch length is oscillating since the energy spread of the beam is as well oscillating. In the dispersive monitor the beam size has a contribution of the dispersion times the energy spread, so the beam size is oscillating as the energy spread. This effect does in fact suppress (or hide) any Microwave Instability that could appears.

On the other hand the monitor in the non-dispersive section is not affected by these oscillations. So we tried to use this one to analyse the effect of the Intrabeam Scattering at low energy.

Intrabeam Scattering

The Intrabeam Scattering has been calculated with the code ZAP [4] for different currents per bunch as a function of the energy, from 500 MeV to 2.5 GeV.

The results are shown in the figure 7, together with the calculated emittances obtained from the measured beam sizes, figure 8. A problem with the calibration of the system did force us to normalise the data to fit with the emittance found by the optics analysis at 2.5 GeV.

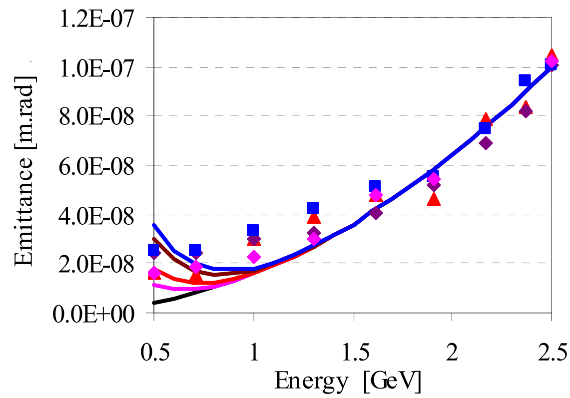

Figure 7: Intrabeam scattering calculations (lines) and emittances calculated from beam size measurements (points). For 0.04 (pink), 0.2 (red), 1 (violet) and 2 (blue) mA per bunch. Black line: natural emittance.

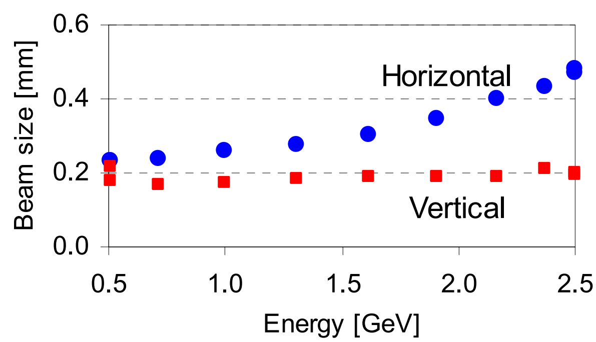

Figure 8: Beam size as a function of the energy for a 2 mA per bunch beam (50 mA in 25 bunches).

As can be seen from the graph, after normalisation, the measured emittances fit quite well the nominal ones for energies over 1.8 GeV. But at lower energies they tend to be higher than the natural ones.

On the other hand the Intrabeam Scattering should not affect the emittance for energies over 1.2 GeV in the range of the measurements.

In conclusion, even if the longitudinal instability should not affect the measurement done at this monitor (with non dispersion), it seems to affect the transverse equilibrium of the beam. Not plausible explanation has been found until now.

REFERENCES

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