INVESTIGATION OF SCRAPER INDUCED WAKEFIELDS AT ANKA

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Abstract

The ANKA synchrotron light source operates in the energy range from 0.5 to 2.5 GeV. Typical requirements for light sources include small beam sizes, large lifetimes and high currents to provide the highest possible photon flux. The understanding of impedance and instability related issues is very important in order to improve the machine performance, in particular when small aperture insertion devices are installed that require protection by a scraper. In the framework of an impedance survey the transverse and longitudinal wake fields induced by a vertical scraper have been measured and analysed. This paper reports the beam observations and compares them with the expectation.

INTRODUCTION

In the course of this year the installation of a superconduction undulator is foreseen in the ANKA storage ring. In order to prevent this device from quenching it is imperative to protect it from the heat load induced by the synchrotron radiation. This will be achieved by the closure of a special scraper. To adapt to the new situation, extensive studies have been performed to investigate in detail the effect of the scraper on the beam. This does not mean the obvious influence on current lifetime but rather the transverse and longitudinal impedance contribution of the scraper jaws.

WAKE FIELD KICK AND VERTICAL CLOSED ORBIT DISTORTION

The wakefield of a scraper is caused by the discontinuities at the leading and trailing edges of the jaws and by the resistance of the metallic material. In our case the jaws can be considered as far apart and the kick therefore is due mostly to the jaw discontinuity: the geometric impedance dominates. For a vertical scraper whose jaw (individual movement of both jaws) is at a distance a from the centre of the vacuum chamber of half height $b = 16$ mm the deflection of the beam can be estimated taking the Bane-Morton model [1] for an untapered round collimator and scaling it with $\pi^2/8$ to account for the difference between the round geometry of the model and flat geometry of the experiment [2]. The expected deflection for a bunch of population N_b, relativistic beam energy parameter γ and RMS

bunch length σ_z is given by

$$\langle y' \rangle = 0.71 \left(\frac{\pi}{2}\right)^{\frac{3}{2}} \frac{r_e N_b}{\sigma_z \gamma} \left(\frac{b-a}{b+a}\right) \quad (1)$$

where r_e is the classical electron radius.

This deflection can be experimentally determined by observing the vertical closed orbit distortion. Figure 1 shows two examples for differences in the measured vertical position with and without one scraper jaw moved in as a function of BPM position in the storage ring. The measurements were done at a beam energy of 0.5 GeV where the effect is expected to be largest. The change in the sign of
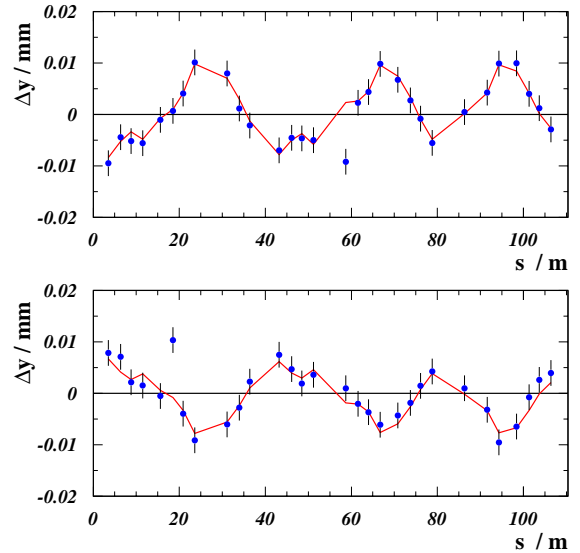

Figure 1: Difference in vertical closed orbit between measurements with and without scraper as a function of BPM position for a top scraper jaw position of 6mm (top plot) and a bottom scraper jaw position of 2.5mm (bottom plot). The opposite jaw is always out. The measurements were done for a total beam current of 120mA and 105mA, respectively, distributed equally over 30 bunches in one train. The solid line represents a fit of a MAD [3] model with scraper kick to the measured difference orbit.

kick for top and bottom jaw is clearly visible. In order to extract a value for the effective scraper wakefield kick from the difference orbit data, a MAD [3] model containing a description of the scraper as source of a kick is fitted to the measurements.

The dependence of the resulting kick on bunch current typical for an impedance related effect is shown for a fixed scraper position in Fig. 2.

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[*] now at ALBA Synchrotron Light Source, Spain
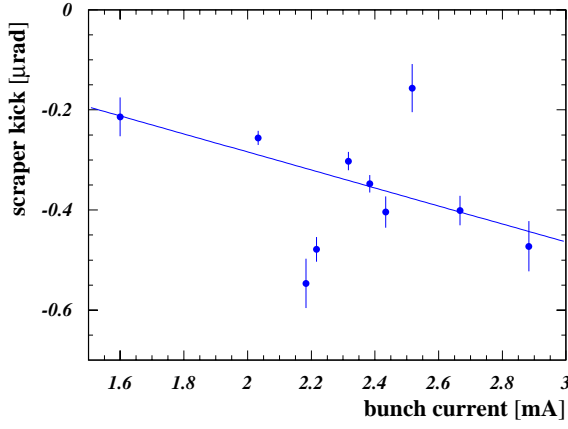[†] now at ALBA Synchrotron Light Source, Spain

Figure 2: Scraper kick extracted from a fit of a MAD model to the measured difference orbit as a function of bunch current. The measurement was done with a bottom scraper jaw half aperture of $a =$ 4mm and a total number of 30 bunches in one train.

Finally, the bunch current normalised kicks for different scraper positions are displayed in Fig. 3. The different symbols stand for independent measurement series. The dashed curves represent the expectation for the wakefield kick according to Eq.(1) for a bunch length of 12 mm. However, there is a longitudinal instability at the beam energy of 0.5 GeV and the bunch length determination has an extremely large uncertainty [4]. Therefore a scaling factor for σ_z was introduced in Eq.(1). Offsets were also added to the model to account for scraper misalignment and onset of the effect ($b \rightarrow b - b_0$). The results of the fit of this modified model is displayed in Fig. 3 as the solid curves. The resulting offsets are 7 and 5 mm with an uncertainty of 1 mm. The scaling factor for the bunch length is found to
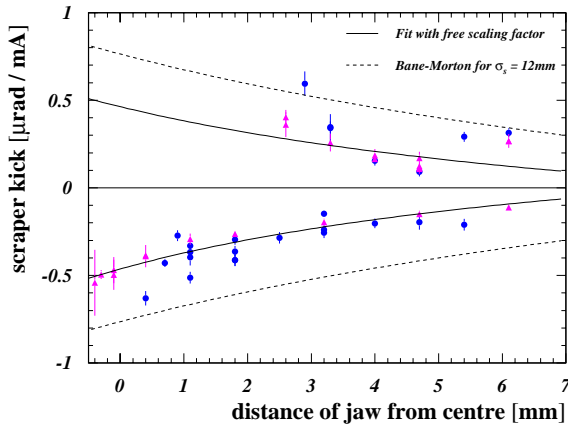

Figure 3: Scraper kick from a fit of a MAD model to the measured difference orbit normalised by bunch current as a function of the jaw's distance form the chamber's centre. Measurements with the top jaw produce a positive kick, those with the bottom jaw a negative kick. The different symbols represent independent measurement series. The dashed curves represent the expectation according to Eq.(1), the solid curves are fits with bunch length scaling and offsets for the onset of the effect.
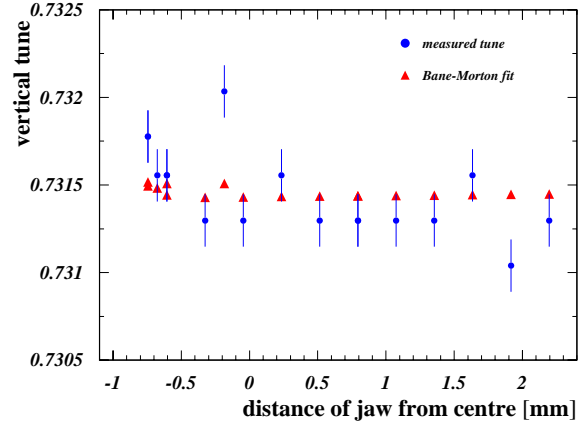

Figure 4: Vertical tune as a function of the jaw's distance form the chamber's centre. The points represent the measured tunes, the triangles are results of a fit of Eq.(3) to the measurements with the bunch length extracted from the analysis shown in Fig. 3. The fact that the measurements have been done at various bunch currents is accounted for in the fit. It is easily visible that the results of this tune shift analysis are consistent with the results obtained from the scraper kicks, in particular if one takes the quantisation steps of the tune measurement into account.

be $\zeta = (1.6 \pm 0.1)$.

This result can be cross-checked by a measurement of the vertical detuning as a function of scraper jaw position. The change in tune can be estimated from the effective quadrupolar defocusing

$$
\frac{d\langle y' \rangle}{dy} = -0.71 \left(\frac{\pi}{2} \right)^{\frac{3}{2}} \frac{r_e N_b}{\sigma_z \gamma} \left(\frac{2}{b+a} \right) \qquad (2)
$$

which follows from the Bane-Morton model. The vertical tune for a given scraper position is therefore

$$
Q_y = Q_{y,0} + \frac{\beta}{4\pi} \frac{d\langle y' \rangle}{dy}, \qquad (3)
$$

the positive sign before the tune shift term coming because the kick of the bottom jaw is negative. Figure 4 shows a measurement of the effect together with a prediction of the tune using the resulting offset and scaling factor of the analysis of the orbit kick displayed in Fig. 3. It is clearly visible that the tune shift measurements are consistent with the Bane-Morton predictions for the individual bunch currents.

ENERGY LOSS AND LONGITUDINAL WAKE FIELD

The longitudinal impedance of the scraper can be determined by studying the energy loss at the scraper as a function of scraper position. The energy loss is estimated from the change in the horizontal beam position measured in a dispersive region close to the scraper:

$$
\frac{\Delta x_{\mathrm{co}}}{D_x} \approx \frac{\Delta E}{E_0} = \frac{1}{E_0} \kappa_{||} e T_0 \Delta I_{\mathrm{bunch}} \qquad (4)
$$

The longitudinal loss factor is

$$\kappa_{||} = \frac{1}{\pi} \int\limits_0^\infty d\omega \, \mathrm{Re}(Z_{||}(\omega)) \, h(\omega, \sigma_z) \qquad (5)$$

where $h(\omega, \sigma_z)$ is the spectral power density of the bunch of RMS length σ_z and $\mathrm{Re}(Z_{||}(\omega))$ the longitudinal resistive impedance. For high frequencies, above cutoff $(\omega > c/h)$ the real part of the impedance is given by

$$Z_{||} \approx \frac{\pi Z_0}{8} \, \ln \frac{b}{a} \qquad (6)$$

where the coefficient takes into account the difference between flat and round geometry. For lower frequencies the impedance is essentially inductive and there is no energy loss. We estimate the loss factor by integrating over the constant impedance from the transition frequency onwards. This gives

$$\kappa_{||} \approx \frac{Z_0 \sqrt{\pi}}{16} \, \ln \left(\frac{b}{a}\right) \int\limits_{c/h}^\infty d\omega \, e^{-\left(\frac{\omega \, \sigma_z}{c}\right)^2} \qquad (7)$$

The measured energy loss as a function of scraper jaw position is shown in Fig. 5. The measurements were done at a beam energy of 0.5 GeV with the beam current distributed equally over all 60 bunches in two trains. The expectation of a single bunch energy loss using the loss factor of Eq.(7) (dotted curve in Fig. 5) with the bunch length scaling determined by the scraper kicks does clearly not represent the
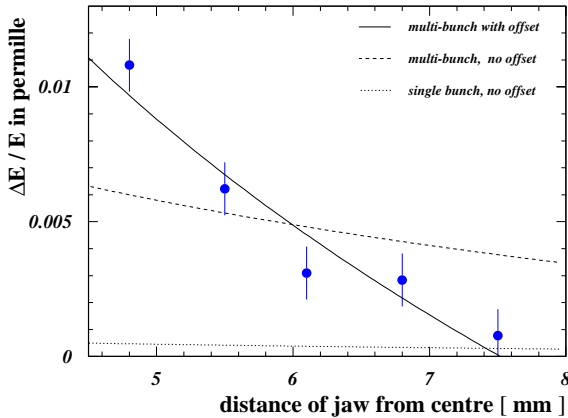

Figure 5: Relative energy loss as a function of scraper half aperture derived from a shift in the horizontal closed orbit in the dispersive section between the scraper and following RF cavity. The dotted line represents the expectation according to Eq.(7) for a single bunch with the bunch length extracted from Fig. 3. The dashed line is a fit of Eq.(7) to the measurements with a variable number of bunches contributing. The solid line finally has an offset in aperture included that seems to be suggested by the measurements. The number of bunches found to be contributing is (55 ± 7).

measurements: the expected effect is much to small. For the presence of trapped modes, however, the effective energy loss could be much higher. We therefore introduce the number of bunches contributing as a fit parameter. The result is shown as a dashed curve in Fig. 5. The energy loss is now of the right size but the slope is not well reconstructed. This can be cured by introducing an offset parameter $(b \rightarrow b - b_0)$ describing the effective size of the chamber with respect to the onset of scraper induced effects. The number of bunches contributing is determined to be (55 ± 7).

SUMMARY

The installation of a superconduction undulator makes it imperative to incorporate scrapers into the regular running of the machine. Therefore the impact of the scraper on the beam dynamics has to be understood. The transverse effects of the scraper wakefields have been investigated by studying vertical closed orbit kicks and vertical betatron tune shifts. The observations seem to be well described by the Bane-Morton formalism and are consistent with each other. Furthermore the method allows the determination of an effective bunch length which is particularly difficult to measure at ANKA for low energies because of a longitudinal instability.

The longitudinal effect of the scraper wakefield was determined by measuring the energy loss from the horizontal closed orbit shift in a dispersive section after the scraper. In this case, the expectation for a single bunch effect greatly underestimates the true effect. This could hint at trapped modes. Allowing for the number of bunches to vary in the fit and therefore to adjust the decay time of the fields can reproduce the measurements.

ACKNOWLEDGEMENTS

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