MEASUREMENTS OF THE IMPEDANCE INTRODUCED BY THE VERTICAL SCRAPER AT ELETTRA AND ITS EFFECTS

L. Tosi, E. Karantzoulis, V. Smaluk
Sincrotrone Trieste, 34012 Trieste, Italy

Abstract

Noticeable excitations of particular narrow band longitudinal coupled multibunch instabilities as a function of the position of the blades of the scraper have been observed. In order to achieve a deeper insight of the phenomenon and in particular that of an eventual crosstalk between the scraper and the RF cavities via the beam, an exhaustive characterization of both the longitudinal and transverse impedances of the scraper has been carried out.

1 INTRODUCTION

With the putting into operation of the transverse multibunch feedback system during user dedicated beam time, questions arose regarding the protection of the vacuum chamber against overheating due to insertion device photons hitting the chamber slot in case of a feedback malfunction. For this purpose the vertical scraper is used as a means to reduce the beam intensity in case large vertical betatron oscillations were present. However, during first measurements, it was observed that the scraper induced longitudinal coupled multibunch modes as a function of the blades' positions when the latter were below ±8 mm. Apart from disturbing user operation in the absence of a developed longitudinal feedback, these modes could compromise the efficiency of the transverse feedback. The modes were found to be strong enough to suppress the transverse ones and at a scraper settings of ±7 mm there was an enhancement of the excitation of a known cavity mode, which could be reduced in amplitude by acting on the cavity. These phenomena gave rise to a series of studies aimed at the characterization of the scraper's impedance.

In Elettra the vertical scraper is discontinuous and is composed of two 1 cm in diameter rods positioned at ±25 mm when it is open. Analytical formulae for the impedance of such a geometry do not exist and evaluation of its behavior has been performed using the electron beam. In this paper, the measurements on the impedance induced by the vertical scraper are presented and compared with those when the scraper is open.

2 LONGITUDINAL LOSS FACTOR

An electron beam passing through any irregularity of a vacuum chamber loses energy. The total energy loss ΔE is proportional to the square of the beam charge q [1]:

$$\Delta E = -k_{\|} q^2 . \qquad (1)$$

The longitudinal loss factor $k_{\|}$ depends both on the vacuum chamber structure characterized by the wake potential $W_{\|}$ and on the particle distribution ρ:

$$k_{\|} = \int_{-\infty}^{\infty} W_{\|}(t)\rho(t)dt , \qquad (2)$$

or, in the frequency domain:

$$k_{\|} = \frac{1}{\pi}\int_{0}^{\infty} \mathrm{Re}\, Z_{\|}(\omega)\left|\tilde{\rho}(\omega)\right|^2 d\omega , \qquad (3)$$

where $Z_{\|}(\omega)$ is the longitudinal broadband impedance of the vacuum chamber and $\tilde{\rho}(\omega)$ is the Fourier transform of the particle distribution $\rho(t)$.

Both the total longitudinal loss factor of the ring and the contribution of the vertical scraper were measured. The measurement method is based on the indirect measurement of the beam energy loss (1) using the standard BPM system. The energy loss ΔE results in a closed orbit deviation in the dispersive regions of the storage ring:

$$\Delta x(s) = \eta(s)\frac{\Delta E}{E} , \qquad (4)$$

where $\eta(s)$ is the dispersion and E is the total beam energy. Thus, the longitudinal loss factor $k_{\|}$ can be estimated by measuring the horizontal closed orbit deviation with beam intensity.

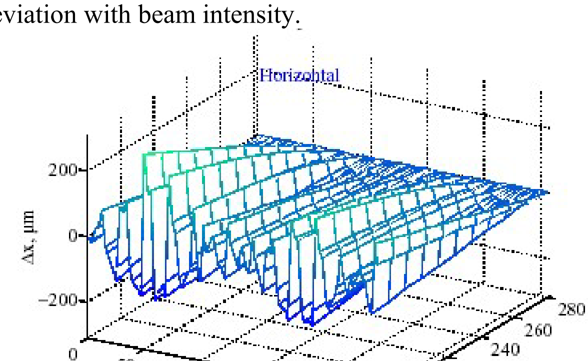

Figure 1. Horizontal orbit deviation vs beam current

Before the measurement, the orbit was corrected globally to minimize the influence of the transverse impedance. The reference orbit was taken to be the one at a beam current of 280 mA and orbit deviations were measured at several decreasing beam currents. There are two known thermal effects, which can introduce a systematic error into the measurement: the thermal motion of the vacuum chamber and, therefore, of the BPMs after the ramping, and the thermal motion due to change of beam heating during the beam current variation. To avoid an influence of these effects, the measurement was done 1 hour after ramping, when the storage ring temperature was stabilized, and it was done in a short time span. Figure 1 shows the measured horizontal orbit deviations as a function of beam current.

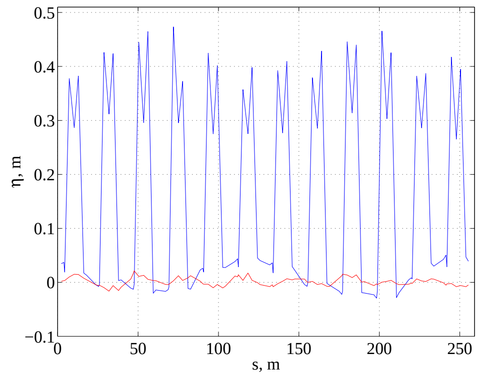

Figure 2. Measured dispersion

Figure 2 shows the measured horizontal and vertical dispersion. By comparing the figures it can be observed that the horizontal orbit deviation is proportional to the dispersion and in particular the slow wave in both measurements is noticed. While the vertical orbit deviation was found to be negligible because of the small vertical dispersion, the horizontal one grows up to about 200 µm. Taking the orbit deviation values at the points with a high dispersion to increase the accuracy, the coherent energy loss proportional to the beam current was calculated. The measurement result is shown in figure 3.

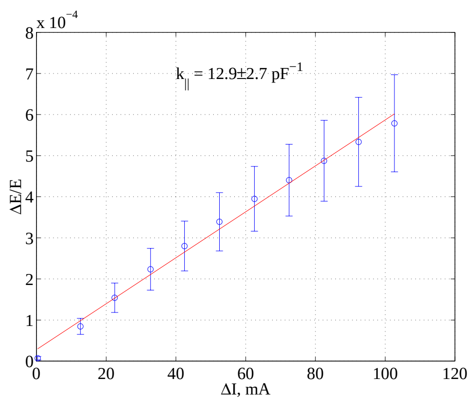

Figure 3. Coherent energy loss vs beam current

In order to estimate the contribution of the vertical scraper to the total loss factor, the orbit deviation with various scraper apertures was measured. The measurement was carried out at a beam current of 195 mA. In order to avoid transverse impedance effects, the beam position at the scraper was corrected to the geometrical centre of the scraper and the scraper blades were moved symmetrically with respect to the centre. Figure 4 shows the measured horizontal orbit deviations.

The horizontal orbit deviation looks similar to the one shown in figure 1, although with an order of magnitude less in amplitude. The vertical one was found to be within the measurement error. Figure 5 shows the longitudinal loss factor caused by the scraper. In order to compare the order of magnitudes, also the loss factor calculated for the axially symmetric collimator [1] and for the rectangular step [2] of the same size are shown.

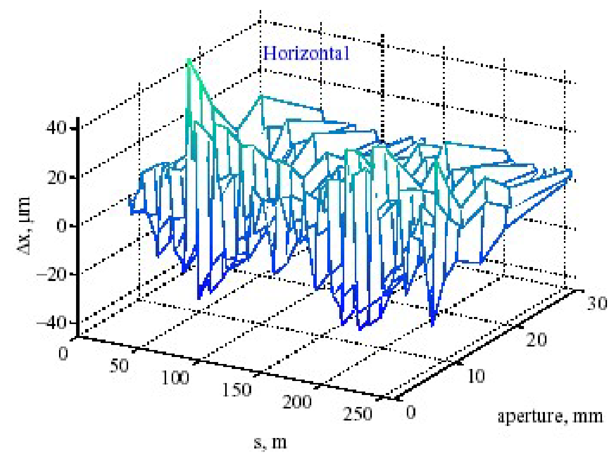

Figure 4. Horizontal orbit deviation vs the scraper aperture

Thus, as a result of the measurement, it can be concluded that the scraper contribution to the total longitudinal loss factor is around 6-10 % when the scraper aperture is 8-10 mm.

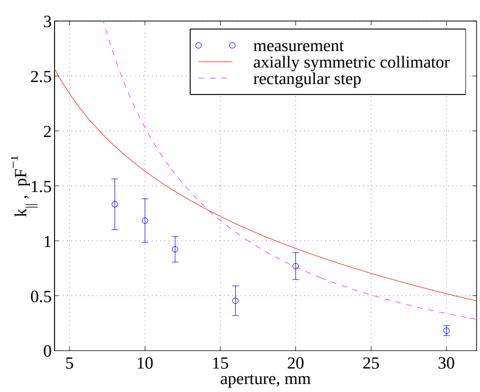

Figure 5. Longitudinal loss factor vs the scraper aperture

3 TRANSVERSE IMPEDANCE

To estimate the scraper contribution to the total reactive transverse impedance of the storage ring, two measurement methods were used. The first method is based on the direct measurement of the coherent tune shift:

$$\Delta\nu = -\frac{R}{4\pi\sigma_s(E/e)} \cdot I \cdot \sum_i \beta_i \operatorname{Im} Z_{\perp i}\,, \tag{5}$$

which is proportional to the beam current I and the reactive impedance Im$Z_{\perp}$. Here R is the average bending radius, σ_s is the r.m.s. bunch length, E is the beam energy and β_i is the beta function at the i-th impedance location. The total machine impedance was estimated by the measurement of the current dependent tune shift $\Delta\nu/\Delta I$ and the contribution of the scraper by the measurement of the tune shift as a function of the scraper blades' position at constant current. Figure 6 shows the results, but the accuracy of the method is limited by the resolution of the tune measurement system which is about $2\cdot10^{-4}$ and insufficient to measure such small effect.

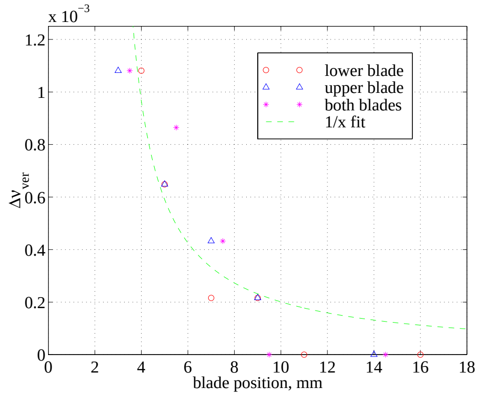

Figure 6. Tune shift vs scraper blades' position

To increase the accuracy, a variant of the bump method [3] was used with an asymmetrical scraper slit instead of the orbit bump. The closed orbit deviation proportional to the impedance and to the scraper blade position was measured using the BPM system:

$$y(s) = -\frac{\sqrt{\beta_s \beta(s)}\cos(\pi\nu - |\phi_s - \phi(s)|)}{2(E/e)\sin\pi\nu} I_{peak}\,\mathrm{Im}\,Z_{\perp}\Delta y, \quad (6)$$

where $I_{\rm peak}$ is the peak bunch current, $\Delta y = y_{b\,max} - y_b$, $y_{b\,max}$ and y_b are the open and closed scraper blade positions respectively. Figure 7 shows the vertical orbit deviation as a function of the scraper blade position. The horizontal one is negligible.

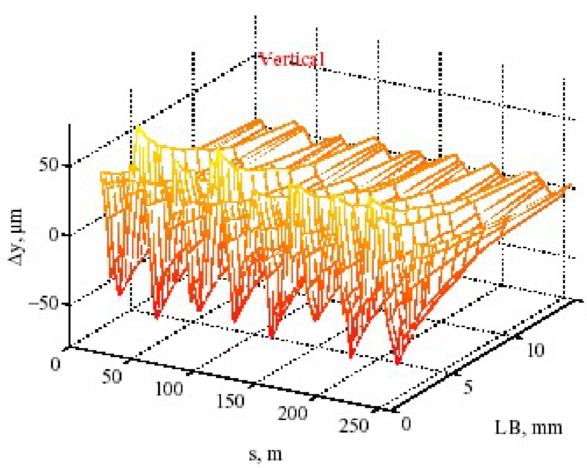

Figure 7. Vertical orbit deviation vs scraper blade position

The corresponding measured scraper impedance is shown in figure 8. The measured data is approximated well by the function describing a small-angle rectangular collimator [4]:

$$Z_{\perp} = -\frac{iZ_0 h}{2}\int\frac{(b')^2}{b^3}dz, \quad (7)$$

where $Z_0 = 120\pi\ \Omega$ is the free space impedance, h in our case is the scraper rod diameter, and $b(z)$ is the half-gap. In order to model $b(z)$, an exponential function

$$b(z) = de^{-\frac{3z}{2d}} \quad (8)$$

was chosen as a best continuous approximation to the situation. With this function, a simple formula for the impedance is obtained as:

$$Z_{\perp} = \frac{3}{4}\frac{Z_0 h}{bd}, \quad (9)$$

where $d = 25$ mm is the maximal half-gap. It can be observed that the formula fits the data very well.

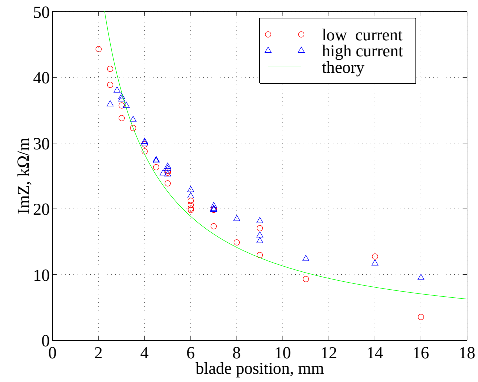

Figure 8. Scraper transverse impedance

Thus at the 5 mm gap the transverse impedance of the scraper is about 10% of the total impedance which is 400 kΩ/m [5].

4 CONCLUSIONS

Both the longitudinal loss factor and the imaginary part of the transverse impedance of the vertical scraper have been measured. It has been found that the contribution of the vertical scraper to the total impedance of the ring is about 10% when the blades are set to ±5 mm. Measurements of the imaginary part of the longitudinal impedance, which would have given a deeper insight on the excitations of the longitudinal coupled multibunch instabilities, have also been tried. The results, however, were found to be of the order of the measurement precision. It can be nevertheless expected that it is of the same order as the resistive part.

REFERENCES

[1] B.W.Zotter, S.A.Kheifets, "Impedances and Wakes in High-Energy Particle Accelerators", World Scientific, 1998

[2] E.Karantzoulis, "The Coupling Impedance of the ELETTRA Storage Ring", ST/M-TN-90/14, Trieste, 1990.

[3] V.Kiselev, V.Smaluk, "A Method for Measurement of Transverse Impedance Distribution along Storage Ring", Proc. of the 4-th European Workshop on Diagnostics for Particle Accelerators, Chester, 1999.

[4] G.V.Stupakov, "High-Frequency Impedance of Small-Angle Collimators" , PAC-2001, Chicago, 2001.

[5] L. Tosi, V. Smaluk, D. Bulfone, E. Karantzoulis, M. Lonza, "Diagnostics and Analysis of Instabilities with the Digital Transverse Multibunch Feedback at ELETTRA", PAC-2001, Chicago, 2001.