EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - AB Department

CERN-AB-2006-051

Kicker Impedance Measurements For The Future Multiturn Extraction Of The Cern Proton Synchrotron

E. Métral, F. Caspers, M. Giovannozzi, A. Grudiev, T. Kroyer, L. Sermeus

CERN, Geneva, Switzerland

Abstract

In the context of the novel multi-turn extraction, where charged particles are trapped into stable islands in transverse phase space, the ejection of five beamlets will be performed by means of a set of three new kickers. Before installing them into the machine, a measurement campaign has been launched to evaluate the impedance of such devices. Two measurement techniques were used to try to disentangle the driving and detuning impedances. The first consists in measuring the longitudinal impedance for different transverse offsets using a single displaced wire. The sum of the transverse driving and detuning impedances is then deduced applying Panofsky- Wenzel theorem. The second uses two wires excited in opposite phase and yields the driving transverse impedance only. Finally, the consequences on the beam dynamics are also analyzed.

Presented at
EPAC'06, Edinburgh, UK, June 26-30, 2006

Geneva, Switzerland
June 2006

KICKER IMPEDANCE MEASUREMENTS FOR THE FUTURE MULTI-TURN EXTRACTION OF THE CERN PROTON SYNCHROTRON

E. Métral, F. Caspers, M. Giovannozzi, A. Grudiev, T. Kroyer, L. Sermeus
CERN, Geneva, Switzerland

Abstract

In the context of the novel multi-turn extraction, where charged particles are trapped into stable islands in transverse phase space, the ejection of five beamlets will be performed by means of a set of three new kickers. Before installing them into the machine, a measurement campaign has been launched to evaluate the impedance of such devices. Two measurement techniques were used to try to disentangle the driving and detuning impedances. The first consists in measuring the longitudinal impedance for different transverse offsets using a single displaced wire. The sum of the transverse driving and detuning impedances is then deduced applying Panofsky-Wenzel theorem. The second uses two wires excited in opposite phase and yields the driving transverse impedance only. Finally, the consequences on the beam dynamics are also analyzed.

INTRODUCTION

The following kickers are installed presently in the PS machine: 1) Injection kicker **KFA45** in Straight Section (SS)45; 2) Extraction kicker **KFA71/79** in SS71 and SS79; 3) Extraction fast bumper **BFA9/21** (pedestal and staircase) in SS9 and SS21; and 4) Injection kicker for ions **KFA28** in SS28. The following kickers will be installed for the novel multi-turn extraction [1]: 1) Two (identical) new kickers **KFA13** and **KFA21** in SS13 and SS21 (the modules are similar to those of the extraction kicker KFA71/79); and 2) One new kicker **KFA4** in SS4 (the modules are recuperated from extraction kickers used in the past for leptons).

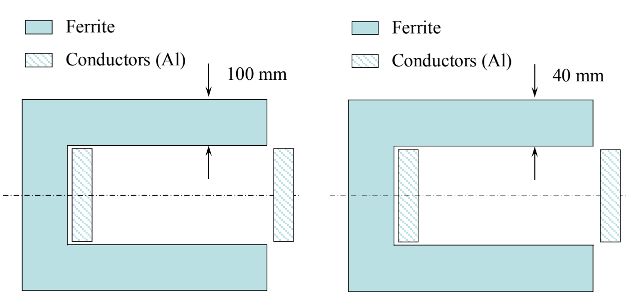


Figure 1: Cross section of the extraction kickers to be installed (left) in SS13 and SS21, and (right) in SS4.

As far as the electrical properties of the Ferrite are concerned, all kickers are made with material Philips 8C11 [1]. The Kickers in SS71/79 are based on a delay line design, i.e. the Ferrite is split longitudinally in 9 cells for each magnet. Each cell is 24 mm long: 19 mm of Ferrite and 5 mm of aluminium. The cross section is shown in Fig. 1 (left). The kicker to be installed in SS4 is also based on a delay line design, i.e. the Ferrite is split longitudinally in 24 cells. Each cell is 24 mm long: 19 mm of Ferrite and 5 mm of aluminium. The cross section is shown in Fig. 1 (right). The transverse betatron functions, which are important for the kicker strength and the effective impedance seen by the beam, are given in Table 1.

Table 1: Transverse betatron functions for all PS kickers

β-function	KFA45	KFA71	KFA79	KFA13	KFA21	KFA4
Horiz. [m]	22.8	20.4	21.9	22.1	20.4	12.6
Vert. [m]	11.8	11.8	12.5	12.5	11.9	20.0

MEASUREMENTS

Two measurement techniques were used to disentangle the transverse driving (also called classical or dipolar) and detuning (also called quadrupolar) impedances [2], which are both important for the beam dynamics. The first consists in measuring the longitudinal impedance, as a function of frequency f, for different transverse offsets using a single displaced wire. The sum of the transverse driving and detuning impedances is then deduced applying Panofsky-Wenzel theorem [3]. The second uses two wires excited in opposite phase (to simulate a dipole), which yields the transverse driving impedance only.

The measured longitudinal impedance vs. transverse offset, using a single displaced wire in a symmetric structure, is given by [2,4]

$$Z_l\left(f\right) = Z_{l,0}\left(f\right) + Z_{l,1x}\left(f\right) x_0^2 + Z_{l,1y}\left(f\right) y_0^2 , \qquad (1)$$

where x_0 and y_0 are the transverse offsets of the wire from the centre of the chamber. The first term is the classical longitudinal impedance (in the centre of the vacuum chamber). The frequency-dependent coefficients $Z_{l,1x}\left(f\right)$ and $Z_{l,1y}\left(f\right)$ are linked to the "generalized" transverse impedances Z_x and Z_y through Panofsky-Wenzel theorem by

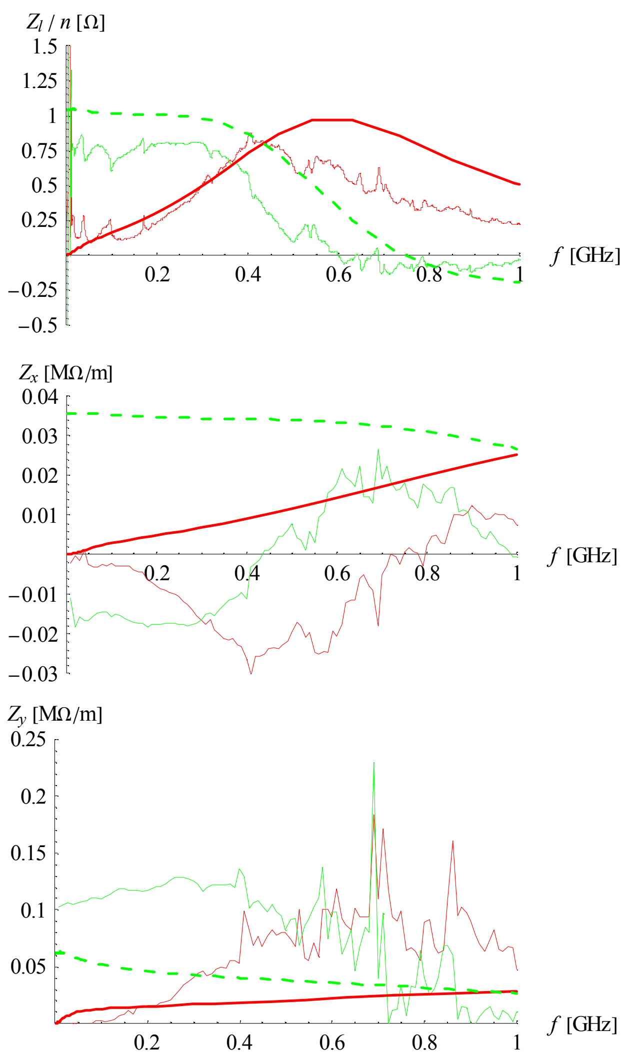
$$Z_x = Z_x^{\text{driving}} - Z^{\text{detuning}} = \frac{c}{2\pi f} Z_{l,1x}\left(f\right), \qquad (2)$$

$$Z_y = Z_y^{\text{driving}} + Z^{\text{detuning}} = \frac{c}{2\pi f} Z_{l,1y}\left(f\right). \qquad (3)$$

Therefore, only the sum of (or difference between) the driving and detuning impedances is measured with a single displaced wire. Note that there is no detuning impedance for chambers invariant over a 90º rotation, and that for some asymmetric structures the detuning impedance can be larger than the driving one [2]. As can be seen from Eqs. (2) and (3), the detuning impedance can be removed by adding the two equations, leading to

$$Z_x + Z_y = Z_x^{\text{driving}} + Z_y^{\text{driving}} . \qquad (4)$$

In the following, the measured longitudinal and transverse impedances are given for the kicker KFA13 (=KFA21). The results are compared to analytical predictions by Tsutsui [5, 6] and Burov-Lebedev [7, 8] using 2D models, i.e. assuming an infinitely long homogeneous kicker (see Fig. 2). The model of Burov-Lebedev used here for the vertical plane only consists of two parallel Ferrite plates, whereas in Tsutsui's model, in addition a perfect conductor is assumed outside, which should be closer to reality. The longitudinal impedance is normalized by $n = f / f_{rev}$, as it is the quantity of interest for beam dynamics considerations.



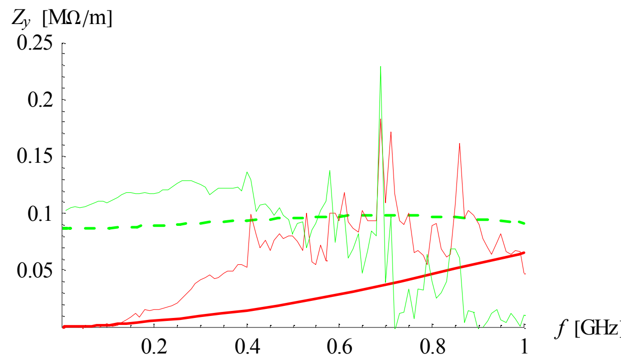


Figure 2: Measured longitudinal (top), horizontal (2nd plot) and vertical (3rd plot) impedances vs. frequency, using a single displaced wire. The real part is in red, whereas the imaginary part is in green. The thick full red line gives the real part of the impedance (only the driving impedance for the transverse planes) from the analytical result of Tsutsui [5, 6], and the thick dashed green line gives the imaginary part. The bottom (4th) picture is the same as the 3rd one but compared to Burov-Lebedev [8].

Examples of the parabolas measured at some frequencies are given in Fig. 3 (upper) for the horizontal plane. The sign of the parabola changes with frequency, which indicates that the sign of the horizontal impedance will also change (see Fig. 2). The same parabolas are shown for the vertical plane in Fig. 3 (lower), where no change of sign is observed (see also Fig. 2).

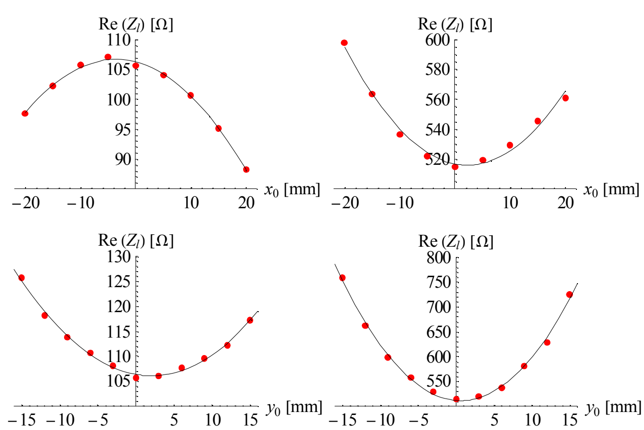


Figure 3: Measured real part of the longitudinal impedance (red dots) vs. (upper/lower) horizontal/vertical offset at 200 MHz (left) and 1 GHz (right). The full black line is the parabolic fit used to deduce the transverse impedance.

Using Eq. (4), the sum of the horizontal and vertical driving impedances can be deduced from the measurements (see Fig. 4). This gives an upper limit for the transverse (vertical) driving impedance, which can be used to estimate the impact of the new kickers on the PS beams dynamics.

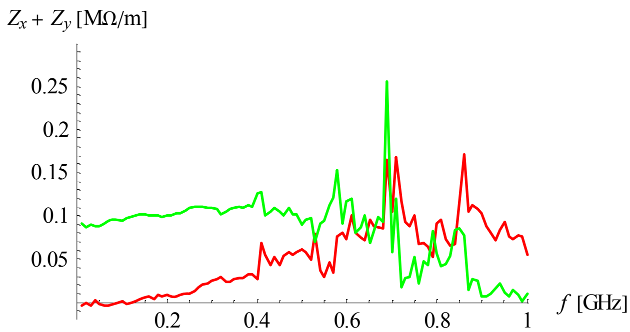


Figure 4: Measured horizontal plus vertical driving impedances. The real part is in red, whereas the imaginary part is in green.

Using the two-wire method, the transverse driving impedances were also measured. The comparison between the two methods for the real part of the sum of the transverse impedances is shown in Fig. 5, where it can be seen that a good agreement is reached for the frequencies between ~ 400 MHz and 1 GHz. The oscillation observed on the blue curve (2-wire method) is due to a residual mismatch. The low-frequency part still has to be analyzed in detail.

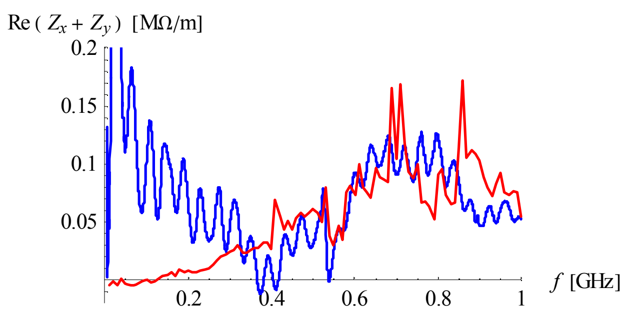


Figure 5: Comparison between the measured horizontal plus vertical driving real impedances using the single-wire (in red) and two-wire (in blue) methods.

Similar results were obtained for the kicker KFA4 [1]. The conclusions from the measurements are that installing the three new kickers (KFA13, KFA21 and KFA4) will add to the PS machine a longitudinal broad-band impedance of ~ 2 Ω, with a resonance frequency near ~ 400-500 MHz, and a maximum (upper limit) transverse broad-band (driving) impedance of ~ 0.25 MΩ/m, with a resonance frequency near ~ 700 MHz. Taking into account the betatron functions (see Table 1) leads to a normalized impedance of ~ 0.2 MΩ/m.

CONCLUSION

The installation of three new kickers for the future multi-turn extraction will add ~10% to the longitudinal and transverse broad-band impedances of the PS machine. The vertical impedance will contribute to the fast instability observed with high-intensity single bunches near transition (see Fig. 6), which might require a slight increase of the longitudinal emittance used to damp it.

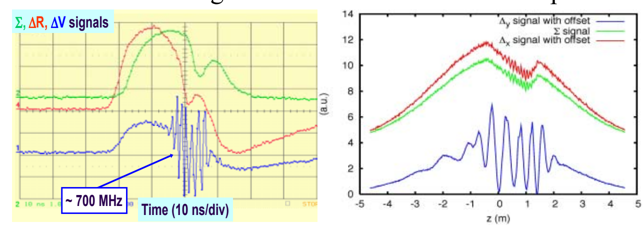


Figure 6: Measured (left) and simulated with the HEADTAIL code [9] (right) fast vertical instability in the PS near transition [10]. For the simulations a broad-band impedance model (R_y = 3 MΩ/m, f_r = 1 GHz and Q = 1) was used. The hole in the longitudinal and horizontal signals reveals that some particles are lost.

The oscillation frequency of the travelling-wave propagating in the second part of the bunch (~ 700 MHz) is very close to the resonance frequency measured in Fig. 2 for the new kickers to be installed in SS13 and SS21, which are similar to the ones already present in SS71/79 but four times shorter. The kickers KFA71/79 together with KFA45 may be the main culprits of this instability [1]. A more precise impedance model of the PS is under development.

Finally, 3D simulations with Ansoft HFSS^{TM}, a finite-element electromagnetic simulator [11], will be performed to crosscheck the measurement results, and study the effect of the finite kicker length.

ACKNOWLEDGEMENTS

Many thanks to A. Burov and B. Zotter for helpful discussions.

REFERENCES

[1] M. Giovannozzi (Ed.) et al., "The CERN PS Multi-Turn Extraction Based on Beam Splitting in Stable Islands of Transverse Phase Space – Design Report", in preparation.
[2] A. Burov and V. Danilov, Phys. Rev. Lett. **82**, 2286-2289 (1999).
[3] A.W. Chao, *Physics of Collective Beam Instabilities in High Energy Accelerators*, New York: Wiley, 371 p, 1993.
[4] H. Tsutsui, CERN-SL-Note-2002-034 AP, 2002.
[5] H. Tsutsui, CERN-SL-2000-004 AP, 2000.
[6] H. Tsutsui and L. Vos, LHC Project Note 234, 2000.
[7] A. Burov and V. Lebedev, Proc. EPAC'02, Paris, France, 2002.
[8] A. Burov, LHC Project Note 353 (revised), 2004.
[9] G. Rumolo et al., CERN-SL-Note-2002-036 AP.
[10] G. Rumolo, Talk at CARE-HHH-APD workshop, GSI, Darmstadt, Germany, 30–31 March 2006.
[11] www.ansoft.com