WAKE COMPUTATIONS FOR UNDULATOR VACUUM CHAMBERS OF PETRA III

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Abstract

At DESY it is planned to convert the PETRA ring into a synchrotron radiation facility, called PETRA III. The wake fields of a tapered transition from the standard vacuum chamber to the small gap chamber of the insertion devices contribute significantly to the impedance budget of PETRA III. The computer codes MAFIA and PBCI have been used to determine the loss and kick parameters of the tapered transition. PBCI is a recently developed parallelized, fully 3D wake field code, which used a purely explicit, split-operator scheme to solve the Maxwell equation in the time domain.

INTRODUCTION

PETRA III

PETRA, originally built as an electron - positron collider in 1976, has since been used mainly as a preaccelerator for the HERA lepton hadron collider at DESY. In July 2007, after the end of the HERA collider physics program, the PETRA ring will be converted into a dedicated 3rd generation synchrotron radiation facility [1], called PETRA III. One octant of the PETRA ring will be completely redesigned to provide space for 13 insertion devices. The planned facility aims for a very high brilliance of about 1021 photons /sec /0,1%BW /mm^2/ mrad^2 using a low emittance (1 nm rad) electron or positron beam with an energy of 6 GeV. A detailed parameter list can be found in [1, 2].

First estimates of beam current limitations have been given in [2]. A more detailed impedance model [3] has shown that an important contribution to the total impedance comes from the tapered transition from a "standard" vacuum chamber to the undulator vacuum chamber with a small gap of 7 mm, which is shown in Fig. 1. A pumping port is integrated in the taper. The taper angle is about 6 degrees. In this paper we report the results from the wake field calculations for two variants of the tapered transition. The first variant of the tapered transition was already studied in [3] using the MAFIA code [4, 5].

Wake fields

A beam circulating in a storage ring interacts with its vacuum chamber surroundings via electromagnetic fields. These wake fields in turn act back on the beam and can lead to instabilities, which limit either the achievable current per bunch or the total current or even both. The wake potential of a Gaussian with total charge q_1 is defined as:

$$\vec{W}(\vec{r}_2,\vec{r}_1,s) = \frac{1}{q_1}\int dz\,(\vec{E} + c\,\vec{e}_z \times \vec{B})_{t=(z+s)/c}, \qquad (1)$$

where r_2 is the transverse coordinate of the witness charge q_2. The loss parameter $k_\parallel$ and the kick parameter $k_\perp$ are defined as:

$$k_{\parallel} = \int ds\; W_{\parallel}(s)\,\lambda(s),\quad k_{\perp} = \int ds\; W_{\perp}(s)\,\lambda(s)\,, \qquad (2)$$

where $W_\parallel(s)$ is the longitudinal and $W_\perp$ (s) is the transverse wake potential of a Gaussian bunch with normalized bunch charge density $\lambda(s)$. Furthermore we define a parameter $k_\parallel(1)$ as:

$$k_{\parallel}(1) = \int ds\;\; \frac{d}{ds} W_{\parallel}(s)\,\lambda(s)\,, \qquad (3)$$

which is used to calculate the synchrotron tune shift for longitudinal coupled mode instabilities.

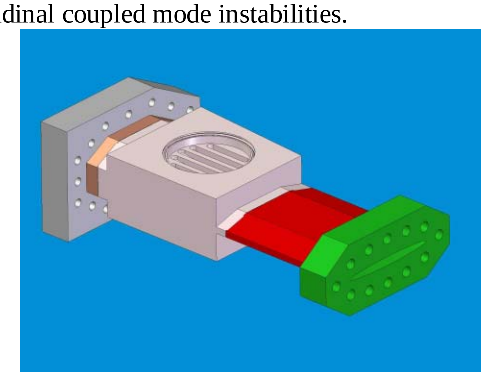

Figure 1: Tapered transition in front of the insertion devices. A pumping port is integrated in the taper.

Instabilities

The instability threshold for mode coupling instabilities can be estimated from the tune shifts of the lowest order modes in the longitudinal and transverse planes [1, 6]:

$$\Delta Q_s = Q_s \frac{I_B\, R\, T_0}{2\,h V_{rf}}\, k_{\parallel}(1), \quad \Delta Q_\beta = \frac{I_B \langle \beta \rangle\, T_0}{4\pi\, E/e}\, k_{\perp}, \qquad (4)$$

where I_B is the single bunch current, R = 367 m is the mean machine radius; $\langle\beta\rangle = 20$ m is the average β–function, and $k_\perp$ and $k_\parallel(1)$ are defined above. The total impedance budget in terms of the kick parameter according to Eqn. (4) is 4800 V/pC/m for a single bunch current of 2.5 mA, which is foreseen for a bunch filling pattern with 40 equally spaced bunches.

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NUMERICAL CODES

For the calculations of wake fields we have used the well established MAFIA code [5] and the newly developed Parallel Beam Cavity Interaction (PBCI) code [7]. In MAFIA, the wake field computations are performed with the time domain module, T3, using a fixed discretization grid. This approach may lead to large computational models which are difficult to be handled on conventional computers.

In contrast to MAFIA-T3, PBCI implements the moving window technique [8]. The wake potential (1) is computed on the fly using the electromagnetic field solution within a comparatively small, moving window. The moving window approach in PBCI is based on a purely explicit split-operator technique which allows for dispersion-free electromagnetic field computations in the longitudinal direction [9].

In order to deal with the large number of degrees of freedom needed in the simulations, PBCI uses distributed memory parallelization. Thus, massive wake field computations with hundreds of millions of grid cells can be performed on a cluster of computers. Grid sizes of this order of magnitude are necessary for resolving the charge distribution of short electron bunches as well as for the accurate approximation of smoothly tapered transitions.

WAKE COMPUTATIONS

Two variants of the transition from a ‘standard” vacuum chamber with a vertical height of 38 mm to the undulator vacuum chamber with a gap of 7 mm are shown in Fig. 2 in a schematic way. The tapered transition, which is shown in a detailed 3d-view in Fig. 1 is marked in blue. A pumping port is integrated in the taper. The bellow is shielded against the beam with rf-fingers. The wakefields of this taper, which dominate the transition to the small gap undulator chamber, have been calculated.

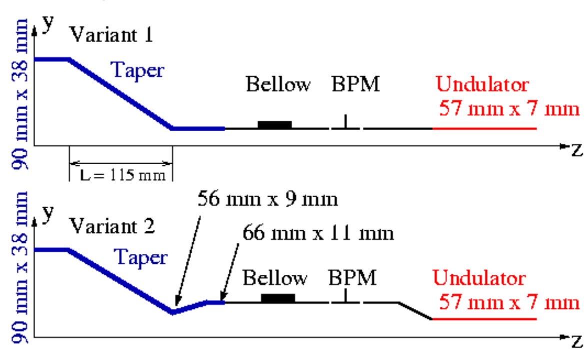

Figure 2: Schematic view of two variants of the transition from a 90 mm x 38 mm “standard” vacuum chamber to the small gap undulator chamber.

In Fig. 3 the actually used 3D structure for the numerical calculations (variant 2) is shown in a “negative” presentation, showing the vacuum system without the surrounding chamber material. The structure starts with a small gap undulator chamber and ends with an undulator chamber with the same cross section, since we are not interested in the log-like (see Eqn. (23) in [10]) contribution to the wake field.

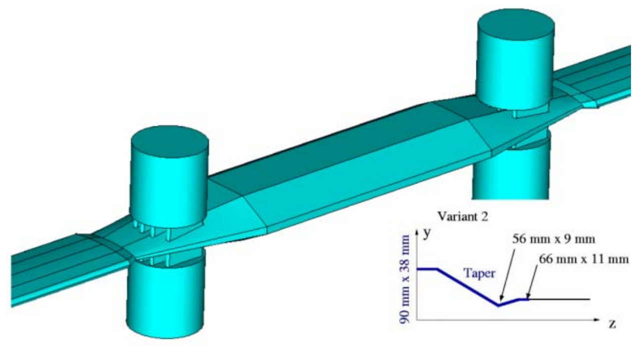

Figure 3: 3D model of the tapered transition with pumping ports (total length of the structure ~ 80 cm).

For variant 1 of the tapered transition the wake potentials have been calculated with both codes, MAFIA and PBCI for different mesh sizes. In Fig. 4 the longitudinal wake potential is show for a beam transversing the vacuum structure on axis. The MAFIA result corresponds to a step size of Δz = 0.1 mm, Δx = 1.0 mm and Δy = 0.5 mm. Due to computer memory limitations it was not possible to use a finer mesh with the MAFIA code. The often used criteria for the step size:

$$\Delta z^2 L / \sigma_z^3 < 1 \qquad (5)$$

is already fulfilled for a step size of 1mm (L = 80 cm, σ_z = 10 mm). But from Fig. 4 it is seen that the MAFIA code did not give sufficiently accurate results for this smoothly tapered vacuum structure although the step size in all directions were much smaller than the bunch length of σ_z=10 mm.

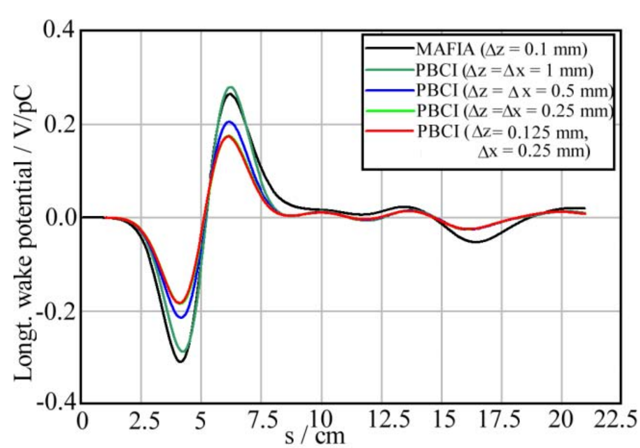

Figure 4: Longitudinal wake potentials of variant 1 of the tapered transition for a bunch with σ_z=10 mm.

But it was possible to improve the results with the PBCI code which convergences to a wake potential which is about 30 % smaller than the MAFIA result. The calculations have been repeated for a bunch which traverses the structure with a vertical offset of 2 mm with respect to the axis of the structure. From the difference of

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the longitudinal wake potentials the transverse wake has been calculated according to the Panofsky-Wenzel-Theorem [11]. The results are shown in Fig. 5 and 6.

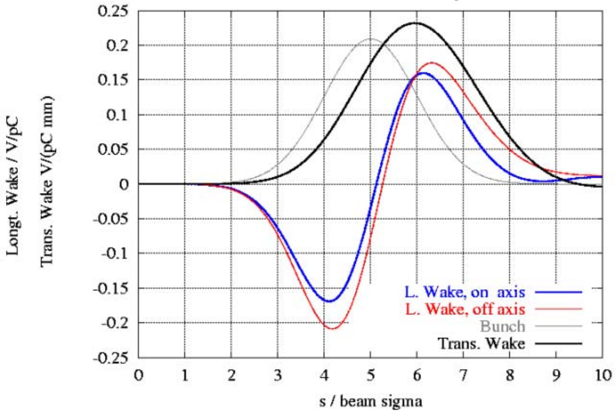

Figure 5: Wake potentials (PBCI) of variant 1 of the tapered transition (L. Wake / V/pC, T. Wake / V/pC mm).

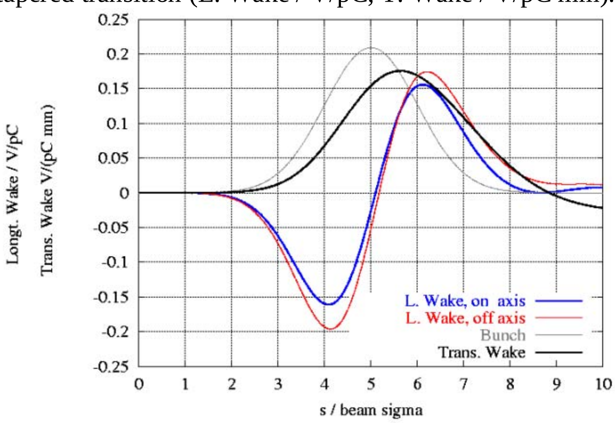

Figure 6: Wake potentials (PBCI) of variant 2 of the tapered transition (L. Wake / V/pC, T. Wake / V/pC mm).

The longitudinal and transverse wake potentials for variant 2 of the tapered transition are shown in Fig. 6. From the wake potentials the loss and kick parameters have been calculated according to Eqn. (2) and (3). The results are summarized in Table 1.

Table 1: Loss and kick parameters for one tapered transition with integrated pumping port

Structure / code	$k_{\parallel}$ / (V/nC)	$k_{\parallel}(1)$ / (V/pC m)	$k_{\perp}$ / (V/pC m)
Variant1 / MAFIA	-7.4	-6.8	138.6
Variant1 / PBCI	-7.1	-4.8	75.6
Variant2 / PBCI	-5.2	-4.6	62.8

CONCLUSION

The loss and kick parameters of tapered transitions, which will be installed up- and down-stream of the undulators, have been calculated with the computer codes MAFIA and PBCI. To get accurate results for the kick parameter of the smoothly tapered transition it was necessary to use a very small step size of Δ/σ_z =0.01 in all spatial directions. The recently developed PBCI code, which uses distributed memory parallelization and a split-operator technique to allow dispersion-free field computations, is the appropriate code to calculate the wake potentials.

In total 16 tapered transitions will be installed into the PETRA III ring. Therefore the contribution to the transverse impedance will be significant even if the values obtained with PBCI are taken into account, which are a factor 1.8 smaller than the previously obtained results [3]. The kick parameter of one seven cell 500 MHz cavity is 35.8 V/pC/m, which is still about a factor 2 smaller than the kick parameter of one tapered transition.

Acknowledgments

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REFERENCES

[1] “PETRA III: A low Emittance Synchrotron Radiation Source”, Technical Design Report, DESY 2004-035
[2] K. Balewski, R. Wanzenberg, “Beam Current Limitations in the Synchrotron Light Source PETRA III”, EPAC’04, Lucerne, July 2004, p. 2308
[3] K. Balewski, R. Wanzenberg, “The Impedance of Selected Components of the Synchrotron Light Source PETRA III”, PAC’05, Knoxville, May 2005, p. 1752
[4] T. Weiland, “On the Numerical Solution of Maxwell’s Equations and Applications in the Field of Accelerator Physics”, Part. Acc. 15 (1984)
[5] MAFIA Version 4.106, CST GmbH, Büdingerstr. 2a, D-64289 Darmstadt (2002).
[6] K. Balewski, “Analyse der transversalen Moden-Kopplungsinstabilitaet fuer lokalisierte HF-Strukturen und ihre Kompensierbarkeit durch Rueckkopplungssystemen, DESY 89-108, Aug. 1989
[7] E. Gjonaj, X. Dong, R. Hampel, M. Kärkäkinen, T. Lau, W.F.O. Müller, T. Weiland, “Large Scale, Parallel Wake Field Computations for 3D-Accelerator Structures with the PBCI Code”, ICAP’06, Chamonix, France, October 2006
[8] K. Bane, T. Weiland, “Wake Force Computation in the Time Domain for Long Structures”, Proc. of 12th Int. Conf. on High Energy Accelerators. Chicago, IL, USA, August 1983, p. 314.
[9] T. Lau, E. Gjonaj, T. Weiland, “Time Integration Methods for Particle Beam Simulations with the Finite Integration Theory”, FREQUENZ, vol. 59, pp. 210–219 (2005)
[10] O. Napoly, Y.H. Chin, B. Zotter, “A generalized method for calculating wake potentials“, Nucl. Instrum. Methods Phys. Res., Sect. A 334, 255 (1993).
[11] W.K.H. Panofsky, W.A. Wenzel, “Some considerations concerning the transverse deflection of charged particles in Radio-Frequency fields “, Rev. Sci. Instrum 27 (1956), 947

