WAKE COMPUTATIONS FOR THE BEAM POSITIONING MONITORS 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, in 2007. For proper design of PETRA III it is very important to estimate the wakes due to various discontinuities along the beam pipe. This article covers the wake computations for the beam position monitors (BPMs) in the PETRA III beam pipe. Two computer codes, namely MAFIA and Microwave Studio, were used for the electromagnetic field computations. Convergence tests and the agreement between the results of both codes were taken as criteria in the validation of the results.

INTRODUCTION

PETRA III

Beginning in mid 2007, the PETRA storage ring will be converted to a 3$^{\text{rd}}$ generation light source, PETRA III. The planned facility aims for a very high brilliance of about 10^{21} photons /sec /0.1% BW /mm^2 /mrad^2 using a low emittance (1 nm rad) beam with an energy of 6 GeV and a total electron or positron design current of 100 mA. More than 100 BPMs are needed to measure the beam orbit around the ring with a high precision (10 μm in the arcs and about 0.5 μm in front of the insertion devices). To estimate the contribution of the BPMs to the impedance budget we consider two vacuum chambers of elliptical shape with different dimensions (80 mm x 40 mm and 90 mm x 7 mm total width and total height). The gap height of the insertion devices is 7 mm while the height of the chamber in the arc bending magnets is 40 mm. Four button pick-up antennae with a diameter of 10 mm are mounted in the vacuum chamber.

Wakefields and potentials

A beam traveling inside a beam pipe excites electromagnetic fields when passing a discontinuity in the beam pipe. These electromagnetic fields are termed wakefields, and the integrated effects of these fields over a given path length of a trailing charge gives rise to longitudinal and transverse wake potentials [1,2]. Wakefields can limit either the achievable current per bunch or the total current or even both. The wake potential of a point charge q_1 is defined as:

$$\mathbf{W}^{\delta}(\mathbf{r},s)=\frac{1}{q_1}\int[\mathbf{E}(r,z,t)+c_0\mathbf{e}_z\times\mathbf{B}(r,z,t)]_{t=\frac{z+s}{c_0}}dz \tag{1}$$

where $\mathbf{E}$ and $\mathbf{B}$ are the electric and magnetic field excited by the charge q_1 at the longitudinal position $z=c_0t$, $\mathbf{r}$ is the radial offset of the charge q_1 and the test charge, c_0 is the velocity of light in vacuum, s denotes the distance between the exciting charge and the test charge in the bunch coordinate system and $\mathbf{e}_z$ is the unit vector along the z-direction (Fig. 1). The wake potential $W(s)$ due to a charge distribution can be obtained as the convolution of the point charge wake potential with the line charge density.

The loss parameter $(k_{\|})$, kick parameter $(k_{\perp})$ and the $k(1)$ parameters are defined according to the equations:

$$k_{\|} = \int_{-\infty}^{\infty}\lambda(s)W_{\|}(s)ds \tag{2}$$

$$k_{\perp} = \int_{-\infty}^{\infty}\lambda(s)W_{\perp}(s)ds \tag{3}$$

$$k(1) = \int_{-\infty}^{\infty}\frac{d\lambda(s)}{ds}W_{\|}(s)ds \tag{4}$$

where $\lambda(s)$ is the charge density and $W_{\|}(s)$ and $W_{\perp}(s)$ are the longitudinal wake and transverse wake potentials as functions of the bunch coordinate s. The loss parameter $(k_{\|})$ can be used to estimate the total energy loss of the beam, while the kick parameter $(k_{\perp})$ and $k(1)$ parameters are used to estimate the coherent tune shifts of the lowest order coupled bunch modes in the transverse and longitudinal planes.

Simulation software

CST Microwave Studio (MWST) and MAFIA are two well-known electromagnetic field simulation codes [3,4] based on Finite Integration Technique [5,6]. MWST has a

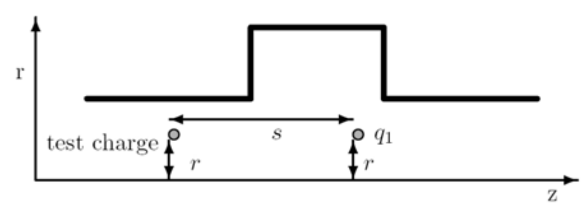

Figure 1: A charge q_1 and the test charge traversing a discontinuity in the beam pipe.

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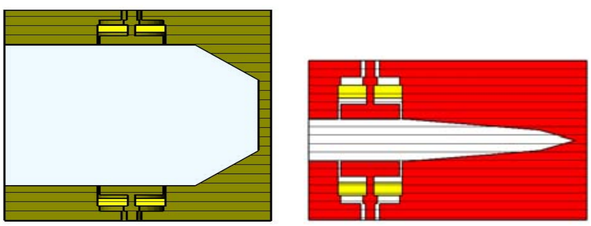
user-friendly GUI interface to conveniently model three-dimensional (3D) structures, while the MAFIA package has the possibility to excite a structure with a particle bunch and to compute the corresponding wakefields.

SIMULATION RESULTS

Beam pipe geometries

Due to the limitations of computer memory and in the modeling of complex shapes with MAFIA, the elliptical beam pipes have been approximated by polygons. The semi major and semi minor axes of the arc beam pipe are 40 mm and 20 mm and those for the narrow beam pipe near an undulator chamber are 45 mm and 3.5 mm respectively. The cross-sections of the approximated beam pipes along with the mounted BPMs are shown in the Fig. 2.



(a) Cross section of the arc beam pipe as modeled (half) with the upper and lower BPMs.

(b) Cross section of the narrow beam pipe as modeled (half) with the upper and lower BPMs.

Figure 2: Cross sectional views of the beam pipes as modeled.

Eigenmode solver results

In order to find trapped modes in the vicinity of the BPM buttons, the eigenmode solvers of MWST and MAFIA have been used. All the eigenmodes up to 10 GHz have been computed. It has turned out that three among these eigenmodes are concentrated near the BPM buttons. The resonant frequencies and quality factors of these three modes are summarized in Table 1. The field distribution of these modes do not change significantly with different boundary conditions at the ports. The electric field plot (from MWST) of the mode with the resonant frequency 9.035 GHz is shown in Fig. 3. The field distributions of the modes near 9 GHz indicate that these almost degenerate modes are orthogonally polarized dipole modes trapped in the vicinity of the BPM button. The same modes have been found to be concentrated near the BPM button in the narrow beam pipe. It may be noted here that the small differences between the results computed with MWST and MAFIA are due to the differences in meshing between the MWST and MAFIA model. Since the MWST model allows for partially filled cells it is more realistic than the MAFIA one. This is specially true for the BPM part which contains many curved surfaces with small radii and small gaps between them.

Frequency GHz (MWST)	Frequency GHz (MAFIA)	Quality factor (MWST)	Quality factor (MAFIA)
1.927	1.865	781	911
9.035	8.671	758	706
9.038	8.764	847	755

Table 1: Frequencies and quality factors of the modes concentrated near the BPM buttons as computed from MWST and MAFIA.

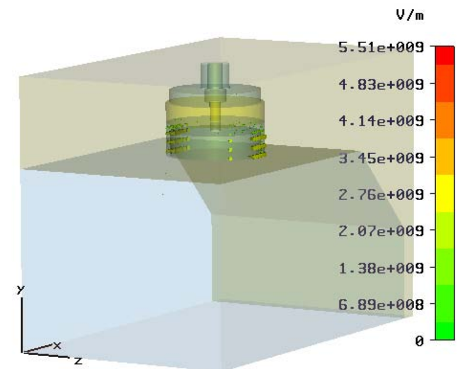


Figure 3: Electric field distribution of the mode at 9.035 GHz.

Wake computation results

Half of the beam pipes with two waveguide ports (one at the upper coaxial port and another at the lower coaxial port) have been modeled using MAFIA for the wake computations. The beam pipes are considered to have a length of 100 mm along the longitudinal (z) direction. A Gaussian charge distribution with σ = 10 mm having a total charge of 1 C has been assumed as the exciting beam.

The longitudinal wake potential along the bunch coordinate is shown in Fig. 4 for the BPMs mounted at the arc beam pipe with an on-axis beam. The transverse wake potential along the bunch coordinate for the BPMs in the arc beam pipe is plotted in Fig. 5 for a beam with 5 mm vertical offset. The loss parameter, kick parameter and the $k(1)$ parameter for the BPMs in the arc beam pipe computed according to the equations 2, 3 and 4 have been tabulated in Table 2.

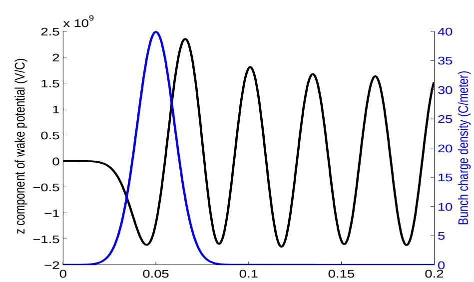


Figure 4: Longitudinal (z) component of the wake potential along the bunch coordinate (s) for BPMs in the arc beam pipe.

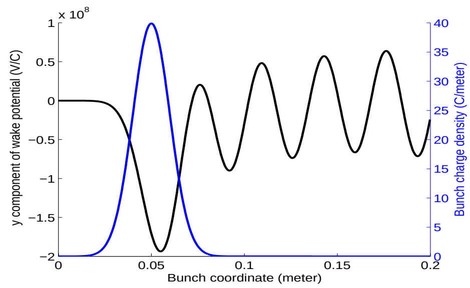


Figure 5: Transverse (y) component of the wake potential along the bunch coordinate (s) for BPMs in the arc beam pipe (transverse beam offset 5.0 mm).

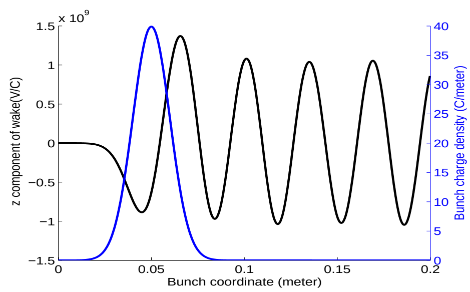


Figure 6: Longitudinal (z) component of the wake potential along the bunch coordinate (s) for BPMs in the narrow beam pipe.

Longitudinal loss parameter V/C	$k(1)$ parameter V/(C m)	Transverse kick parameter V/(C m)
-3.5276×10^{8}	-9.0985×10^{10}	n.a
-3.3527×10^{8} (offset = 5.0 mm)	-8.6656×10^{10} (offset = 5.0 mm)	-2.5256×10^{10}

Table 2: The loss and kick parameters for the BPMs in the arc beam pipe.

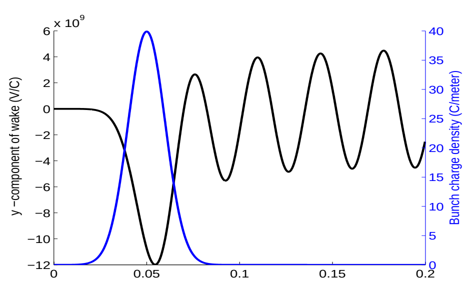


Figure 7: Transverse (y) component of the wake potential along the bunch coordinate (s) for BPMs in the narrow beam pipe (transverse beam offset 2.0 mm).

The longitudinal and transverse components of the wake potential are shown in Figs. 6 and 7 for the BPMs mounted in the narrow beam pipe with an on-axis beam and a beam with 2 mm vertical offset, respectively. The loss parameter, kick parameter and the $k(1)$ parameter for BPMs in the narrow beam pipe are summarized in Table 3.

Longitudinal loss parameter V/C	$k(1)$ parameter V/(C m)	Transverse kick parameter V/(C m)
-1.6211×10^{8}	-5.2732×10^{10}	n.a
-7.0962×10^{7} (offset = 2.0 mm)	-2.3176×10^{10} (offset = 2.0 mm)	-3.8739×10^{12}

Table 3: The loss and kick parameters for the BPMs in the narrow beam pipe.

SUMMARY

Wake computations for the BPMs mounted in two different beam pipe sections of PETRA III have been done. The longitudinal loss parameter and the kick parameters for both cases have been calculated for the wake potentials. An eigenmode analysis using MWST and MAFIA has also been done to analyze the trapped modes in the vicinity of the BPM buttons. A good agreement has been found between the simulation results obtained from MWST and MAFIA.

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