COMPUTATION OF WAKEFIELDS AND IMPEDANCES FOR THE PETRA III LONGITUDINAL FEEDBACK CAVITY

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Abstract

At DESY the existing PETRA II storage ring will be converted into a 3rd generation synchrotron radiation source, called PETRA III. The total beam current is limited by coupled bunch instabilities which are mainly driven by the parasitic modes of the RF cavities. It is planned to use longitudinal and transverse feedback systems to achieve the design current of 100 mA. Eight single cell feedback cavities will be installed into the PETRA III ring to damp the coupled bunch longitudinal phase oscillations. It is important to know the contribution of the feedback cavity to the impedance budget of PETRA III. In this article, the wake and impedance computation results, using the loss and kick parameters, will be reported. The computer codes MAFIA and Microwave Studio have been used to compute the electromagnetic fields.

INTRODUCTION

PETRA III

Beginning in mid 2007, the PETRA storage ring will be converted into a 3rd generation light source, PETRA III [1]. 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. It is essential to use powerful feedback systems to prevent coupled bunch instabilities which are mainly driven by parasitic modes of the 500 MHz RF cavities. Eight single cell cavities will be installed to provide the required damping of $1/\tau = 800$ Hz. The cavity design has been adopted from the SLS [2] and DAFNE [3] overdamped feedback cavity designs. The cavities will be operated at a frequency of about 1375 MHz. The cavities are necessary to prevent longitudinal coupled bunch instabilities but are a potential source of higher order modes and wakefields which may cause beam instabilities. The impedance of the feedback cavities, investigated by numerical methods, are presented here.

Wakefields and potentials

The electromagnetic fields excited by a charged particle traversing any discontinuity in the beam pipe are called wakefields. The integrated effects of these fields over a given path length of a trailing charge gives rise to longitudinal and transverse wake potentials [4, 5]. 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 $z = c_0 t$, $\mathbf{r}$ 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 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.

The frequency domain description of the wakes are represented by the impedances, which are defined as the Fourier transforms of the wake potentials. The longitudinal

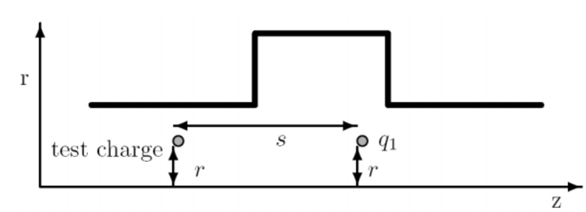

Figure 1: A charge q_1 and the test charge traversing a discontinuity in the beam pipe.

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($Z_{\|}$) and transverse impedances ($Z_{\perp}$) are defined as

$$Z_{\|}(\omega) = \frac{1}{c_0}\int_{-\infty}^{\infty} W_{\|}(s)e^{-\frac{i\omega s}{c_0}}\, ds \quad (5)$$

$$Z_{\perp}(\omega) = \frac{-i}{c_0}\int_{-\infty}^{\infty} W_{\perp}(s)e^{-\frac{i\omega s}{c_0}}\, ds. \quad (6)$$

SIMULATION RESULTS

Kicker geometry

One quarter of the PETRA III longitudinal feedback cavity is shown in Fig. 2. Four of the total eight coaxial ports, two waveguide ports (beam pipe), the relevant coordinate system and ports designation used for the simulations can be seen in the figure. Due to the geometrical symmetry of the cavity, only one quarter of it has been modeled for the electromagnetic simulations with Microwave Studio and MAFIA [6, 7].

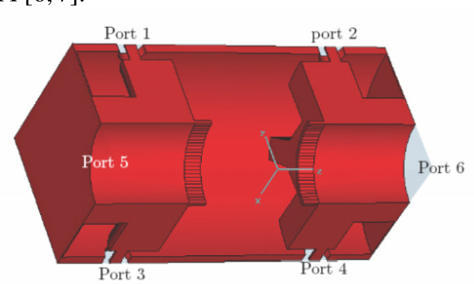

Figure 2: One quarter of the longitudinal feedback cavity as modeled for the simulations.

Scattering parameters

The resonant frequency of the TM_{010} like mode, which is the operating mode of the cavity, was computed as 1.3079 GHz with the MAFIA eigenmode solver. The scattering parameters have been computed covering the operating band of the cavity. Port 1 has been used for the excitation, keeping the other ports terminated with their corresponding wave impedances. As the cutoff frequency of the beam pipe (2.92 GHz for the TE modes and 3.82 GHz for the TM modes) is well above the operating band frequency, the beam pipe terminations have almost no influences on the scattering parameters. This point has been confirmed by simulations with matched terminations and short circuits at the beam pipe ports. The amplitudes of the reflection coefficient at port 1 and the transmission coefficient from port 1 to port 2 computed with MAFIA and Microwave Studio are shown in Figs. 3 and 4 respectively. The agreement between the results computed with MAFIA and Microwave Studio confirms the consistency in modeling and meshing of the structure with both codes.

Wakes and impedances

The longitudinal wakefields has been calculated with the MAFIA time domain solver. For the simulations a Gaussian charge distribution with an rms bunch length (σ_z) of 10 mm and a total charge of 1 C was used, which traversed

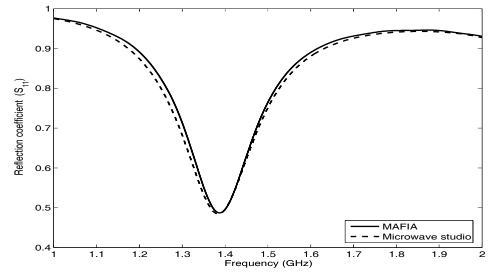

Figure 3: Amplitude of the reflection coefficient (S_{11}) at port 1 versus frequency.

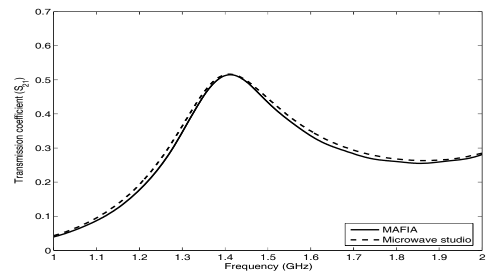

Figure 4: Amplitude of the transmission coefficient (s_{21}) from port 1 to port 2 versus frequency.

the feedback cavity on the z-axis. The longitudinal wake and the bunch charge density along the bunch coordinate are shown in Fig. 5. The longitudinal loss parameter and the $k(1)$ parameters were computed according to equations (2) and (4) as -4.6997×10^{11} V/C and 1.7489×10^{13} V/(C m), respectively.

A discrete Fourier transform (DFT) has been applied to obtain the impedances of the cavity. Fig. 6 shows the longitudinal impedance spectrum normalized to the bunch spectrum. Below the cutoff frequency of the beam pipe, sharp impedance peaks corresponding to the resonant modes of the cavity are present. The first impedance peak (which corresponds to the operating mode of the cavity) appears to be at 1.379 GHz. This frequency is higher than the computed resonant frequency of the operating mode at 1.3079 GHz since the coaxial waveguide ports were shorted for the eigenvalue computations but matched with a matched waveguide impedance for the time domain computation. In addition to the impedance peak due to the fundamental cavity mode, the presence of another peak around 2.28 GHz

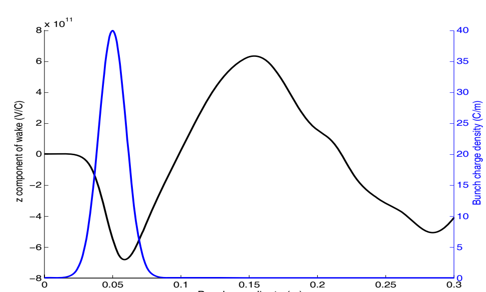

Figure 5: Longitudinal (z) component of the wake for PETRA III feedback cavity and the bunch charge distribution along the bunch coordinate.

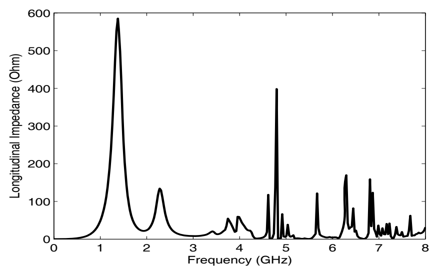

Figure 6: Longitudinal impedance versus frequency for the longitudinal feedback cavity.

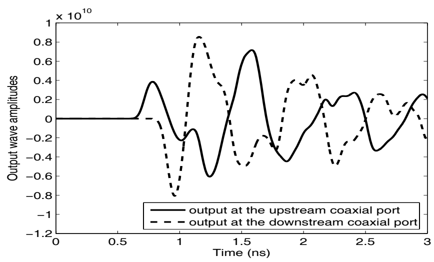

Figure 7: Output wave amplitudes at the upstream and downstream coaxial ports during the on axis wakefield computations.

can be noticed. The output wave amplitudes recorded at the upstream and downstream coaxial ports (ports 1 and 2, respectively) are shown in Fig. 7. Due to the symmetry of the cavity, the output signals recorded at ports 3 and 4 are exactly the same as those recorded at ports 1 and 2.

The transverse kick parameters and impedances have been computed considering one quarter of the cavity and combining the wake computation results with different boundary conditions at the x-z plane. Fig. 8 shows the transverse wakes normalized to the beam offset. Also for the transverse wake computations, all the coaxial ports have been terminated with matched loads. The transverse impedance normalized to the beam offset is shown in Fig. 9. The longitudinal loss parameter and the $k(1)$ parameter have been computed according to equations (2) and (4) for a 2 mm y-offset beam as -4.7400×10^{11} V/C and 1.7195×10^{13} V/(C m), respectively. The corresponding transverse kick parameter (equation 3) normalized to the beam offset is 1.3150×10^{13} V/(C m). All the computed loss and kick parameters for the feedback cavity are summarized in Table 1. Due to the geometrical symmetry of the cavity the vertical and horizontal impedances and hence also the kick and loss parameters are identical.

SUMMARY

The longitudinal and transverse wakefields, corresponding impedances, and loss and kick parameters for the PETRA III longitudinal feedback cavity have been computed with the MAFIA code. The scattering parameters of the cavity in the operating frequency band has been calculated with MAFIA and Microwave Studio codes.

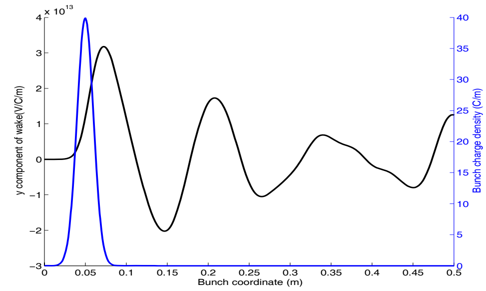

Figure 8: Transverse (y) wake normalized to the beam offset.

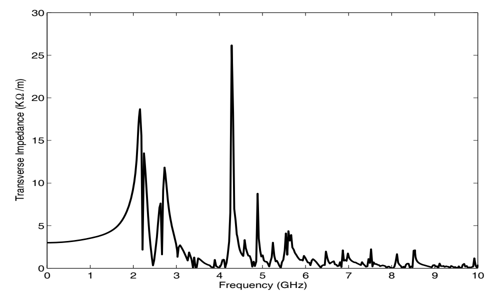

Figure 9: Transverse (y) impedance normalized to the beam offset.

Table 1: The loss and kick parameters for the PETRA III longitudinal feedback cavity with nose cones.

Longitudinal loss parameter [V/C]	$k(1)$ parameter [V/(C m)]	Transverse kick parameter [V/(C m)]
-4.6997×10^{11}	1.7489×10^{13}	n.a.
-4.7400×10^{11} (offset=2.0 mm)	1.7195×10^{13} (offset=2.0 mm)	1.3150×10^{13}

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