International Committee for Future Accelerators

Sponsored by the Particles and Fields Commission of IUPAP

Beam Dynamics Newsletter

No. 45

Issue Editor:
R. Wanzenberg

Editor in Chief:
W. Chou

April 2008

4.10 Wake Computations for Selected Components of PETRA III

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4.10.1 Introduction

At DESY construction is underway to convert the existing PETRA II storage ring into the 3rd generation synchrotron radiation source PETRA III. The design goal for the maximum beam current is 100 mA. To meet this goal it is essential to estimate the overall machine impedance, hence that of the individual machine components. In this contribution, we summarize the wake and impedance computation results for selected components of PETRA III. The analysed components are the button type Beam Position Monitors (BPM) (in the normal arc and in the narrow beam pipe near the insertion devices) and the longitudinal feedback cavity. The wake and impedance computations are supplemented by modal analysis and shunt impedance computations (for the feedback cavity) which are briefly presented here.

4.10.2 PETRA III

The main design parameters for PETRA III are shown in Table 1. The facility aims at a high brilliance of about 10^{21} photons /sec /0.1%BW /mm^2 /mrad^2 using a low emittance (1 nm rad) beam. More than 100 BPMs are needed to measure the beam orbit around the ring with high precision (10 μm in the arcs and about 0.5 μm in front of the insertion devices). Hence it is important to estimate the contribution of the BPMs to the overall machine impedance and to check if undesired modes can be excited in the vicinity of the BPM which can distort the beam operation.

Table 1: The main design parameters of PETRA III.

Parameter	Unit	Value	
energy	GeV	6	
circumference	m	2304	
RF frequency	MHz	500	
total current	mA	100	
number of bunches	-	960	40
bunch population	10^{10}	0.5	12
bunch seperation	ns	8	192

To ensure the multibunch mode functionality of PETRA III, it has been planned to use powerful feedback systems. The feedback systems should prevent various multibunch instabilities, which are otherwise inevitable in multibunch operations. Eight single cell cavities (adopted from the SLS and DAFNE overdamped feedback cavity design [2,3]) have been foreseen to provide the required damping of $1/\tau$ = 800 Hz.

Although these cavities are needed to prevent coupled bunch instabilities, they also contribute to the overall machine impedance. Hence it is important to calculate the wakes and impedances due to these cavities. Another very important parameter is the shunt impedance of these cavities, which basically shows the efficiency of the cavity to transmit the correction signal to the beam.

In this contribution, we report the wake computation results and related analysis for the beam position monitors of PETRA III, mounted at two different positions of the beam pipe. The wakes and impedance computation results due to the longitudinal feedback cavity adopted for PETRA III are also presented. The forward and backward wave shunt impedances of the feedback cavity is also presented. For the computations, the well-known software packages for three-dimensional electromagnetic simulations, namely MAFIA and Microwave Studio [4,5], has been used.

4.10.3 Wakes and Impedances

In a particle accelerator, charged particle beams travel inside a conducting pipe (beam pipe) maintained at high vacuum. The beam encounters different cross sections of the beam pipe and interacts with these discontinuities many times while circulating along the beam pipe. The interactions of the beam with its surroundings are described in the time domain by the wakefields (or wakes) and they are described in the frequency domain by the impedances [6, 7]. From the wakes several quantities, including the loss and kick parameters, can be calculated [1,6]. These loss and kick parameters represent integral measures of the interaction of the beam with the considered part of the accelerator.

4.10.4 Computation Results

4.10.4.1 Computations for the BPMs

The considered geometries of the BPMs at two different positions are shown in Figs. 1 and 2. Fig. 1 shows the modeled BPM at the normal beam pipe, whereas Fig. 2 shows the same at the narrow beam pipe near the insertion devices.

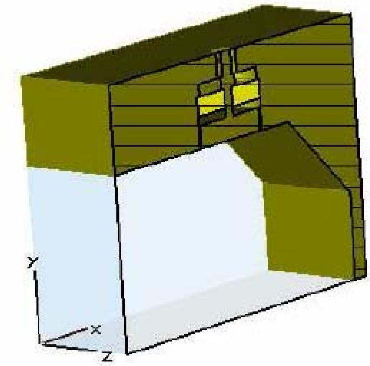

Figure 1: Cross-section of the BPM at the normal beam pipe.

The semi major and semi minor axes of the normal 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 gap between the BPM button and the beam pipe is considered to be 0.4 mm.

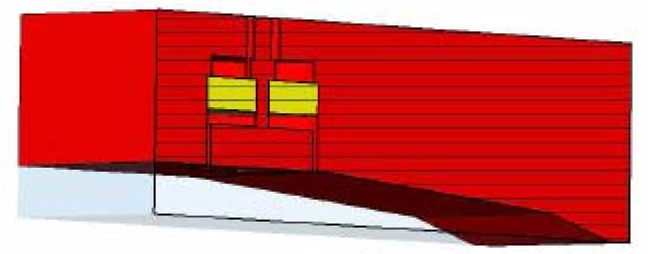

Figure 2: Cross-section of the BPM at the narrow beam pipe near the insertion devices.

4.10.4.1.1 Modal Analysis

The eigenmode solvers have been used to find trapped modes in the vicinity of the BPM buttons. All the eigenmodes up to 10 GHz have been computed and it turns out that three among these are concentrated near the BPM buttons. The resonant frequencies of these three modes computed with Microwave Studio are 1.927 GHz, 9.035 GHz and 9.038 GHz. The field distribution of these modes does not change significantly with different boundary conditions at the boundaries. The field distributions of the modes near 9 GHz indicate that these two modes are almost degenerate 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. To check if these modes can be excited by a particle beam, a time domain computation with a particle beam excitation has been performed. The electric field has been recorded at the gap between the BPM button and the beam pipe (for both the geometries at normal arc and at narrow beam pipe). From the recorded fields, the frequency comes out to be very near to the dipole mode. But as the computed modal loss parameters and quality factors due to these modes are small, it can be concluded that existence of these modes will not noticeably affect the functioning of the BPMs.

4.10.4.1.2 Time Domain Analysis

For the wake computations in the time domain, the three-dimensional simulation tool MAFIA has been used. A beam with Gaussian charge distribution (rms bunch length 10 mm, total charge 1 C) has been used as the excitation source. The uniform mesh step along the longitudinal direction has been taken as 0.12 mm. In order to compute the loss and kick parameters, both cases with on- and off-axis excitations have been considered.

The longitudinal wakes normalized to the bunch charge for the BPMs mounted at the normal beam pipe and at the narrow beam pipe are shown in Figs. 3 and 4 respectively. For the wake computations, the coaxial output ports from the BPMs have been terminated with the corresponding matched terminations. From the wakes, the loss parameter, the k(1) parameter and the kick parameters can be computed [1,6]. The loss and kick parameters computed for the BPMs are tabulated in Table 2. From Table 2 it can be seen that the transverse kick parameters computed for the BPMs at the narrow beam pipe are two orders of magnitude higher than those computed for the BPMs at the normal beam pipe. It may be noted that the estimated impedance and the loss and kick parameters due to the BPMs are well inside the impedance budget.

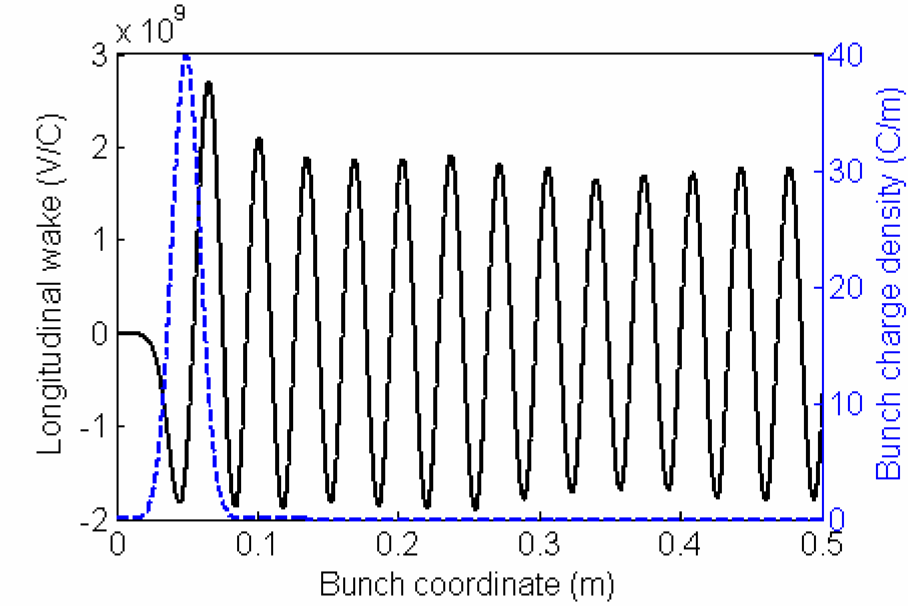

Figure 3: The longitudinal wake and bunch charge density (dashed line) vs the bunch coordinate for the BPMs in the normal beam pipe.

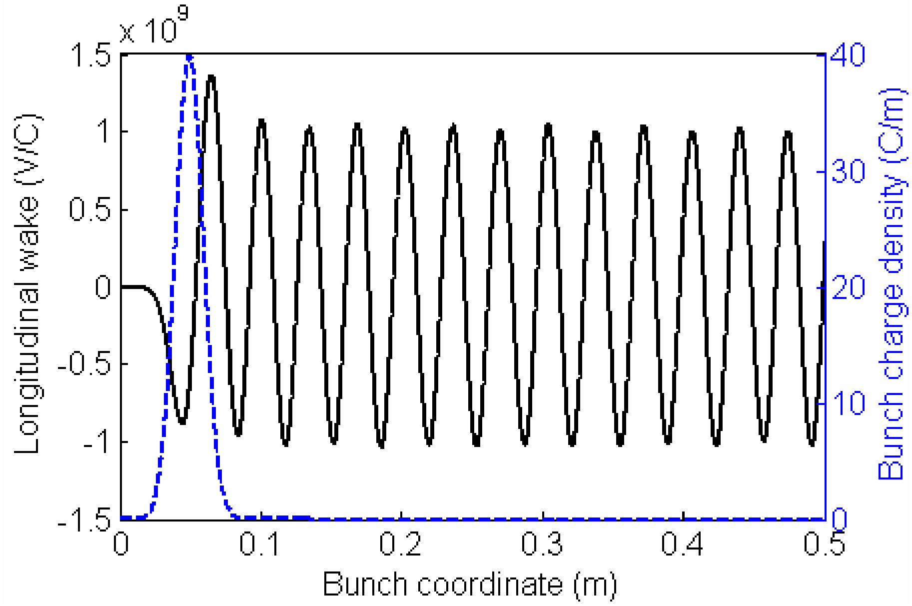

Figure 4: The longitudinal wake and bunch charge density (dashed line) vs the bunch coordinates for the BPMs in the narrow beam pipe.

Table 2: The loss and kick parameters for the button type BPMs of PETRA III in the normal and narrow beam pipes.

BPM mounted at	Longitudinal loss parameter (V/C)	k(1) parameter [V/(C m)]	Transverse kick parameter [V/(C m)]
Normal beam pipe	-3.5276×10^{8}	-9.0985×10^{10}	n.a.
	-3.3527×10^{8} (Offset 5.0 mm)	-8.6656×10^{10}	-2.5256×10^{10}
Narrow beam pipe	-1.6211×10^{8}	-5.2732×10^{10}	n.a.
	-7.0962×10^{7} (Offset 2.0 mm)	-2.3176×10^{10}	-3.8739×10^{12}

4.10.4.2 Computations for Longitudinal Feedback Cavity

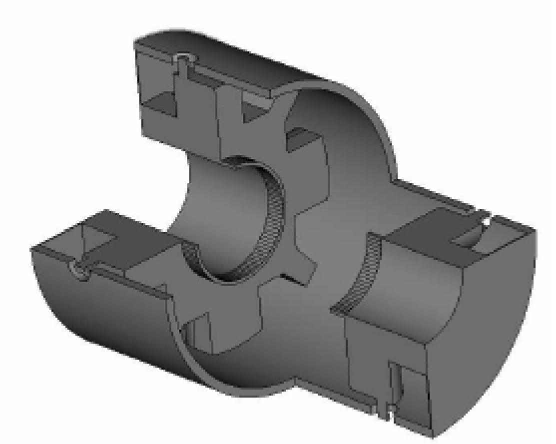

Figure 5: Cut view of the PETRA III longitudinal feedback cavity (adopted from SLS/ DAFNE design).

The longitudinal feedback cavity of PETRA III is basically a heavily loaded pillbox cavity. It has eight coaxial ports to connect the driving amplifiers (input ports) and the dummy loads (output ports). A cut view of the longitudinal feedback cavity is shown in Fig. 5. In order to damp all coupled bunch instabilities, the required maximum bandwidth is (f_{RF} /2), if all rf-buckets are filled. For PETRA III, the maximum required bandwidth is 62.5 MHz, corresponding to a bunch spacing of 8 ns [1]. The high bandwidth is achieved by strongly loading the cavity with specially ridged waveguides, which can be connected to the external loads.

4.10.4.2.1 Modal Analysis

The resonant frequency of the TM_{010} like mode, which is to be used for the beam correction, is 1.3020 GHz with a quality factor of 10579. The resonant frequency of the operating mode without the nose cones is 1.392 GHz. It may be noted that Microwave Studio has been used for the eigenmode computations. The resonant frequencies of the operating modes with and without the nose cones computed with MAFIA are found to be 1.3079 GHz and 1.398 GHz respectively. The slight difference in the resonant frequencies computed with the two software packages is due to the difference in meshing schemes between Microwave Studio and MAFIA. Fig. 6 shows the electric field distribution of the operating mode for the PETRA III longitudinal feedback cavity with nose cones. From the field distributions this mode can clearly be identified as the TM_{010} mode, which is the operating mode.

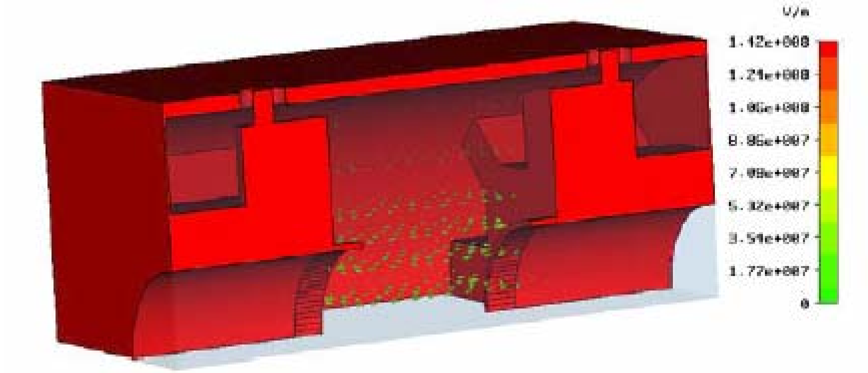

Figure 6: Electric field distribution of the operating TM_{010} like mode at 1.3079 GHz

4.10.4.2.2 Wake Computations

For the wake computations, a uniform mesh step size of 0.77 mm in the longitudinal direction has been used. This is a compromise between the available computer memory and the necessity to model the small details of the cavity geometry. The properties of the exciting beam are the same as those used for the wake computation of the BPMs.

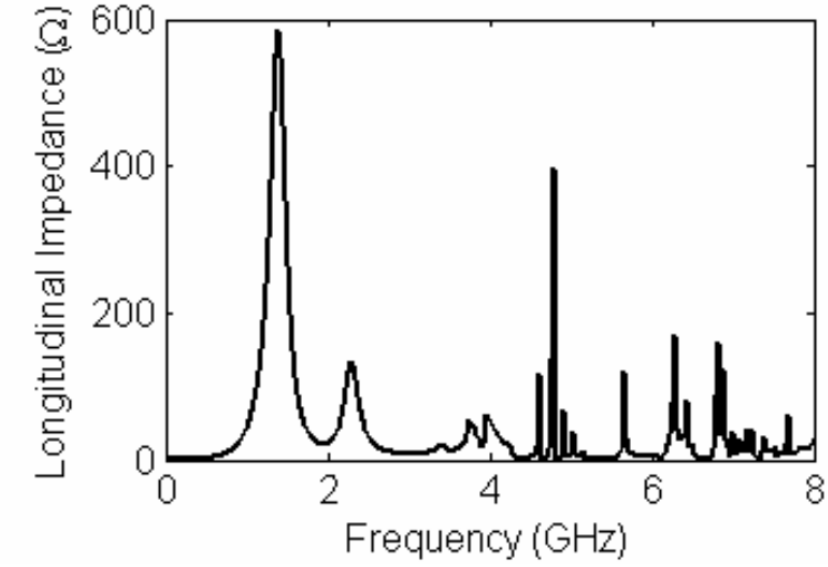

Figure 7: Longitudinal impedance of the feedback cavity

Fig. 7 shows the impedance spectra of the PETRA III longitudinal feedback cavity, normalized to the bunch spectrum. Under the cutoff frequency of the beam pipe (3.829 GHz, for TM mode) some impedance peaks are visible due to the resonant modes of the cavity. From the plot, it can be seen that the frequency of the first peak (corresponding to the operating mode of the cavity) is 1.379 GHz. This is a bit higher than the computed resonant frequency (1.3079 GHz) of the cavity fundamental mode. The reason for the difference is that for the eigenmode computations the coaxial ports of the cavity have been treated as short-circuited. On the other hand, for the time domain wake computations the ports have been terminated with corresponding matched termination. In addition to the peak due to the fundamental cavity mode, the presence of another impedance peak at 2.278 GHz can be noticed. A similar computation with short-circuited coaxial ports shows the impedance peak corresponding to the fundamental mode at 1.39 GHz. In this case additional impedance peaks appears with much larger values.

For the transverse impedance computations one quarter of the cavity have been considered, with different boundary conditions at the horizontal plane. Combining the wake computation results with different boundary conditions, the wakes due to an offset beam can be obtained [8]. It may be noted here that for the wake computations, the coaxial ports of the cavity have all been terminated with matched loads. Table 3 summarizes the different loss and kick parameters due to the feedback cavity.

Table 3: The loss and kick parameters for the PETRA III longitudinal feedback cavity.

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}	1.3150×10^{13}

4.10.4.2.3 Shunt Impedance Computations

For the shunt impedance computations, the MAFIA T3 module has been used. The excitation signal to the cavity has been provided through one of the coaxial ports. A wakefield monitor along the path of the beam has been used to compute the accelerating voltage due to the excitation through the coaxial port [8]. Two sets of computation runs have been done - one for the forward wave case and the other for the backward wave case. For the forward wave case, the excitation signal is fed through one of the upstream coaxial ports, while keeping all the other ports matched. As the beam pipe is circular, it is sufficient to use one coaxial port for the excitation. Fig. 8 shows the variation of the forward and backward wave shunt impedances with frequency. From the plot, it can be noticed that the peaks of the shunt impedances occur around 1.38 GHz with the maximum values 1282 Ω (forward wave) and 1058 Ω (backward wave). The shunt impedances have also been computed for the feedback cavity without the nose cones. The computed shunt impedances without the nose cones are 13 % lower than those with the nose cones.

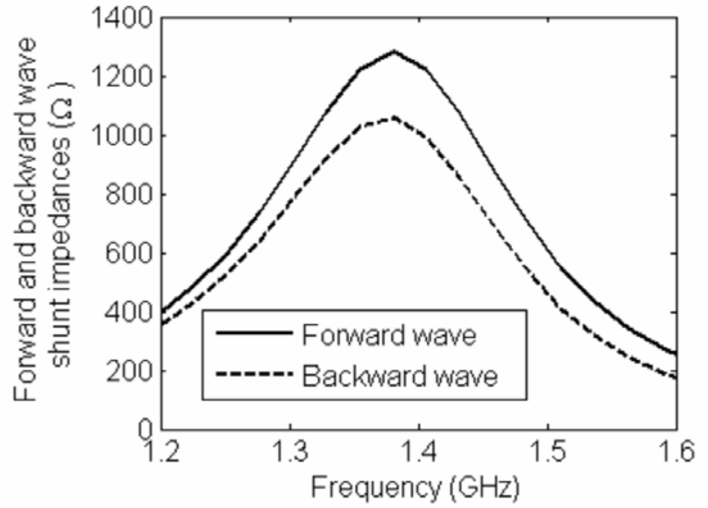

Figure 8: Forward and backward wave shunt impedances for the feedback cavity (with nose cones)

4.10.5 Summary

Wake computation results for the button type BPMs mounted at the normal and the narrow beam pipe have been presented. The loss and kick parameters for both cases have also been calculated. Modal analysis has been done to investigate the trapped modes in the vicinity of the BPM. The wakes and impedances computation results for the PETRA III longitudinal feedback cavity have been presented. The corresponding loss and kick parameters have been calculated. The forward and backward wave shunt impedances have also been presented.

4.10.6 Acknowledgment

We would like to thank Mark Lomperski for carefully reading the manuscript.

4.10.7 References

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