THE IMPEDANCE OF SELECTED COMPONENTS OF THE SYNCHROTRON LIGHT SOURCE 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. Since the impedance of the machine determines its performance with respect to coupled and single bunch instabilities it is important to know the wakefields and higher order modes (HOMs) of the different components of the vacuum system. Numerical calculations of wakefields are presented for several components of PETRA III, including the rf-cavities, shielded bellows and tapered vacuum chamber transitions. The impedance of these components is presented in terms of the loss and kick parameters.

INTRODUCTION

PETRA III

At Present PETRA, originally built as an electron - positron collider in 1976, is mainly used as a preaccelerator for the HERA lepton hadron collider at DESY. After the end of the HERA collider physics program in 2007 it is planned to convert the PETRA ring into a dedicated 3rd generation synchrotron radiation facility [1,2], 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 10^{21} 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. The main parameters of PETRA III are summarised in Tab. 1.

Table 1: PETRA III parameters

Parameter	**PETRA III**	
Energy / GeV	6	
Circumference /m	2304	
Total current / mA	100	
Number of bunches	960	40
Emittance (horz. / vert.) /nm	1 / 0.01	
Bunch length / mm	12	
Damping time H/V/L / ms	16 / 16 / 8	

Two different bunch filling patterns are considered: one with a large number of equally spaced bunches with a low bunch population, and one with higher bunch charges (2.5 mA per bunch) in 40 equally spaced bunches, which is for time-resolved experiments. First estimates for beam current limitations have been given in [2]. To improve the impedance model of PETRA III the wakefields of several components have been recently calculated using the MAFIA [3] code. Before we discuss the numerical results in more detail we will introduce some characteristic parameters used for the analysis of beam instabilities.

Wakefields

A beam circulating in a storage ring interacts with its vacuum chamber surroundings via electromagnetic fields. These wake fields [4] 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 point charge q_1 is defined as:

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

where r_2 is the transverse coordinate of the witness charge q_2. The impedance is simply the Fourier transform of the point charge wake potential. The wake potential of a bunch is the convolution of the point charge wake potential with the line charge density $\lambda(s)$:

$$\vec{W}(\vec{r}_2,\vec{r}_1,s) = \int d\bar{s}\ \ \lambda(s-\bar{s})\ \vec{W}^{\delta}(\vec{r}_2,\vec{r}_1,s)\ .$$

The loss parameter $k_{\|}$ and the kick parameter $k_{\perp}$ are defined as:

$$k_{\|} = \int ds\ \ W_{\|}(s)\,\lambda(s),\ \ k_{\perp} = \int ds\ \ W_{\perp}(s)\,\lambda(s)\ ,$$

where $W_{\|}(s)$ is the longitudinal and $W_{\perp}(s)$ is the transverse wake potential of a bunch with normalized bunch charge density $\lambda(s)$. The total energy loss of the beam is $q^2\ k_{\|}(0)$. Furthermore we define a parameter $k_{\|}(1)$ as:

$$k_{\|}(1) = \int ds\ \ \frac{d}{ds}W_{\|}(s)\,\lambda(s)\ ,$$

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

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 [1,5]:

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

where I_B is the single bunch current, R = 367 m is the mean machine radius; $\langle\beta\rangle$ is the average β–function, and $k_{\perp}$ and $k_{\|}(1)$ are defined above.

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IMPEDANCE BUDGET

A transverse instability has been observed in PETRA when the storage ring was operated in collider mode [6]. Presently single bunch currents of 10 mA can be stored in PETRA II without any evidence for a transverse or longitudinal instability. Based on measurements, calculations and estimates the total impedance of PETRA II is given in Table 2 in terms of the loss and kick parameters (using an average beta function of 20 m).

Table 2: loss and kick parameters for PETRA II

Parameter	PETRA II (total)
$k_{\|}(0)$ (V/pC)	-128
$k_{\|}(1)$ (V/ pC m)	-2900
$k_{\perp}$ (V/ pC m)	1500

The impedance of the seven octants of PETRA III without insertion devices ("the old octants") will not exceed the corresponding impedance of the existing machine [1]. But this is not true for the new octant with many narrow vacuum chambers in the insertion devices. Fortunately a single bunch current of 2.5 mA is still stable even when the impedance of PETRA III is twice as large as the impedance of PETRA II (see table 2) [1].

SHORT-RANGE WAKEFIELDS

Seven Cell Cavities

In PETRA III 12 seven cell cavities will be installed, which have been already used for PETRA II, see Fig. 1. A two dimensional layout of the cavity shape was modelled on a equidistant mesh with a 0.5 mm step size using the MAFIA [3] code. The longitudinal and transversal loss and kick parameters are listed in Table 3. The longitudinal monopole and dipole wake potentials are shown in Fig. 2, while the transverse dipole wakepotential is shown in Fig. 3.

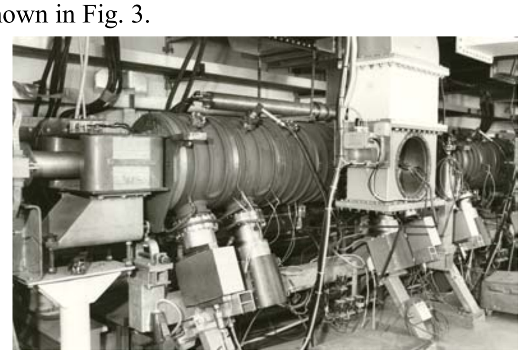

Figure 1: A seven cell cavity in the PETRA tunnel.

Table 3: loss and kick parameters of one seven cell cavity for an rms bunch length of 1 cm.

$k_{\|}(0)$ (V/pC)	$k_{\|}(1)$ (V/ pC m)	$k_{\perp}$ (V/ pC m)
-3.8	-96.0	35.8

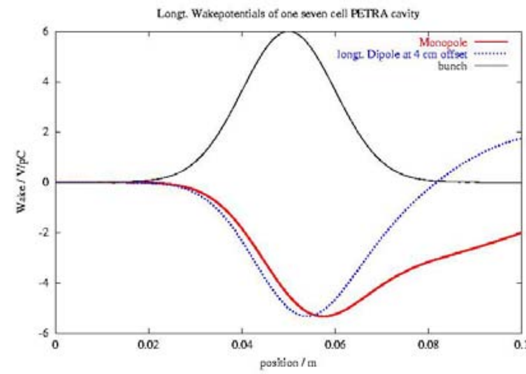

Figure 2: Longitudinal (mono and dipole) wake potentials of one seven cell cavity.

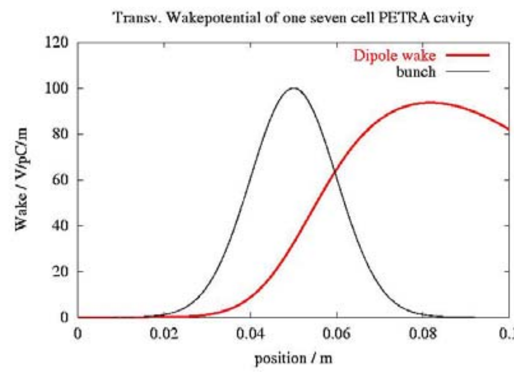

Figure 3: Transverse dipole wake potential of one seven cell cavity.

Dipole Vacuum Chamber in the Arc

The standard vacuum chamber in the arc of PETRA III will have an elliptical shape with the dimension of 80 mm x 40 mm. A cut through a prototype of the chamber is shown in Fig. 4. A 60 cm long section of the chamber has been modelled on the MAFIA gird with the step size $\Delta x = \Delta y = 1$ mm and $\Delta z = 0.25$ mm. Although the real chamber is longer than 5 m we believe that the main geometrical transitions which are important for the impedance are included in our model.

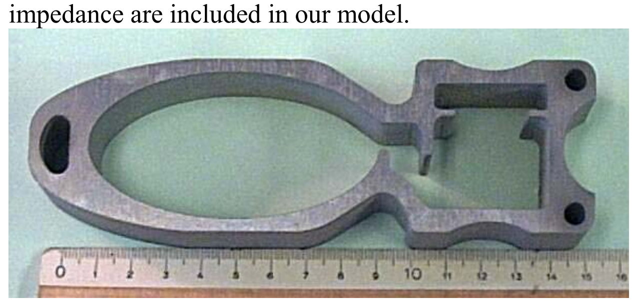

Figure 4: Cross section of a prototype design of the dipole vacuum chamber in the seven "old" octants. An ante-chamber will house the NEG pump.

The loss and kick parameters are given in Table 4. In total 200 vacuum chambers of this type will be installed in the PETRA III ring.

Table 4: loss and kick parameters of one dipole vacuum chamber for an rms bunch length of 1 cm.

$k_{\|}(0)$ (V/pC)	$k_{\|}(1)$ (V/ pC m)	Horz. $k_{\perp}$ (V/ pC m)
-3.1 x 10^{-7}	-1.5 x 10^{-5}	4.5 x 10^{-3}

Shielded Bellows

In the “old octants” of PETRA III a total of 200 shielded bellows will be installed. To protect the rf-spring from synchrotron radiation the bellow section has an elliptical cross section of 92 mm x 42 mm which is larger than the standard chamber profile of 80 mm x 40 mm. Since the transition is tapered the kick parameter is small (see Table 5).

Table 5: loss and kick parameters of one shielded bellow for an rms bunch length of 1 cm.

$k_{\|}(0)$ (V/pC)	$k_{\|}(1)$ (V/ pC m)	Vert. $k_{\perp}$ (V/ pC m)	Horz. $k_{\perp}$ (V/ pC m)
-5.4 x 10^{-4}	-0.27	0.25	0.14

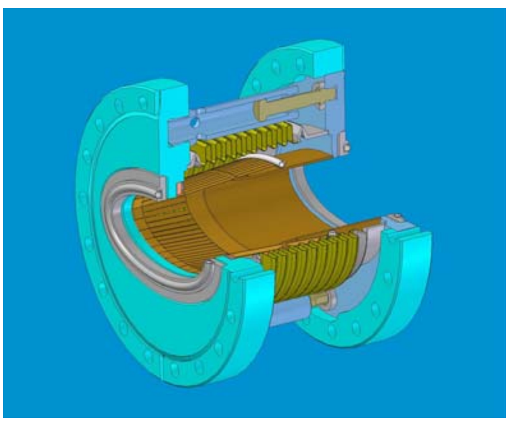

Figure 5: shielded bellow (not showing the tapered transitions).

Tapered Transitions for Insertion Devices

In the new octants several tapered transitions will be installed in front of the insertion devices. In total 16 transitions from a chamber with a cross section of 90 mm x 38 mm to the undulator chamber with a cross section of 80 mm x 7 mm will be installed. The transition is tapered over a length of 115 mm. A shielded pumping port is integrated in the taper. In the horizontal plane a synchrotron light absorber has been integrated, too. The geometry is shown in Fig. 6. From MAFIA calculations on a grid with a step size of Δx = 1 mm, Δy = 0.5 mm and Δz = 0.1 mm (about 28 million mesh points in total) the loss and kick parameters are obtained (see Table 6). Studies with a simplified two dimensional geometry indicate that the grid may be too coarse and the kick parameter may be smaller than obtained from the 3D calculations.

Table 6: loss and kick parameters of one tapered transition for insertion devices (rms bunch: 1 cm).

$k_{\|}(0)$ (V/pC)	$k_{\|}(1)$ (V/ pC m)	Vert. $k_{\perp}$ (V/ pC m)
-0.01	-6.85	138.6

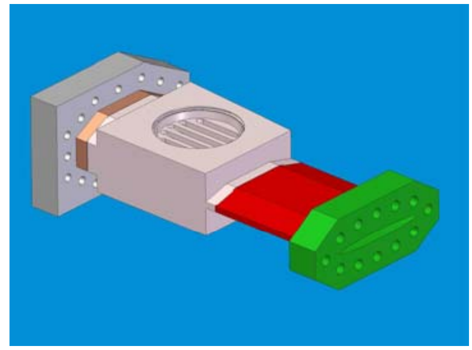

Figure 6: Tapered transition in front of the insertion devices. A pumping port is integrated in the taper.

CONCLUSION

Taking into account the different beta functions at the different vacuum components one obtains a total scaled (vertical) kick parameter for 12 cell cavities, 200 dipole vacuum chambers, 200 shielded bellows and 16 taper transitions of about 1000 V/pC/m which is well below the impedance budget of 3000 V/pC/m (20 m beta function). But many other components which have not yet been investigated in detail will also be installed in the PETRA III ring. Therefore it is necessary to keep track of the impedance of every component which be installed in the ring, especially the damping wiggler with many synchrotron light absorbers has to be investigated in detail.

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