BEAM IMPEDANCE STUDY FOR THE BESSY-II STORAGE RING

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Abstract

The longitudinal impedance of components of the BESSY-II storage ring is studied using the computer code MAFIA.

1 INTRODUCTION

BESSY-II is a high-brilliance synchrotron radiation source presently under construction at Berlin-Adlershof [1]. Since instabilities of the electron beam deteriorate the quality of the delivered synchrotron radiation, it is important to design the storage ring components such that wakefields excited by the beam at discontinuities are reduced as much as possible.

Section 2 summarizes the relations used in this study (see also [2] [3]). Section 3 describes the strategy followed here. The results are given in sections 4 and 5.

2 LONGITUDINAL WAKE AND IMPEDANCE

The longitudinal wake function for a pointlike unit charge $q_1(\vec{r}_1)$ is defined as the energy lost by a unit charge $q_2(\vec{r}_2)$ that follows q_1 with a time delay t:

$$w_z(\vec{r}_1, \vec{r}_2, t) \equiv \frac{U(\vec{r}_1, \vec{r}_2, t)}{q_1\, q_2}. \qquad (1)$$

In the following, the transverse displacements $\vec{r}_{1,2}$ of the charges are neglected, and, assuming longitudinal quantities, the index z is dropped. A numerical time-domain integration of Maxwell's equations on a mesh can only yield the wake function for an extended charge distribution $i(t)$ normalized to q_1:

$$W(t) = \frac{1}{q_1} \int_{-\infty}^{\infty} i(t')\, w(t-t')\, dt'. \qquad (2)$$

The coupling impedance $Z(\omega)$ i.e. the complex power spectrum of the wake function for a point charge is obtained by dividing the spectrum of $W(t)$ by the spectrum of the charge distribution $I(\omega)$:

$$Z(\omega) \equiv \int_{-\infty}^{\infty} w(t)\, e^{-i\omega t}\, dt = \frac{\int_{-\infty}^{\infty} W(t)\, e^{-i\omega t} dt}{I(\omega)}. \qquad (3)$$

Figure 1 shows an example. Assuming a Gaussian particle bunch of rms duration τ, the charge distribution reads

$$i(t) = \frac{q_1}{\sqrt{2\pi}\tau} e^{-t^2/2\tau^2} \quad \text{or} \quad I(\omega) = q_1 e^{-\omega^2\tau^2/2}. \qquad (4)$$

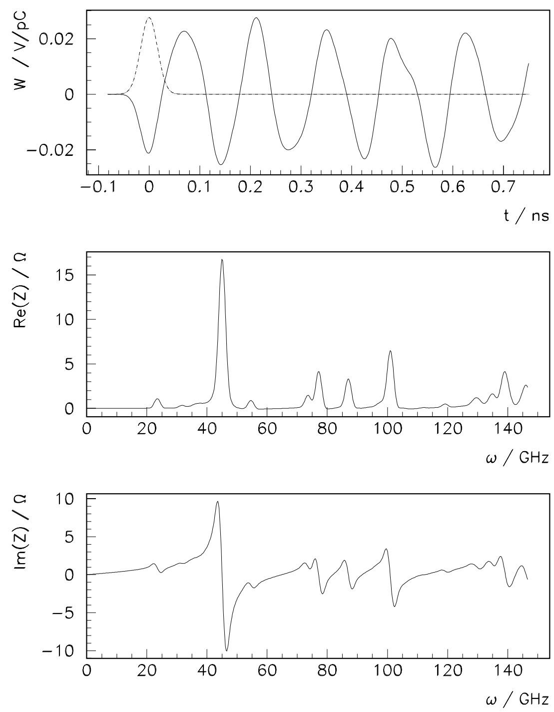

Figure 1: Wake function of a beam position monitor (top). Dividing the Fourier transform of the wake function by the bunch spectrum yields the corresponding impedance.

In order to optimize the design of a vacuum component, the loss factor may be used as a figure of merit. The longitudinal loss factor k is defined as the energy deposited by a charge distribution after its passage through the object under study and can be either computed from the wake function or from the impedance:

$$k = \frac{1}{q_1} \int_{-\infty}^{\infty} W(t)\, i(t) dt = \frac{1}{\pi q_1^2} \int_{0}^{\infty} \mathrm{Re}\left[Z(\omega)\right] \left|I(\omega)\right|^2 d\omega. \qquad (5)$$

The total impedance is usually quoted in terms of

$$|Z/n| \quad \text{with} \quad n \equiv \omega/\omega_\circ, \qquad (6)$$

where $\omega_\circ$ is the revolution frequency. Since $Z(\omega)$ is in many cases inductive and linear in ω, this quantity is expected to be constant over a wide frequency range.

Traditionally, $|Z/n|$ is obtained by fitting a broadband model to the loss factor as function of the bunch length.

In the present case, however, such a fit was found to yield rather ambiguous results, and the total impedance was estimated as described in the next section.

3 NUMERICAL COMPUTATION

Using the time domain modules of the computer code MAFIA [4], the wake function $W(t)$ for the shortest applicable bunch length ($c\tau = 5$ mm in multibunch mode) was obtained. The mesh size was 1 mm or smaller. the wake function was monitored over a range of 3.3 ns. In most cases, the component under study required a 3-dimensional model (e.g. figure 2 and 3).

For each machine component, the design option with the lowest longitudinal loss factor was favored.

The impedance $Z(\omega)$ as function of frequency was computed by applying a Fast Fourier Transform to $W(t)$ and dividing the result by the bunch spectrum (equation 3). The mesh size in the time domain determines the frequency range, while the finite time range limits the frequency resolution. The time domain calculation does not resolve the higher order cavity modes (HOMs), which were studied in the frequency domain by [5].

In order to obtain a worst-case value for $|Z/n|$, the absolute values of the impedance of all individual components were summed up.

Component	quantity	total k [V/pC]
Rf cavities	4	4.57
insertion device chambers	13	1.30
beam position monitors	112	0.88
bellows, short	80	0.17
bellows, long	48	0.14
flanges, NW100	192	0.13
flanges, NW250	32	0.02
depolarization kicker	1	0.14
excitation striplines	4	0.11
current monitors	2	0.05
dipole chambers	32	0.05
pumping slots	96	0.03
septum chamber	1	0.02

Table 1: Longitudinal loss factors k for components of the BESSY-II storage ring. The value quoted for the rf cavities includes the fundamental mode.

4 RELEVANT STORAGE RING COMPONENTS

The longitudinal loss factors and the respective number of components in the storage ring are listed in table 1. Some comments on the individual components are in order.

The largest contribution comes from the rf cavities. The 2-d MAFIA model comprises four 500 MHz DORIS-type pillbox cavities connected by 400 mm long tubes of 146 mm diameter with pumping slots, and two 100 mm long end pieces tapered from 146 mm down to 35 mm.

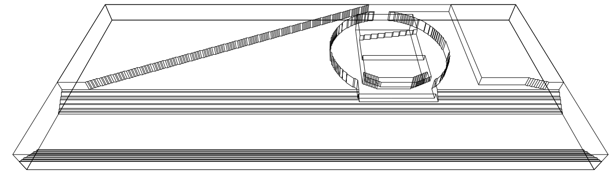

Figure 2: MAFIA 3-d model for the dipole chamber with a 15 mm wide slot for synchrotron radiation and a radiation absorber suspended in a cylindrical pumping port.

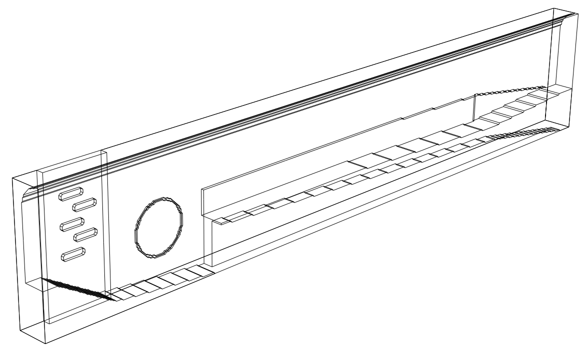

Figure 3: MAFIA 3-d model for the injection region. In this picture, the beam is injected from the right. The model includes the septum, a screen monitor and an array of pumping slots.

The elliptical insertion device chamber (60×18 mm) is connected to an ante-chamber by a 10 mm wide channel. The ante-chamber does not contribute significantly to the impedance budget, neither does the radiation absorber at the end of the chamber. The loss factor is essentially given by the tapers at both ends, where the vertical size of the chamber changes from 18 mm to 35 mm.

Another large contribution comes from the 112 beam position monitors with a button diameter of 15 mm. Their impedance shows a prominent resonance at $\omega = 45$ GHz (figure 1).

The discontinuities at bellows and flanges are shielded by sliding rf fingers. Their design was optimized using a 2-d model of 35 mm diameter, corresponding to the vertical chamber size.

A kicker close to the beam is required to depolarize the beam in order to measure the beam energy. A chamber with a vertical size of 18 mm and a stripline embedded in its wall yields a significantly lower loss factor compared to a wider chamber with a stripline protuding into it.

Each of the 32 dipole chambers a has 15 mm wide slot for synchrotron radiation. The main contribution of its impedance comes from the radiation absorber. The curvature of the beam had to be neglected in the MAFIA model

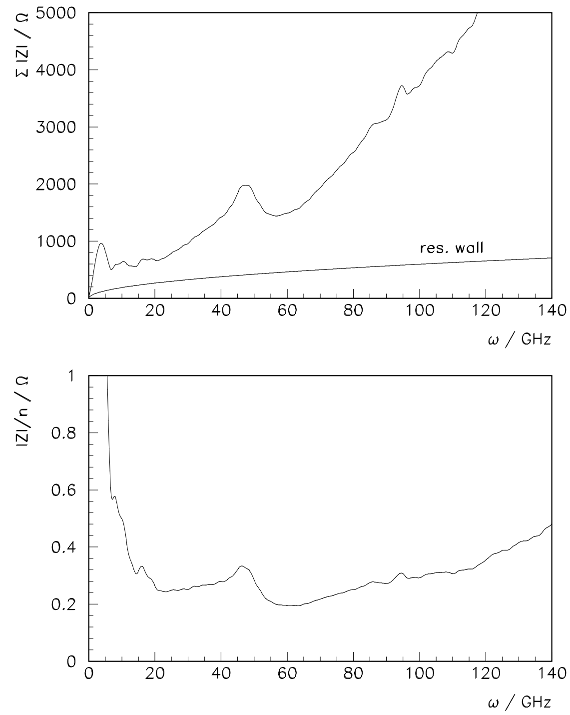

Figure 4: Summed longitudinal impedance of all components including the resistive wall impedance (top), and $|Z/n|$ as function of frequency.

(figure 2).

The 65×35 mm chamber in the region of the quadrupole and sextupole magnets has no ante-chamber. The only discontinuities are the pumping ports, where the compromise between impedance and pumping speed is an array of 96 mm long and 7 mm wide slots with semi-circular ends.

The model of the chamber in the injection region is shown in figure 3. The impedance contribution of the septum, the pumping slots and the screen monitor is negligible.

5 TOTAL STORAGE RING IMPEDANCE

The summed impedance of all components listed in table 1

$$|Z(\omega)| \equiv \sum_i |Z_i(\omega)| \tag{7}$$

is shown in the upper part of figure 4. As mentioned before, HOMs do not appear as prominent peaks due to the limited frequency resolution.

Also shown is the longitudinal resistive wall impedance given by

$$Z_{rw}(\omega) = \frac{(1-i)}{2\pi\, b\, \delta\sigma} L, \tag{8}$$

where b is the chamber radius, which was approximated by the smaller (vertical) semi-axis of the respective chamber. L is the chamber length, σ is the conductivity of the chamber material and

$$\delta = \frac{c}{\sqrt{2\pi\,\sigma\,\omega}} \tag{9}$$

is the skin depth. While most of the vacuum chambers are made of stainless steel ($\sigma = 1.4 \cdot 10^6\ 1/\Omega$m, $b = 17.5$ mm), the narrow insertion device chambers are made of aluminium ($\sigma = 3.5 \cdot 10^7\ 1/\Omega$m, $b = 9$ mm).

The lower part of the figure shows the quantity $|Z/n|$ which is nearly constant over the frequency range of $\omega = 20-120$ GHz. A value of $|Z/n| \approx 0.3\,\Omega$ can be concluded. This moderate broadband impedance may slightly increase when additional diagnostic elements or insertion devices with smaller gaps are introduced.

The transverse impedance was not considered in the context of optimizing the machine components. A discussion of the transverse resistive wall impedance of the BESSY-II storage ring can be found in [6].

6 ACKNOWLEDGEMENTS

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