WAKE FIELD AND IMPEDANCE CALCULATION DUE TO THE BEAM POSITION MONITOR IN THE ILSF STORAGE RING

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Abstract

The Beam Position Monitors (BPMs) are usually used in the particles accelerators to observe position of the beam and to record longitudinal bunch shape. As the vertical beam size demands beam stabilities on the submicron level in the particle accelerators, there must be a sever precision on designing and fabrication of the BPMs. In this paper, we have explored effect of the BPMs on the total impedance and loss factor of the ILSF storage ring.

INTRODUCTION

In order to achieve optimum performance of an accelerator in particularly a storage ring, a good understanding of interaction of the charged particles with the surrounding structures which can be described by wake fields in the time domain, or equivalently by impedances in the frequency domain is needed. The usual approach is to calculate impedances of the separate components such as BPMs, bellows, tapers, flanges, RF cavity, etc and multiply each by the total number of them. It helps to reach the total impedance budget which plays a key role in determining the threshold beam current and to avoid the single bunch instabilities like microwave instabilities or transverse mode coupling instabilities.

The BPMs have to be in an accelerator to provide reliable beam position readings and to record the location of beam bunches moving through a particular segment of the accelerator. The BPM optimization has dealt with the sensitivity and intrinsic resolution parameters, as well, the wake field loss factor of the buttons which may cause thermal deformation effects due to the dissipated power there. In the 3 GeV Iranian Light Source Facility (ILSF) storage ring aiming to store an electron beam with current and emittance of 400 mA and 0.477 nm.rad respectively, there would be 360 button type beam position monitors (BPMs) to observe the beam coordinates for orbit study. The BPMs have been placed at the crucial points in the lattice with proper phase advances, near the quadrupoles to minimize the closed orbit distortion (COD), near the sextupoles to decrease the feed-down effects and at both ends of each straight section to improve the control of stable light sources from insertion devices.

In this paper, we have further optimized the designed BPM for the high intensity ILSF storage ring in view of wake field, impedance and loss factor minimization. For this propose, a 2.9 mm bunch with 1nC charge has been passed through the designed BPM placed around the ring with certain vacuum chamber size. Locations of the BPMs in a period of the ILSF ring are shown in Fig. 1, [1].

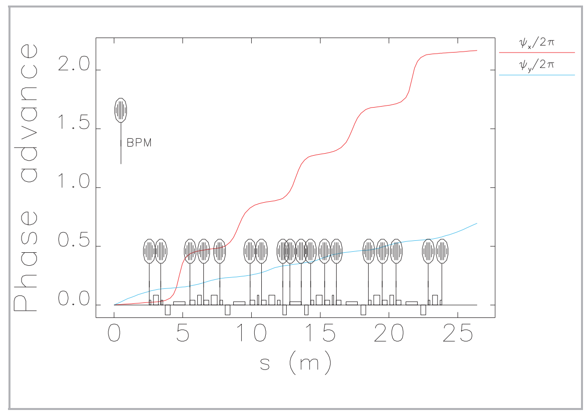

Figure 1: Location of BPMs in a period of the ILSF ring.

THE THEORY

The electromagnetic interaction of the particles beam in accelerators with surrounding environment is a relatively small effect that can be considered as a perturbation but it will leads to several types of beam instabilities. Let us consider a leading particle 1 of charge q moving along axis z with a velocity close to the speed of light, so that $z=ct$. After the charge passes the perturbing element, a local concentration of the electromagnetic fields may remain that exerts a force on trailing charge, Fig. 2, [2].

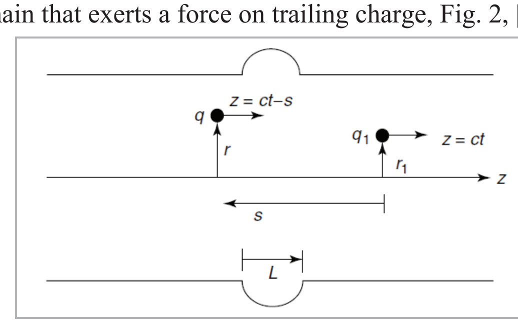

Figure 2: An ultra relativistic source charge $q1$ passes through a geometry perturbation and induces wake fields that extend over a length L, followed by an ultra relativistic test charge q.

A trailing particle 2 of unit charge moves parallel to the leading one, with the same velocity, at a distance s with offset $r=r(x,y)$ relative to the z-axis. After solving Maxwell's equation and finding the electromagnetic field generated by the first particle, change in the momentum of the second particles due to this field as a function of the offset and distance s is given by

$$\Delta\vec{p}(\vec{r},s) = \int_{-\infty}^{+\infty}[E(\vec{r},z,t) + \vec{z_0} \times \vec{B}(\vec{r},z,t)dt]dt, \quad (1)$$

where z_0 is a unit vector in the z-direction. With the proper sign and the normalization factor *of* c/q, the longitudinal (l) and transverse (t) components of changed momentum are called the longitudinal and transverse wake functions or the δ-function wake potentials which characterize the integrated effect of reflected fields, [3]

$$\vec{w_l}(\vec{r},s) = -\frac{c}{q}\,\overrightarrow{\Delta p_z} = -\frac{c}{q}\int_{-\infty}^{+\infty} E_z dt]_{z=ct-s}\ ,$$
$$\vec{w_t}(\vec{r},s) = \frac{c}{q}\,\overrightarrow{\Delta p_\perp} = \frac{c}{q}\int_{-\infty}^{+\infty} E_\perp + \vec{z_0} \times \vec{B} dt]_{z=ct-s}\ . \quad (2)$$

The bunch wake potential in terms of δ function wake potential for a distribution of particle, λ, is given by

$$W(z) = \frac{1}{Q_{tot}} \int_0^z w(s)\ \lambda(s) ds. \quad (3)$$

Description in the time domain is convenient for short times, but for longer times the wake potential rings at perhaps one or just a few discrete frequencies. Thus it is more convenient to describe the problem in the frequency domain. The impedance is the frequency spectrum or the Fourier transform of the δ-function wake potential as

$$Z_l(\omega) = \frac{1}{c}\int_0^\infty w_l(s) e^{i\omega s/c} ds\ ,$$
$$Z_t(\omega) = -\frac{i}{c}\int_0^\infty w_t(s) e^{i\omega s/c} ds \quad (4)$$

For a Gaussian bunch with *rms* length of σ_s the longitudinal and transverse loss factor are given by

$$k_l(\sigma_s) = \frac{1}{2\pi}\int_{-\infty}^{\infty} Z_l(\omega) e^{-\omega^2 \sigma_s{}^2/c^2} ds\ ,$$
$$k_t(\sigma_s) = \frac{1}{2\pi}\int_{-\infty}^{\infty} Z_t(\omega) e^{-\omega^2 \sigma_s{}^2/c^2} ds. \quad (5)$$

The according dissipated power from the bunch with current I and RF frequency f_{RF} is

$$P = \frac{k_l\ I^2}{f_{RF}}. \quad (6)$$

The Broad-band impedance of an element could be evaluated from the calculated wake using appropriate analytical function. There are three types of wakes produced by a component; capacitive (cavity-like), resistive and inductive [4],[5]. These types of wakes are distinguished from their behaviours early after the start of the bunch distribution, presented in Fig. 3,

for capacitive

$$\frac{Z}{n} = 1.225\ (\frac{\sigma_{rms}}{c\,\omega^3})^{1/2} \omega_0 w_{max}, \quad (7)$$

for inductive:

$$\frac{Z}{n} = \sqrt{2\pi e}\ (\frac{\sigma_{rms}}{c})^2 \omega_0 w_{max}, \quad (8)$$

for resistive:

$$\frac{Z}{n} = \sqrt{2\pi}\ \frac{\sigma_{rms}}{c}\ (\omega_0/\omega) w_{max}. \quad (9)$$

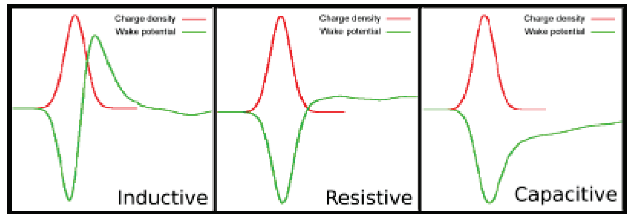

Figure 3: The longitudinal wakes for inductive, resistive and capacitive components, taken from Ref. [5].

ILSF BPM OPTIMIZATION

General overview of the designed BPM in the ILSF hexagonal vacuum chamber is depicted in Fig. 4.

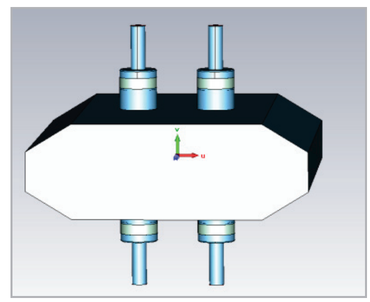

Figure 4: BPM in the ILSF vacuum chamber.

The main concern in designing the buttons of BPMs is usually the dissipated power by the beam. A small button diameter and large button thickness reduces both power loss and signal transmission. However, compromise between a higher intrinsic resolution and a low deposited power in the buttons defines the final buttons dimensions [6]. For this propose, the loss factors is firstly calculated for different values of diameter and thickness of the button where the vacuum chamber full gap is assumed to be 18 mm, and gap of the BPM button with its electrode (G) is set to 0.5 mm, see Table 1.

Table 1: Loss Factors (K) for Different Values of Thickness (T) and Radius (R) of Button of the Designed BPM.

R(mm)	5	3.5	2
T(mm)		2.5	
K(V/pC)	45.85E-3	22.80e-3	6.11e-
T(mm)		4.0	
K(V/pC)	42.19e-3	21.29e-3	5.98e-

As given, the lowest loss is given when the thickness is 4 mm. Although 2 mm radius of the BPM button results to low loss factor but 3.5 mm button was chosen since the former would have reduced the transmission through the button. For further power losses minimization study, the gap between the BPM button and its electros is scanned and the results are given in Table 2.

Table 2: Loss Factors (K) for Various Values of Gaps					
G (mm)	0.5	0.4	0.3	0.2	0.1
K(V/pC)	0.021	0.016	0.012	0.007	0.004

As given, 0.1 mm gap provides the lowest losses, but considering the ratio of transmission to reflection which should be high enough [6], 0.3 mm gap button seems to be the optimized value. The optimized and reliable dimensions of the designed BPM in view of loss factor minimization are shown in Fig. 5.

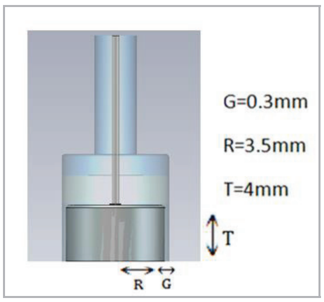

Figure 5: The BPM button with optimized dimensions for the ILSF ring.

WAKE FIELD CALCULATIONS

For a whole ring, sum of the broad band impedances Z/n is generally called broadband impedance budget of ring, where $n=\omega/\omega_0$ and $\omega_0=C/R$ is the revolution frequency. Due to various vacuum chamber gap height where the BPM can be placed, the BPM impedance and according wake field function are calculated for different vacuum gap, Fig. 6 and Fig. 7 respectively.

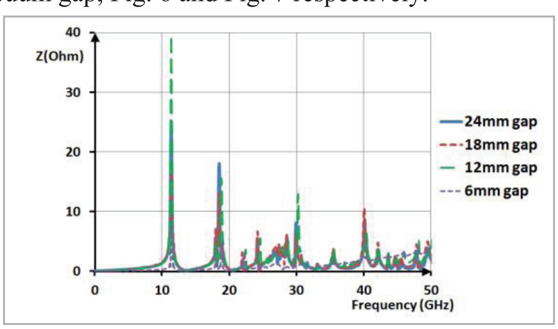

Figure 6: Longitudinal impedances due to a BPM as a function of vacuum chamber gap height.

Two high peaks in the frequencies of around 12 GHz and 18 GHz are seen which their magnitudes are changing for different gap height. These are the modes showing how the fields are trapped in these frequencies while for the higher ranges, the electromagnetic waves are free to propagate almost unimpeded around the ring. Thus the wake field has leaked out and broad band impedance with more smooth modes appears.

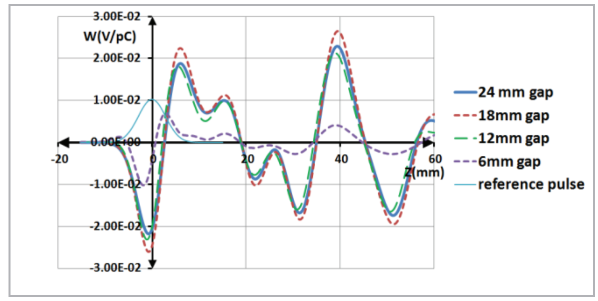

Figure 7: Longitudinal wake function due to a BPM versus vacuum chamber gap height.

Considering inductive behaviour of the wakes, variation of broad band impedance, loss factor and correspond dissipated power for the different vacuum chamber gap height are given in Table 3.

Table 3: Impedance Quantities for ILSF BPMs with for Various Values of Gaps

Gap height (mm)	$\lvert Z/n \rvert$ (Ω)	K (V/pC)	Diss. Power (W)
6	1.40e-5	1.89e-3	0.60
12	3.19e-5	9.58e-3	3.06
18	3.60e-5	12.13e-3	3.88
24	3.00e-5	10.51e-3	3.36

As given, highest value of the impedance and dissipated power are when chamber heitgh is 18 mm. However they don't change considerably unless the gap heitgh is about 6 mm that the least ones emerge.

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