Estimation of Broad Band Impedance of the SPring-8 Storage Ring

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Abstract

The broad band impedance of the vacuum chamber of the SPring-8 storage ring was estimated with several analytical equations and the numerical simulation with MAFIA T2. The estimated value of the total impedance is a few $10^{-1}\Omega$.

The vacuum chamber consists of the beam chamber and the slot-isolated antechamber. The effect of the obstacles in the slot is estimated numerically, which shows that the designed shape is effective to reduce the impedance of them.

I. INTRODUCTION

The broad band impedance of the vacuum chamber of the SPring-8 storage ring, which is a 8GeV electron/positron ring for a high brilliance light source, should be low enough to get the design current of 5mA/bunch with less than 2 times higher value of the energy spread than the natural. To meet this requirement, the vacuum chamber is carefully designed to reduce the discontinuities in the beam chamber.

The estimation of the impedance is performed with some theoretical and approximated equations and with the simulations by MAFIA[2] T2.

In numerical simulation with MAFIA T2, the approximation that the beam chamber has round shape of 20mm radius while the real shape is ellipse of 20mm × 35mm, and several models of the wake factions such as cavitylike, inductive and resistive are assumed.

There exist obstacles in the slot and antechamber such as absorbers, pumping holes and NEG stripes. The effect of them are also estimated numerically with MAFIA T3 and S3.

II. MODEL WAKE FUNCTIONS

The models of the wake functions adopted here are cavitylike, inductive and resistive.

A. *cavitylike*

A cavitylike element is a groove with a larger gap and depth compared with the wave length of the wake field of interest.

The theoretical impedance of a cavitylike element of inner radius a and gap g is[3, 4, 5]

$$Z = \frac{Z_0}{2\pi}\frac{1}{a}\sqrt{\frac{cg}{\pi\omega}}(1+i) \tag{1}$$

,where $Z_0 = 377\Omega$.

The impedance can be obtained with MAFIA T2, assumming above frequency dependence of the impedance, with[6]

$$Z = \frac{1}{\frac{\Gamma(1/4)}{4}\frac{2\sqrt{c}}{\pi}}\sqrt{\sigma}k_l\frac{1+i}{\sqrt{\omega}} \tag{2}$$

,where σ is the bunch length(r.m.s.) and k_l is the loss parameter which MAFIA T2 can calculate.

B. *inductive*

The impedance of elements which have the discontinuitirs of the scale smaller than the wave length of the wake field of interest are inductive.

The theoretical impedance of a small rectangular groove is[7, 8]

$$Z = -i\omega\frac{Z_0}{2\pi c}\frac{g(b-a)}{a} \tag{3}$$

, where b is an outer radius of the groove.

The impedance of a pair of shallow transitions is approximated with the formula[9]

$$Z = -i\omega\frac{3Z_0}{2\pi c}\frac{a(b-a)^2}{b^2}\left(\frac{2\theta}{\pi}\right)^{\frac{1}{2}} \tag{4}$$

,where θ is the tapering angle.

The impedance can be obtained with MAFIA T2, assuming above frequency dependence, with[6, 10]

$$Z = -i\omega\frac{2\pi e}{c^2}\sigma^2 W_{max} \tag{5}$$

, where σ and W_{max} are the bunch length(r.m.s.) and the maximum value of the wake function which MAFIA T2 can calculate, respectively.

Elements	Number	Total Impedance $\frac{Z_{//}}{n}[\Omega]$	
		Equations	MAFIA T2
RF cavities	32	$1.5 \times 10^5 \frac{1+i}{n\sqrt{n}}$	$1.3 \times 10^5 \frac{1+i}{n\sqrt{n}}$
weldments	2000	$-0.005i$	$-0.006i$
flanges	700	$-0.005i$	$-0.005i$
offsets	2700	$-0.013i$	$-0.019i$
BPMs	300	–	$\frac{360}{n}$
pump slots	6000	$-\frac{72}{n}i$	–
bellows	400	–	$-0.040i$
valves	100	$-0.03i - \frac{2.3}{n}i + \frac{20}{n}$	–
BPMs	300	$\frac{1.2}{n}$	–
ID sections	40	$-0.018i$	$-0.012i$
resistive wall	–	$1.9\frac{1-i}{\sqrt{n}}$	–
synchrotron radiation	–	0.026	–

Table 1: Impedance of SPring-8 storage ring

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C. *resistive*

The simulation with MAFIA T2 shows that a groove which is deep compared with the wave length of the wake field of interest has resistive impedance of the form

$$Z = R \tag{6}$$

, and with this impedance, R can be obtained with MAFIA T2 with[6]

$$R = 2\sqrt{\pi}\frac{\sigma}{c}k_l \tag{7}$$

III. THE IMPEDANCE OF ELEMENTS

A. *An RF cavity*

An RF cavity has the beam pipe of 50mm radius and the acceleration gap of 220mm wide. The wake function obtained with MAFIA T2 shows that it has a cavitylike impedance as expected.

B. *A flange*

The gap of a flange is shielded with RF contact fingers. The residual discontinuity is a triangle groove of 0.5mm wide × 1mm deep. The wake function calculated with MAFIA T2 shows that its impedance is inductive and the value of the impedance obtained with the Eq.(5) is almost half of the theoretical value of the impedance of the rectangular groove of 0.5mm wide × 1mm deep, obtained with Eq.(3).

C. *A weldment*

A weldment is designed to be a rectangular groove smaller than 0.2mm wide × 1mm deep.

D. *An offset*

The offset at the flange or at the weldment are designed to be less than 0.5mm. This is modeled as a step change of the radius of the beam pipe and estimated analytically with Eq.(4) and numerically with Eq.(5).

E. *An insertion device section*

A insertion device(ID) section consists of a pair of 5 degree taper transitions which connects the normal section of 35mm radius and the ID section of 10mm. The impedance is estimated analytically with Eq.(4). The wake function calculated with MAFIA T2 shows that the impedance is inductive.

F. *A pump slot*

The pumping slot is a longitudinal slot of 2mm wide × 9mm long. The theoretical impedance is inductive and estimated with [3]

$$Z = -i\frac{Z_0\pi w^2}{4(2\pi)^3a^2} \tag{8}$$

, where w is the width of the slot.

G. *A valve*

The gap of a valve is shielded by RF contact fingers.

The valve consists of a triangle groove of 3mm wide × 1mm deep, a deep groove of 0.5mm wide and 30 longitudinal slots of 0.5mm wide × 100mm long between the RF contact fingers. the impedance of the triangle groove is estimated with Eq.(3) as in the case of the flange and the impedance of the slot is estimated with Eq.(8). and the slots is The wake function of the deep groove calculated with MAFIA T2 shows that its impedance is resistive. The total impedance is estimated by the sum of them.

H. *Shielded bellows*

Bellows are shielded with RF contact fingers. The shape of shielded bellows consists of an outward taper transition of 105mm long and 4mm high, an outward step of 1mm high and an inward taper transition of 50mm long and 5mm high.

The wake function calculated with MAFIA T2 shows that the impedance is inductive.

I. *A beam position monitor*

The button beam position monitor(BPM) is coaxial line with 0.5mm wide gap. This structure is modeled with a deep groove of 0.5mm wide The upper limit of the effect of BPM can be estimated with this model.

The wake function obtained with MAFIA T2 shows that its impedance is resistive and obtained with Eq.(7).

J. *Resistive wall*

The resistive wall impedance is estimated with the equation

$$Z = Z_0\frac{1-i}{2}\frac{\delta}{b} \tag{9}$$

,where $\delta = \sqrt{2/\omega\mu\sigma}$ is the skin depth.

K. *Synchrotron radiation*

The synchrotron radiation impedance is estimated with the equation

$$\left|\frac{Z}{n}\right| = 300\frac{b}{R} \tag{10}$$

,where b, R is the radius of the vacuum chamber and the average radius of the machine.

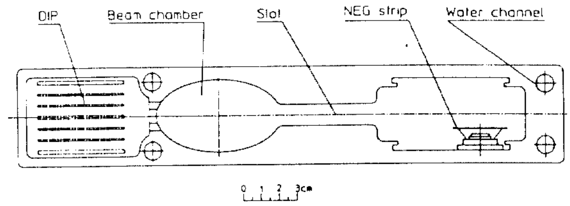

Figure 1: Cross section of the vacuum chamber.

IV. EFFECT OF OBSTACLES IN SLOTS AND ANTECHAMBERS

In the slot, there exist absorbers and pumping holes.

The effect of these obstacles in the slot and antechamber is estimated numerically with MAFIA T3 and S3.

The typical crosssection of a vacuum chamber are shown in Fig.1.

The structures used in this simulation with MAFIA T3 and S3 are shown in Fig.2 and Fig.3 ,respectively.

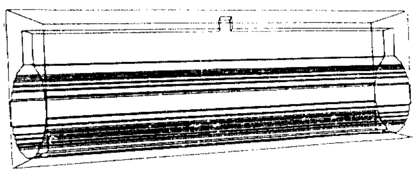

Figure 2: Model structure for MAFIA T3.

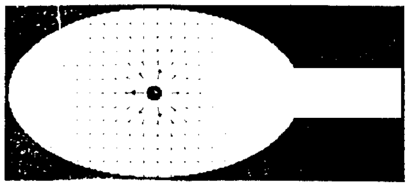

Figure 3: Model structure for MAFIA S3.

With MAFIA T3, which solves in time domain, the wake function was calculated for a test obstacle, which is a hole of 10mm long × 10mm deep × slot height high opened to the end wall of the slot.

The disturbance of the wall current causes the wake field hence the strength of the wake field can be estimated with the strength of the wall current.

With S3, which solves the electro-static problems, the wall current flowing at the end wall of the slot was calculated. The charge are placed at the beam axis and the induced charge on the end wall of the slot was calculated for several height and depth of the slot. This induced charge is proportinal to the wall current.

The result for several height of slot(10mm,12mm,14mm) are shown in Fig.4. The relative strength of the wake field is parameterized by the peak value of the wake functions.

This result shows that the strength of the wake field and the wall current both depends only on $d = depth/height$ and the strength of the wake field and the strength of the wall current are proportional to $1/d^2$ and $1/d$, respectively.

V. CONCLUSION

The total impedance of the SPring-8 storage ring is estimated to be of the order of $10^{-1}\Omega$ for $n = \omega/\omega_{rev} \sim (c/\sigma)/\omega_{rev} \sim 2 \times 10^4$.

The numerical simulation shows that the obstacles in the slot should be at least 2 × height apart from the beam chamber surface to reduce their effect and the design of the vacuum chamber fulfills this requirement. In this design, the width of the slot fulfills height/width > 4, which is enough that the effect of the pumping system in the antechamber is negligible.

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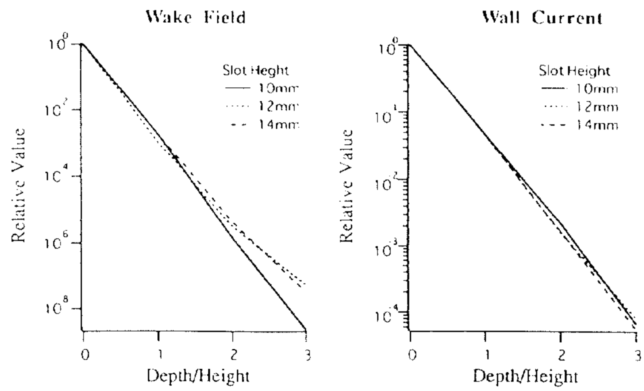

Figure 4: Relative strength of the wake functions(left) and the wall current on the end wall of the slot(right). Depth/Height is the depth from the beam chamber normalized by the slot height.

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