THE BROAD-BAND IMPEDANCE
OF THE SPRING-8 STORAGE RING

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Abstract

The longitudinal and transverse broad-band impedance of the vacuum chamber of the SPring-8 storage ring is estimated by simulations assuming several model impedance and the relation between longitudinal and transverse impedance. These assumptions are confiremed by the simulation.

1 DIMENSION OF STRUCTURE OF BEAM PIPE

Figure 1 , Figure 2, Figure 3, Table 1 and Table 2 show the shape of discontinuities of the inner wall of the beam pipe of the storage ring[1].

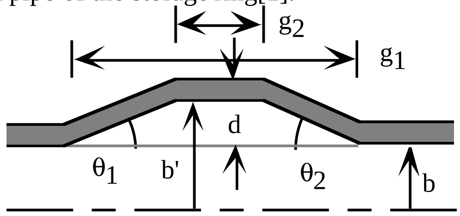

Figure 1. Dimension of two-dimensional models of elements

Table 1. Dimensions of two-dimensional models of elements of the vacuum chamber.

element	dimension [mm, rad]						
	b	b'	d=|b'-b|	g_1	g_2	θ_1	θ_2
RF cavity	50	250	200	220	220	90	90
weldments	20	22	2	0.2	0.2	90	90
flanges*	20	23	3	0.5	0	-	90
offsets	20	20.5	0.5	-	0	0	90
ID† section	20	5	15	-	-	5	5
transition at RF section	20	50	30	-	-	10	10
absorbers at RF section	50	35	15	-	-	10	10
BPM††	20	-	-	0.5	0.5	90	90

†: ID is Insertion Device, ††: BPM is Beam Position Monitor, *:with RF contact finger

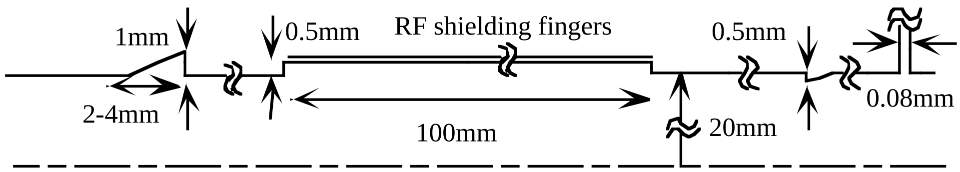

Figure 2. Shape of a valve

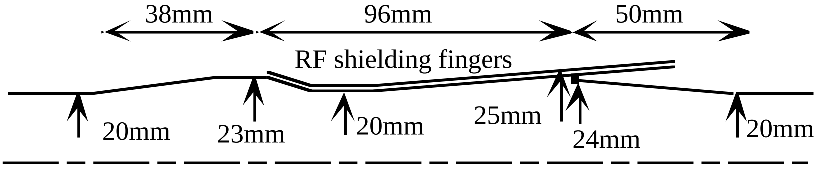

Figure 3. The shape of a bellows.

Tabel 2. Dimension of slots

slot size[mm]	height	length	depth
between RF contact fingers	1	1~100	1
to antechamber	10 ~ 12	-	> 20
to DIP†	2	50	4

†: DIP is Distributed Ion Pump

Table 1 shows the dimemensions of elements for which two-dimensional simulation byMAFIA T2 is applied.

Table 2 shows the dimension of various slots. The impedance of these slots are estimated by three-dimensional simulation by MAFIA T3.

2 LONGITUDINAL IMPEDANCE

The impedance is estimated with simulations by MAFIA. With simulations, we can easily obtain the shape and parameters of wake potentials such as loss parameter k_l and the maximum and minimum of wake functions $W^{\|}_{min}$, $W^{\|}_{max}$ or wake potentials $V^{\|}_{min}$, $V^{\|}_{max}$.

Theese parameters of wake functions are compared with the wake functions based on several models of impedance which are shown in Table 2[3,4,5].

Table 2. Longitudinal impedance models and $W^{\|}_{max}$, k_l [3,4,5]

Model	cavitylike	inductive	resistive
$Z^{\|}$ Frequency dependence	$Z_c \frac{1+i}{\sqrt{\omega}}$	$-i\omega L$	R
$Z^{\|}$ with $W^{\|}_{max}$ for Gaussian bunch	$\frac{1}{1.2824}\frac{\pi}{2}\sqrt{\frac{\sigma}{c}}W^{\|}_{max}\frac{1+i}{\sqrt{\omega}}$	$-i\omega\sqrt{2\pi e}\left(\frac{\sigma}{c}\right)^2 W^{\|}_{max}$	$\sqrt{2\pi}\frac{\sigma}{c}W^{\|}_{max}$
$Z^{\|}$ with k_l for Gaussian bunch	$\frac{1}{\frac{\Gamma(1/4)}{4}\frac{2}{\pi}}\sqrt{\frac{\sigma}{c}k_l}\frac{1+i}{\sqrt{\omega}}$	-	$2\sqrt{\pi}\frac{\sigma}{c}k_l$
Wake function W_0'	$Z_C\sqrt{\frac{2c}{\pi}}\|z\|^{-\frac{1}{2}}\theta(-z)$	$L c^2 \frac{\partial\delta(z)}{\partial z}$	$R c\, \delta(z)$

3 TRANSVERSE IMPEDANCE

By the Panofsky-Wenzel theorem, m-th moment of longitudinal and transverse impedance, $Z^{\|}_m(\omega)$ and $Z^{\perp}_m(\omega)$, have the relation ;

$$Z^{\perp}_m(\omega) = \frac{c}{\omega} Z^{\|}_m(\omega) \quad . \qquad (1)$$

The same impedance models can be applied to obtain $Z^{\|}_1$ from wake potentials $V^{\|}_1$. Then $Z^{\perp}_1$ is obtained from $Z^{\|}_1$ using Eq. (1). But this scheme is not used here.

On the other hand, with a dimensional analysis, we have a relation between $Z^{\|}_0(\omega)$ and $Z^{\perp}_1(\omega)$;

$$Z^{\perp}_1(\omega) \approx \frac{2c}{d^2\omega} Z^{\|}_0(\omega) \qquad (2)$$

,where d is a constant of the dimension of length and $\omega=n\omega_{rev}$; ω_{rev} is the angular frequency of revolution.

For the resistive-wall impedance and cavity impedance based on the diffraction model, this relation is strictly valid if we set d=b.

With equation (1) and (2), we can get the relation

$$Z^{\|}_1(z) \approx \frac{2}{d^2} Z^{\|}_0(z) \quad . \qquad (3)$$

The corresponding relation between wake functions $W_1'(z)$ and $W_0'(z)$ is

$$W_1'(z) \approx \frac{2}{d^2} W_0'(z) \qquad (4)$$

In terms of the wake potentials at (x,y)=(x,0),, produced by a charge at (x',y')=(a,0), this relation is

$$V^{\|}_1(z) \approx \frac{2ax}{d^2} V^{\|}_0(z) \quad . \qquad (5)$$

If we set a=x=b, this becomes

$$V^{\|}_1(z) \approx 2\frac{b^2}{d^2} V^{\|}_0(z) \quad . \qquad (6)$$

And if we set d=b, which is the case of resistive wall impedance or cavity impedance based on the diffraction model, the equation (6) is

$$V^{\|}_1(z) \approx 2V^{\|}_0(z) \ . \qquad (7)$$

Eq. (6) or Eq. (7) show that, with comparing the shape of $V^{\|}_0(z)$ and $V^{\|}_1(z)$, we can test the validity of equation (2) and find the value of d.

This comparison is very intuitively because the function shapes and magnitude of $V^{\|}_0=-W_0'$ and $V^{\|}_1=-b^2W_1'$ are almost same.

For three-dimensional structures, $Z^{\perp}_1$ are defined for each transverse direction x and y. We assume that the corresponding equation to (2)

$$Z^{\perp}_{x,y1}(\omega) \approx \frac{2c}{d_{x,y}^2\omega} Z^{\|}_0(\omega) \qquad (8)$$

is good approximation even in three-dimensional structure, where d_x and d_y is defined for each direction to x and y, individually.

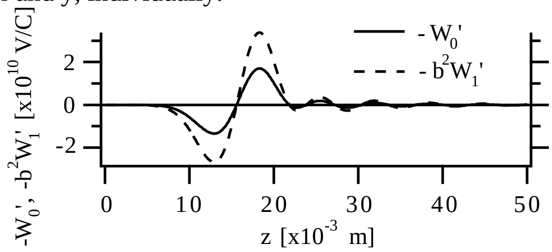

Figure 2. The wake functions for a frange. The bunch length is 3mm(r.m.s.). The shape of two wake functions, $V^{\|}_0=-W_0'$ and $V^{\|}_1=-b^2W_1'$, are the same and scale is factor 2. From Eq. (4), this result shows Eq. (2) is valid for the impedance of frange and d=b.

4 SIMULATION OF CONVEX SHAPE

The ID sections and the RF absorbers have convex shape like the shape I in Figure 3. It is difficult to get stable simulatin result for these convex shapes because the indirect method can not be applied in such shapes with MAFIA T2 and T3.

But the simulations show that the impedance of the shape II, to which the indirect method can be applied, have weak dependence on the length L. This result shows that the interference between the wake of the section A and the wake of the section B is small and they can be treat individually. Based on this fact, it is assumed that the interference is also small in the shape I. Hence the shape II is used for simulation instead of the shape I in the simulations for ID sections and RF absorbers.

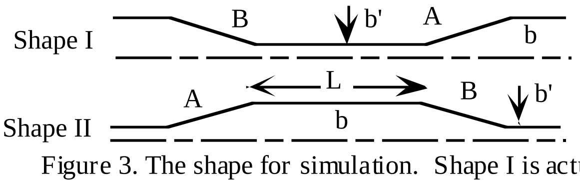

Figure 3. The shape for simulation. Shape I is actual convex shape at ID sections or absorbers. Shape II is for the simulation

Table 3. Impedance of the SPring-8 storage ring

Elements	Number of Elements	Total Impedance: Theory $Z^{\parallel}/n$ [Ω]	Total Impedance: Simulation $Z^{\parallel}/n$ [Ω]	Total Impedance: Simulation $Z^{\perp}$ [MΩ/m]	d /min.{b,b'} [mm/mm]
RF cavities	32	$1.5\times10^5 \frac{1+i}{n\sqrt{n}}$	$1.3\times10^5 \frac{1+i}{n\sqrt{n}}$	$2.8\times10^4 \frac{1+i}{n\sqrt{n}}$	50 / 50
weldments	2000	- 0.005 i	- 0.006 i	- 0.007 i	20 / 20
flanges†	700	- 0.005 i	- 0.007 i	- 0.008 i	20 / 20
offsets	2700	- 0.013 i	- 0.020 i	- 0.023 i	20 / 20
bellows†	400	-	- 0.060 i	- 0.068 i	20 / 20
BPMs	300	-	360 / n	410 / n	20 / 20
transitions at RF sections	4 pair	- 0.007 i	- 0.006 i	- 0.007 i	20 / 20
absorbers at RF sections†	8	- 0.007 i	- 0.003 i	- 0.003 i	35 / 35
ID sections	40	- 0.020 i	- 0.020 i	- 0.092 i	10 / 5
valves†	100	-	40 / n - 0.003 i	46 / n - 0.003 i	20 / 20
pumping slots	3000	-	$- 2\times10^{-5}$ i	$- 2\times10^{-5}$ i	(20/√2) / 35
slots to antechamber	500	-	- 0.001 i	- 0.001 i	(20/√2) / 35
slots between RF fingers	24000	-	- 0.001 i	- 0.001 i	(20/√2) / 35
resistive wall (b=20mm)	-	1.9 (1-i) / √n	-	2.2 (1-i) / √n	20 / 20
synchrotron radiation	-	0.026	-	-	-

† : These elements have RF shielding fingers.

5 RESULT

The impedance of the SPring-8 storage ring is shown in Table 2 The total impedance is

$$\frac{Z^{\parallel}}{n} = -0.127i + \frac{400}{n} + 1.3\times10^5 \frac{1+i}{n\sqrt{n}} \quad [\Omega]$$

$$Z^{\perp} = 0.213i + \frac{456}{n} + 2.8\times10^4 \frac{1+i}{n\sqrt{n}} \quad [\mathrm{M\Omega/m}] .$$

This transverse imedance $Z^{\perp}$ is for vertical direction.

These values are valid at $\omega < c/d$ where d is the depth of the structure shown in Figure 1[2].

The loss parameters are shown in Table 3 and the parasitic loss power at a single element at at one of the operation mode, 100mA=5mA/bunch×20 bunch, are shown in Table 4. The expected natural bunch length is 3.5-5mm and the bunch length including potential-well distortion and instabilities caused by this impedance is 7mm at the bunch current 5mA/bunch[6].

Table 3. Loss parameters of a single element

BunchLength [r.m.s.]	loss parameters [V/C] 3 mm	5 mm	10 mm
an RF cavity	8.07E11	6.43E11	4.82E11
a weldment	5.02E09	2.78E08	1.88E07
a flange	6.61E08	8.09E07	7.58E06
an offset	2.81E09	8.69E08	1.21E08
an ID section†	6.93E10	1.11E10	1.36E09
a transition at RF	8.57E11	1.56E11	1.16E10
an absorber at RF	2.56E11	1.22E11	3.87E10
bellows	9.81E10	4.14E10	9.57E09
a valve	1.50E10	6.04E09	9.60E08
a slot to antechamber	9.65E08	1.08E08	1.88E06
Total (One Turn)	8.28E13	3.69E13	1.77E13

Table 4. Parasitic loss power of a single elements at the stored current of 100mA=5mA/bunch×20 bunch

Bunch Length [r.m.s.]	Parasitic Loss Power [W] 3 mm	5 mm	10 mm
an RF cavity	1932.7	1539.9	1154.3
a weldment	12.02	0.67	0.05
a flange	1.58	0.19	0.02
an offset	6.73	2.08	0.29
an ID section	165.97	26.58	3.26
a transition at RF	2052.5	373.6	27.78
an absorber at RF	613.11	292.19	92.69
a bellows	234.95	99.15	22.92
a valve	35.92	14.47	2.30
a slot to antechamber	2.31	0.26	0.00
Total (One Turn)	1.98E5	8.84E4	4.24E4

6 REFERENCES

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