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 analytical and numerical methods.

The vacuum chamber consists of the beam chamber and the slot-isolated antechamber. The effects of the slot and the obstacles in the slot are estimated numerically.

I. INTRODUCTION

The SPring-8 storage ring, which is 8-GeV electron/positron storage ring for a high brilliance light source, should have flexibilities of the operation to meet the various requirements of the users of light, including the high single bunch current.

To store such a high bunch current beam, the broad band impedance of the storage ring should be kept lower as possible to avoid the instabilities, to minimize the loss of the beam energy and to avoid heating of the elements.

The design value of the bunch current of the SPring-8 storage ring is 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 and adopt the antechamber scheme[1] for pumping systems to reduce their effect on the beam.

The estimation of the impedance is performed with some theoretical and approximated equations and with the simulations by two and three dimensional codes of MAFIA T2 and T3[2], respectively.

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.

The effect of the obstacles in the slots and antechambers such as absorbers, pumping holes and NEG pumps are also estimated numerically with MAFIA T3 and S3.

II. IMPEDANCES OF ELEMENTS

The impedance is estimated with some analytical equations based on theories and experience for small gaps, shallow transitions, slots and cavities, and also estimated with numerical methods with MAFIA T2/T3 assuming several model shapes of wake functions[3,4,5,6].

The shape of the structures is modeled as Figure 1. and the values of the parameters a, b, g, θ and θ of the elements are listed in Table 1. They are the values at the worst case and the vacuum group keep the real value below them.

The impedance obtained is shown in table 2. In this table, the elements which have negative imaginary value produce the inductive wake functions and their impedancee aer assumed of the form $Z = -i\,\omega L$.

The shape of the impedance of the RF cavities is assumed to be $Z = A\,(1+i)/\sqrt{\omega}$ based on theoretical estimations[7].

The L and A can be obtained from the peak value of wake functions and the loss parameters.and both of them can be calculated with MAFIA T2/T3.

The theoretica value of the impedance of the slot[7] between RF contact fingers used in the bellows and valves are of the order of -i 1×10-4 [Ω] and we neglect it in Table 2.

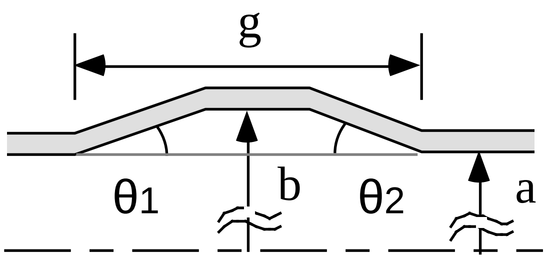

Figure 1. Parameters to show the dimension of the structures.

Figure 2. The vacuum chamber cross section

II. LOSS PARAMETERS OF ELEMENTS

The loss parameters of elements are estimated with the simulation with MAFIA T2/T3. The loss parameters are related to the power lost at the elemnts and we can estimate the stregth of the heating of the elements by the beam.

The total loss parameters per turn are shown in the end of Table 3

The parasitic power loss in the elements is also calculated with these loss parameters and listed in Table 4.

With this values, the voltage loss of the stored electrons per turn are 1.98 MV, 0.88 MV and 0.42 MV for bunch length 3mm, 5mm and 10mm, respectively.

The r.m.s. bunch length is estimated to be 4mm ~ 5mm at low bunch current and with the natural energy spread. But the preliminary result of the tracking simulation with the impedance shown in Figure 2, the potential distortion caused by the inductance component of the impedance may lengthens the bunch to neary 10mm.

Table 1
Dimension of the structures in the vacuum chamber

	a	b	g	θ1	θ2
	[mm]	[mm]	[mm]	[deg]	[deg]
RF cavities	50	~250	220	90	90
weldments	20	22	0.5	90	90
flanges †	20	22	0.5	90	45
offsets	20	20.5	-	90	~0
BPMs	20	-			
ID sections	20	10	-	10	10
pumping slots	20	height×length is 2mm×5mm			
transitions at RF	20	50	-	10	10
absorbers at RF	50	35	-	10	10
bellows*,†	20	25	145	10	10
Slot to ante-chambers	20	slot height is 10mm~12mm and the depth is 3-4 × height			

* A bellows has a 1mm outward step at the top of the tapers.
† The bellows, the valves and the flanges have slots of width 0.5mm~1mm between their RF shielding fingers.

Table 2
Impedance of elements

	Num	total $\frac{Z_{//}}{n}$ [Ω]	
		Equations	MAFIA T2
RF cavities	32	$1.5\times10^5\ \frac{1+i}{n\sqrt{n}}$	$1.3\times10^5\ \frac{1+i}{n\sqrt{n}}$
weldments	2000	-0.005 i	-0.006 i
flanges	700	-0.005 i	-0.005 i
offsets	2700	-0.013 i	-0.019 i
BPMs †	300	-	360 / n
ID sections	40	-0.018 i	-0.014 i
pumping slots	6000	$-\frac{72}{n}\ i$	-
transitions at RF	4	-0.005 i	-0.005 i
absorbers at RF	12	-0.007 i	-0.003 i
bellows	400	-	-0.032 i
valves (transverse slit)	100	-0.004 i + 20 / n	-0.002 i
Slot to ante-chambers	200	$-\frac{86}{n}\ i$	-0.001 i *
resistive wall	-	$1.9\ \frac{(1-i)}{\sqrt{n}}$	-
synchrotron radiation	-	0.026	-

* This value is obtained with MAFIA T3.
† A BPM is modeled as transverse slit of gap 0.5mm wide

Table 3
Loss parameters of a single elements

	loss parameters [V/C]		
Bunch Length (rms)	3 mm	5 mm	10 mm
an RF cavity	8.07E+11	6.43E+11	4.82E+11
a weldment	5.02E+09	2.78E+08	1.88E+07
a flange	6.61E+08	8.09E+07	7.58E+06
an offset	2.81E+09	8.69E+08	1.21E+08
an ID section	8.46E+10	1.07E+10	1.26E+09
a transition at RF	8.57E+11	1.56E+11	1.16E+10
an absorber at RF	2.56E+11	1.22E+11	3.87E+10
bellows	6.83E+10	2.56E+10	3.07E+09
A valve	1.50E+10	6.04E+09	9.60E+08
a slot opening	9.65E+08	1.08E+08	1.88E+06
Total (One Turn)	8.28E+13	3.69E+13	1.77E+13

Table 4.
Parasitic Loss Power of a single elements
at the stored current of 5mA/bunch ¥ 20 bunch = 100 mA

	Parasitic Loss Power [W]		
Bunch Length[rms]	3 mm	5 mm	10 mm
an RF cavity	1.93E+03	1.54E+03	1.15E+03
a weldment	1.20E+01	6.66E-01	4.51E-02
a flange	1.58E+00	1.94E-01	1.81E-02
an offset	6.73E+00	2.08E+00	2.90E-01
an ID section	2.03E+02	2.56E+01	3.01E+00
a transition at RF	2.05E+03	3.74E+02	2.78E+01
an absorber at RF	6.13E+02	2.92E+02	9.28E+01
bellows	1.63E+02	6.14E+01	7.34E+00
valves	3.59E+01	1.45E+01	2.30E+00
a slot opening	2.31E+00	2.59E-01	4.50E-03

III. EFFECT OF OBSTACLES IN SLOTS AND ANTECHAMBERS

In the slots and the antechambers, there exist many structures such as absorbers and pumping systems such as NEG, pumping hole.

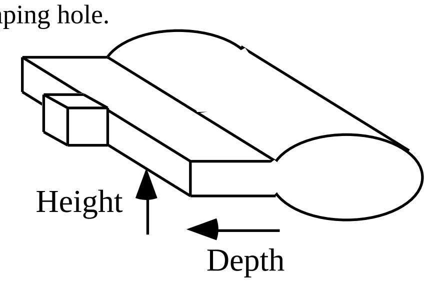

Figure 3. The structure used to estimate the effect in the obstacles in slot.

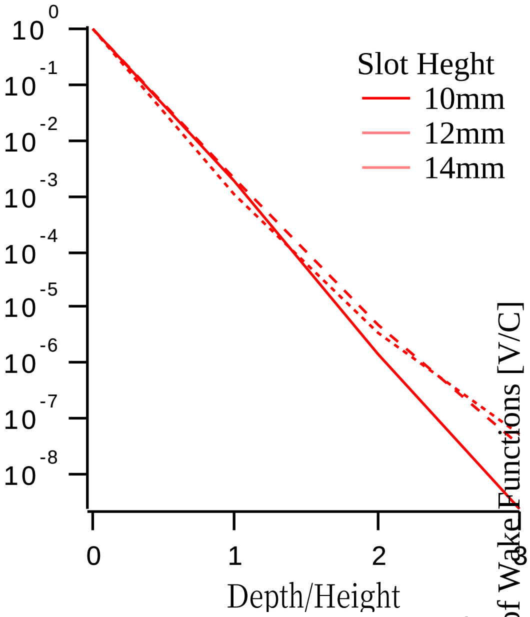

Figure 4. Wake Function vs. Depth / Height of the slot for different height(from ref. [3])

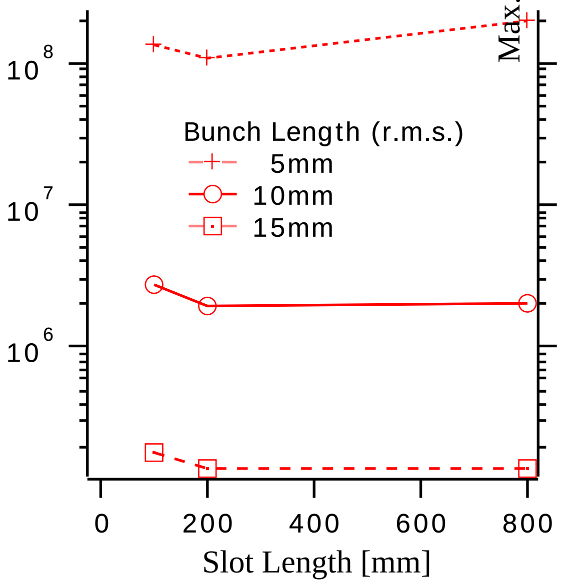

Figure 5. Wake Function vs.Slot Length

The effects of these obstacles in the slot and antechamber is estimated numerically with MAFIA T3[3]. The structures used in this simulation with MAFIA T3 are shown in Figure 3. The size of a test obstacle is a hole of 10mm long ¥10mm deep ¥ slot height 10mm~14mm opened to the end wall of the slot as show in Figure 3.

The effect of the opening of the slot to the beam chamber is estimated with MAFIA T3. The results for different length and depth of the slot are shown in Figure 5 and Figure 6. In them, the slot heght is 12mm.

The strength of the wake functions weekly depends on the length and the depth of the slot.

IV. CONCLUSION

The total impedance of the SPring-8 storage ring is estimated to be ~0.1 W for n = w / w ~ (c / s)/w ~ 2 ¥ 10^4 and with this value, we estimated that the bunch current of ~ 5mA / bunch can be stored with twice of the natural energy spread 1×10^{-3} for the microwave instability.

The numerical simulation shows that the obstacles in the antechamber do not affect the stored beam and that the slot opening slao small effect on the stored beam.

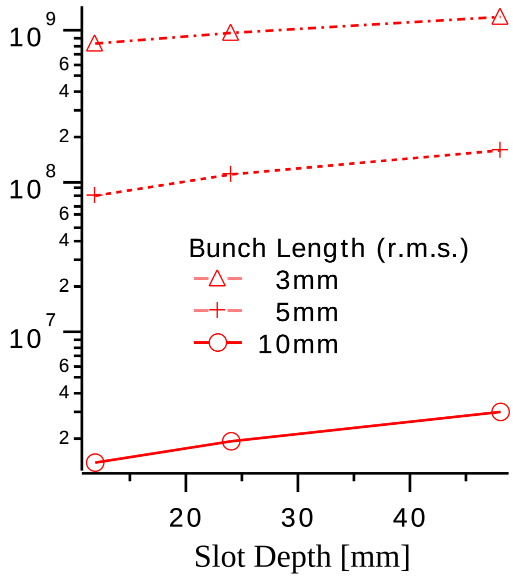

Figure 6. Wake Function vs..Slot Depth

ACKNOWLEDGMENT

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