Coupling Impedance Measurement of Pohang Light Source Storage Ring Vacuum Components

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Abstract

Loss factor measurements were carried out for various storage ring vacuum components using the synthetic pulse technique. The measurement was done for bunch lengths (σ_l) ranging from 7.1 to 30 mm. The measured devices were elliptical and circular photon masks, bellows with elliptical and circular cross sections, ellipse-to-diamond transition, ellipse-to-ellipse transition, beam position monitor chamber, and circular T-piece. Broadband impedances were obtained by fitting the measured loss factors to broadband resonator model. The total broadband impedance of 250 devices was 0.17 ohm, which is a small fraction of the total machine impedance budget as expected in the calculation.

1 INTRODUCTION

The Pohang Light Source(PLS) is a 2 GeV, third-generation synchrotron radiation source which was designed to produce ultraviolet and X-rays with critical photon energy of 2.8 keV.

In the case of the broadband impedance of the PLS ring, no detailed investigation had been performed before the present work. So far, broadband impedances were estimated based on over-simplified analytical formula and as a result a budget table for the PLS broadband impedance has been provided as shown in Table 1[1]. It was therefore needed to check out the validity of the analytical estimation and this motivates our work.

Loss factor defined as the energy loss by charge q per unit charge squared is

$$k(\sigma_t) = \frac{1}{q^2}\int_{-\infty}^{\infty} I(t)V(t)dt, \tag{1}$$

where $V(\tau)$, $I(\tau)$, q, and σ_t are bunch wake potential [V], current distribution [A], rms pulse length in time, respectively. The broadband impedance can be calculated from the loss factors using a broadband resonator model. When modeled as a parallel resonant circuit with small quality factor[2], the impedance of the resonator is

$$Z(\omega) = \frac{R_s}{1 + jQ(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega})}, \tag{2}$$

where R_s, ω_r, and Q are shunt impedance, resonant angular frequency, and quality factor, respectively. The quality factor is fixed to 1 in this study. The impedance and the loss factor for Gaussian pulse shape are related by[3]

$$k(\sigma_t) = \frac{1}{\pi}\int_{0}^{\infty} Z_R(\omega)e^{-\omega^2\sigma_t^2}d\omega, \tag{3}$$

where Z_R is the real part of $Z(\omega)$. The shunt impedance and the resonant frequency can be found by fitting the measured loss factors in Eq. (3). Then, the broadband impedance $|Z/n|$ is calculated from

$$\mid \frac{Z}{n} \mid = R_s\frac{\omega_0}{\omega_r}, \tag{4}$$

where ω_0 is the revolution angular frequency.

In this article, we describe the experimental setup of loss factor measurement by synthetic pulse technique and show measured results for various vacuum components and broadband impedance of the storage ring obtained by measuring the betatron tune shift as a function of beam current in single bunch operation.

Table 1: PLS Impedance budget

Item	Broadband Impedance $\mid Z/n \mid$
RF cavity (4)	0.7
Synchrotron radiation	0.16
Space charge	1.3×10^{-4}
Resistive wall	0.02
Steps and transitions	0.17
Bellows (shielded)	0.01
BPM chamber	0.015
Ceramic chamber coating	1×10^{-4}
Other components and safety margin	1.0
Total	~ 2

2 EXPERIMENTAL ARRANGEMENT

Loss factor can be measured either by the real pulse technique [4] or by the synthetic pulse technique[5]. The latter is used in this study, in which frequency domain data are converted to the synthetic pulse by the inverse Fourier transformation with Hamming window.

The whole measurement system is shown in Fig. 1. The measurement system consists of APC-7 connectors, space ducts, transitions between them, the device-under-test(DUT), and the reference(REF). The REF was an extension from one space duct to another to be used in place

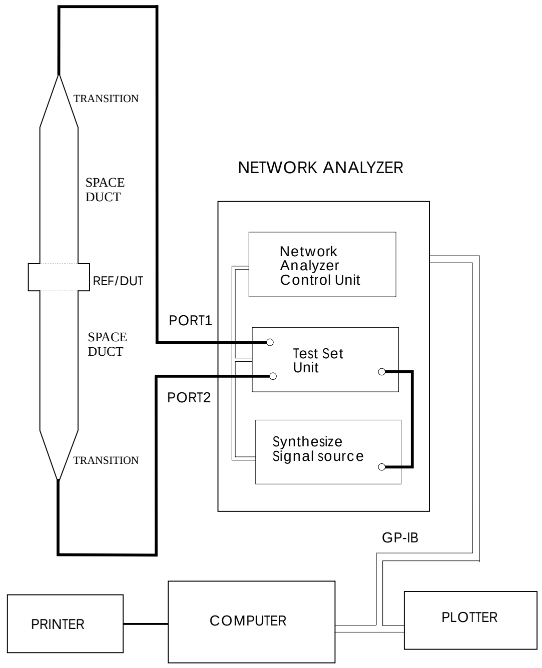

Figure 1: A layout of the loss factor measurement system

of the DUT. A copper tube with 3 mm in diameter was used as the center conductor. The length of the space duct was selected as approximately 1.5 times the length of the DUT to remove the effect of multiple reflections in time domain gating method. The measurement system was set up vertically to prevent center conductor from sagging. A good repeatability was achieved by APC-7 connectors, semi-rigid cable, fine machining, and careful treatment of the center conductor. Also, the tension of the center conductor was carefully adjusted to almost be constant during the measurement.

Equation (1) is arranged to calculate the loss factor from the measured current pulse as

$$k(\sigma_t) = \frac{2Z_0}{q^2}\int_{-\infty}^{\infty} I_0(t)\Delta I(t)dt, \qquad (5)$$

where Z_0 is the characteristic impedance of the coaxial line composed of REF and the center conductor, $\Delta I(t) = I_0(t) - I_1(t)$ is the current difference, $I_0(t)$, $I_1(t)$ are the output current through the REF, and the DUT, respectively. The characteristic impedance was calculated analytically for circular and elliptical cross sections[6] and numerically for the diamond shape cross section using the MAFIA code[7].

Since it was difficult to make the REF and the DUT with exactly the same length, the measured $I_1(t)$ was time shifted to coincide rising edge with $I_0(t)$ as suggested by Izawa[8].

Total of 9 different DUTs, including two kinds of photon masks, three kinds of bellows, T-piece, beam position monitor(BPM) chamber, and two kinds of transition pieces were prepared for measurement.

The transverse ring impedance can be deduced from the measured betatron tune shift data assuming that the lowest head-tail mode is dominant in measuring current range. The transverse tune shift is expressed as [9]

$$\Delta Q_\perp = -\frac{e\bar{\beta}_\perp R}{4\sqrt{\pi}E\sigma_l} Z_\perp \Delta I_b, \qquad (6)$$

where e, $Z_\perp$, $\bar{\beta}_\perp$, R, E, and ΔI_b are the electron charge, the transverse coupling impedance, the average transverse betatron function, the average radius of the ring, the machine energy, and the variation of beam current, respectively. The broadband impedance of storage ring can be obtained from transverse impedance by Panofsky-Wenzel theorem

$$Z_\perp = \frac{R}{b_\perp^2}\left|\frac{Z}{n}\right| \qquad (7)$$

where $b_\perp$ is the length of the transverse axis of the vacuum chamber and $|Z/n|$ is the broadband impedance of the ring.

3 RESULTS AND DISCUSSION

DUTs with different shapes of cross section for the input and output ports were measured by connecting two of them in cascade where the end with smaller cross section of two same DUTs were connected together to eliminate the possible resonance effect. The loss factors for the nine DUTs are shown in Fig. 2.

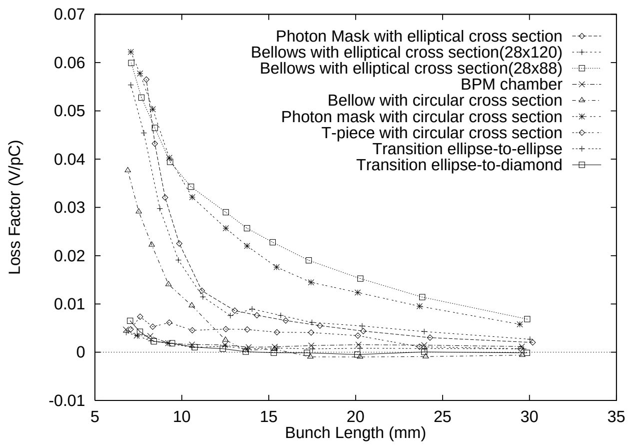

Figure 2: Loss factors for all nine various vacuum components used as DUTs in our measurements. Note that photon masks and bellows are showing relatively higher values.

The BPM chamber, circular T-piece with longitudinal pumping slots, and two kinds of transitions pieces show small loss factors as expected since they all have small longitudinal variations. In the contrary the photon masks and the bellows show the higher loss factors, and the result suggests that it might be better to make the photon mask longer if space is permitted.

The broadband impedance are calculated from Eq. (4) after some numerical manipulations. In Table 2, the calculated broadband impedances are listed as well as the total number installed around the PLS storage ring. It should be noted that the absolute value of the the broadband impedance below $5 \times 10^{-4}\,\Omega$ is not significant and that for transition, BPM chamber and circular bellows, the measured impedance is very low below the significant level. The order in magnitude of the calculated impedances generally agrees well with that of measured loss factors, except for the case of the ellipse-to-diamond transition.

The total accumulated broadband impedance for nine sort of chambers installed in the PLS storage ring turned out to be 0.17 ohm. The rest part of the ring consists of the main vacuum chambers, kicker ceramic chambers and RF cavities. Comparing values in the Table 1 and 2, for transitions, bellows and BPM chamber, somewhat large discrepancies are observed between measurements and calculations. However, the share of the total impedance by these components is small enough in both cases. Even though no measurement has been made for the rest of ring components, it is easily assumed that the main vacuum chamber with ante-chamber configuration has small impedance[10] as well as the ceramic coated chamber as seen in Table 1 and obviously the straight section chamber. It is also obvious that from both measurement and calculation the RF cavities are the major source of the ring impedance.

The measured ring impedance was 1.3 ohm at the worst case. Even though the measured broadband impedance of the ring has quite large uncertainty due to the impurity in the single bunch and the bunch length, the result confirms that the broadband impedance is within the impedace budget.

4 CONCLUSIONS

Loss factors for various vacuum components used in the PLS storage ring were measured by synthetic pulse technique. As expected, the devices with small longitudinal variations showed very small loss factors. The photon masks and the bellows showed higher loss factors suggesting that the photon mask could have been made longer if the machine geometry permitted. The total broadband impedance calculated from the loss factors for total of 250 components was 0.17 ohm. This is a small fraction of the total impedance budget of 2 ohm set by the simplified calculation with some safety margin. The broadband impedance of the ring is estimated 1.3 ohm at the worst case.

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Table 2: Broadband impedance, total number used and total impedance

Device	Total number used	Broadband impedance	Total impedance
Photon mask with elliptical cross sections	12	2.25E-3	2.7E-2
Bellows with elliptical cross sections (28×88)	36	2.0E-3	7.2E-2
Bellows with elliptical cross sections (28×120)	12	1.0E-3	1.2E-2
Transition (ellipse-to-ellipse)	24	1.15E-4	2.76E-3
Transition (ellipse-to-diamond)	48	1.39E-4	6.67E-3
BPM chamber	108	4.1E-4	4.43E-2
T-Piece with (pumping port)	2	2.55E-4	5.1E-4
Photon mask with circular cross sections	2	1.3E-3	2.6E-3
Bellows with circular cross sections	6	8.4E-4	5.04E-3
		Total	0.17 Ω

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