Preliminary Study on SRRC Storage Ring Impedance

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Abstract— A preliminary measurement of the ring broadband impedance was taken for the 1.3 GeV storage ring at SRRC in this study. Some interesting phenomena, e.g. vacuum deterioration and single bunch impurity, were observed. The vertical betatron tune shift was measured as a function of the beam current up to 40 mA in the single bunch mode to deduce the effective longitudinal ring broadband impedance $|Z/n|_{eff}$. The value of the effective ring broadband impedance was obtained as 2 ± 1 Ω for the present status of the SRRC storage ring. Further investigation involving more refined measurement techniques is currently in progress.

I. INTRODUCTION

The impedance calculations and measurements taken for the 1.3 GeV storage ring at SRRC are reported in this study. The longitudinal ring broadband impedance, i.e., one of the basic design criteria to reflect the ring performance, is deduced from the vertical betatron tune shift measurement. The stored current in the single bunch mode is currently restricted to 40 mA, probably limited by the competition of non-maximized injected bunch current values with the short life time of a stored beam. A global deteriorated vacuum condition was observed to occur, after the circulating current had been held at about 35 mA via the assistance of continual electron beam injection. The reason for vacuum deterioration remains unclear and a detailed analysis is presently underway.

II. LOSS PARAMETER CALCULATION AND IMPEDANCE MODELLING

The wake field[1] is excited by the electromagnetic interaction of a bunch of charged particles circulating in the storage ring with its environment, such as cavities, bellows, screen monitors, beam position monitors, cavity adaptors, etc. The energy that the beam must lose in order to generate the wake field can be either quantified in terms of loss parameter in time domain or else interpreted by the coupling impedance in frequency domain. One of the most commonly used numerical tools employed for loss parameter calculation is the 2-D simulation program TBCI[2] as developed by T. Weiland. TBCI is a suitable program for the geometrical configuration of the DORIS I cavity. However, most of the ring components installed in the SRRC storage ring, e.g., the screen monitor (Fig. 1), have complicated 3-D structures which necessitate the use of 3-D simulation programs. In this study, the loss parameter assessment of such components was performed by adapting the 3-D numerical program T3/MAFIA (version 2.)[3] as developed by T.Weiland and provided to SRRC by the Mafia Collaboration (DESY, LANL and KFA).

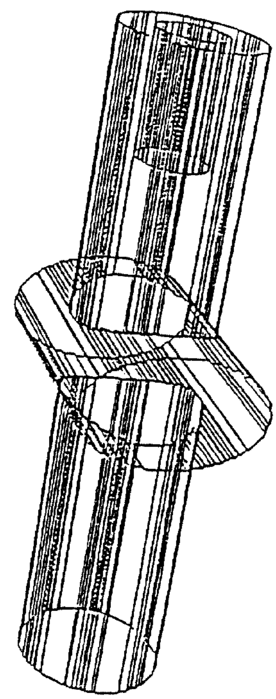

Figure 1: Numerical modelling of the SRRC screen monitor

The longitudinal coupling impedance of individual ring components is estimated by using broadband impedance model[4] and is expressed as

$$Z_{comp}(\omega) = \frac{R_s}{1 + jQ(\omega/\omega_r - \omega_r/\omega)}, \qquad (1)$$

where R_s is the longitudinal shunt impedance, ω_r the resonance angular frequency, and Q the quality factor. Numerical calculations are simplified in this study by affixing the value of quality factor Q as 1. The resonance angular frequency ω_r is estimated by angular cutoff frequency ω_c of an equivalent vacuum chamber with beam pipe radius $\overline{b}$. $\overline{b}$ is selected to be the average geometrical beam pipe radius of the elliptic vacuum chamber[5] installed in

Table 1: List of calculated longitudinal loss parameters with derived broadband impedances for some of the SRRC ring components. A Gaussian beam with 10 mm rms bunch length is assumed.

component	K[V/pc]	$\lvert\frac{Z_{comp}}{n}\rvert_o$ [Ω]
DORIS I cavities &		
cavity adaptors	1.0509	0.4781
screen monitors	7*0.2205	7*0.1003
cir. bellows	3*0.2074	3*0.0944

the SRRC storage ring. The vacuum chamber has an elliptic cross section with 38 mm vertical height ($2b_v$) and 80 mm horizontal width, and $\bar{b}$ is equal to 28.7 mm, i.e., $\omega_c = c/\bar{b} = 10.45 \times 10^9$ rad/s. The longitudinal coupling impedance of individual ring components $Z_{comp}(\omega)$ is related to the longitudinal loss parameter K[6] by

$$K(\sigma) = \frac{1}{\pi}\int_0^\infty \mathrm{Re}\,[Z_{comp}(\omega)]\, e^{-\omega^2\sigma^2} d\omega, \qquad (2)$$

where $\sigma_l = \sigma \cdot c$ is the standard deviation of the Gaussian bunch length and c is the light velocity.

The longitudinal broadband impedance of each ring component is defined by:

$$\left|\frac{Z_{comp}}{n}\right|_o = \lim_{\omega\to 0}\left|\frac{Z_{comp}}{\omega/\omega_o}\right| = R_s\left(\frac{\omega_o}{\omega_c}\right), \qquad (3)$$

where ω_o is the revolution angular frequency, and n the harmonic value of the fundamental angular revolution frequency.

The calculated results of some vacuum components are summarized in Table 1.

III. BETATRON TUNE SHIFT MEASUREMENT

The imaginary part of the transverse ring coupling impedance results in a betatron tune shift. The lowest head-tail mode is assumed here to be dominant for the betatron tune shift in our measurement current range. Under this assumption, the transverse ring coupling impedance can be deduced from the measured tune shift data[7] by

$$\Delta Q_v = -\frac{e \cdot \bar{\beta}_v \cdot R}{4\sqrt{\pi} \cdot E \cdot \sigma_l} \cdot Z_v \cdot \Delta I_b, \qquad (4)$$

where e is electron charge, Z_v the effective vertical ring coupling impedances, and $\bar{\beta}_v$ the averaged vertical betatron function. R is the ring average

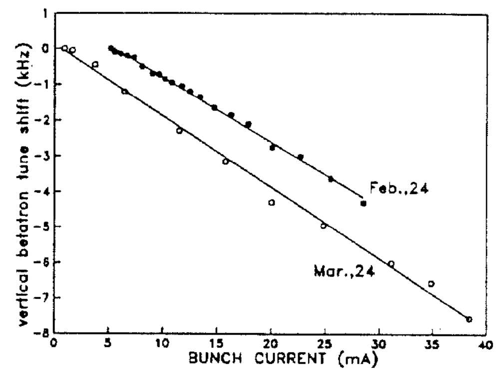

Figure 2: Vertical betatron tune shift as a function of beam current.

radius, E the machine energy, and ΔI_b the variation of beam current. The longitudinal ring broadband impedance is estimated from the knowledge of the transverse ring coupling impedance by using Panofsky-Wenzel formula[8]

$$Z_v \simeq \frac{2R}{b_v^2} \cdot \left|\frac{Z}{n}\right|_{eff},$$

here $\left|\frac{Z}{n}\right|_{eff}$ is effective ring broadband impedance, and b_v the length of minor axis of the vacuum chamber.

Vertical betatron tune shifts as a function of beam current in the single bunch mode were measured by HP Spectrum analyzer HP8544A at RF gap voltages $V_{RF,1}$=350 kV and $V_{RF,2}$=360 kV. Results obtained from the two independent measurements are illustrated in Figure 2. The measurement repeatability appears to be good. The vertical betatron tune shift for 40 mA bunch current variation is approximately 7.5 kHz.

A typical oscillation spectrum is shown in Figure 3. Two separated vertical betatron oscillation frequencies appear as the stored current rises to 10 mA, possibly resulting from the impurity of a single bunch. The bunch profile is observed by sampling optical oscilloscope HAMAMATSU OOS-01. The total bunch current in Figure 4 is 0.57 mA, and the RF gap voltage is at 208 kV. Two or more satellite bunches are generally present in the neighborhood of the main bunch. The weighting between main and satellite bunches varies to a large extent as dependent on such factors as the injection condition, etc. However, the effective bunch current for tune shift measurement is assumed here to be half of the stored current in the single bunch mode.

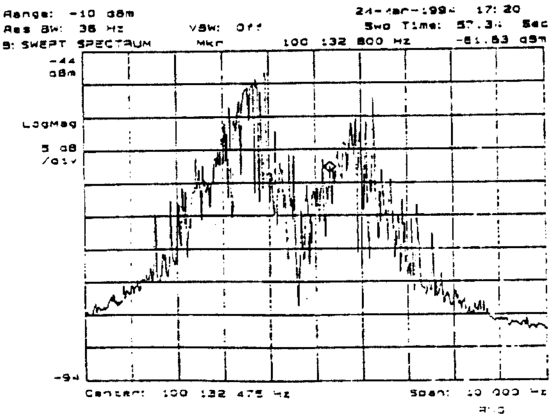

Figure 3: Vertical betatron oscillation spectra. The beam current was 38.5 mA.

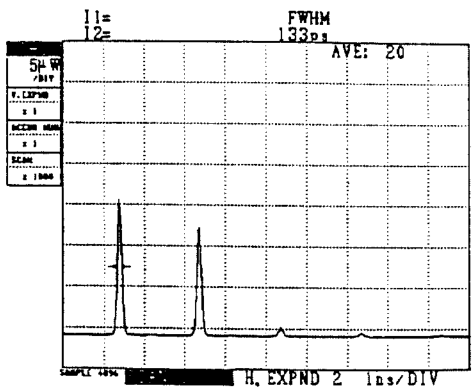

Figure 4: Impurity of single bunch.

To deduce the effective longitudinal ring broadband impedance, the nominal ring design parameters for SRRC storage ring are used: $\bar{\beta}_y$ = 5.78 m, f_o = 2.5 MHz, $2\pi R$ = 120 m, and E = 1.3 GeV. The value of the effective ring broadband impedance is obtained as 2±1 Ω for the present status of the SRRC storage ring. Further investigation involving more refined measurement techniques is currently in progress.

IV. CONCLUSION

The effective longitudinal ring broadband impedance of about 2 Ω was deduced in this preliminary study from the measured data of the vertical betatron tune shift as a function of current. The loss factors of some impedance contributing components of the SRRC storage ring were calculated by using either the 3D code MAFIA/T3 code or its 2D version TBCI. Next, the theoretical value of the longitudinal broadband impedance of individual vacuum components was derived by applying the calculated values to an equivalent resonance model. A comparison of the measured and calculated results indicated that the longitudinal ring broadband impedance could not be estimated only by a summation of the impedance contributions from the vacuum components listed in Table 1. More complete loss factor calculations for other major impedance contributing vacuum components of the SRRC storage ring would be required.

ACKNOWLEDGMENTS

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