RF IMPEDANCE MEASUREMENTS OF THE VARIOUS VACUUM CHAMBERS FOR THE ADVANCED PHOTON SOURCE (APS) *

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ABSTRACT

Coupling impedances (Z) for the 7-GeV APS storage ring have been numerically estimated [1]. In order to confirm these calculations, measurements of the coupling impedance of various vacuum components around the main storage ring was done with a synthetic pulse technique. A section of the beam + ante-chamber, a vacuum valve with and without the internal RF screen, and a photon absorber were used as a device under test (DUT) to obtain the preliminary results. The result in the frequency domain (FD) measurement was compared with previous time domain (TD) measurement and with the computer simulation of the APS impedance budget [2]. The Z or k dependence on the pulse length and the thickness of the center wire was examined.

I. INTRODUCTION

The coupling impedance must be kept small so that the desired operating current is achieved. A computational investigation has been carried out to estimate the coupling impedance of a large variety of structures in the APS ring. This was done mainly by W.Chou [2], using the 2D, 3D MAFIA codes and TBCI code. The results are summarized in Table 1 as the APS impedance budget. As seen, the largest longitudinal impedance is contributed by the RF cavities (even though the contribution of the fundamental mode has been subtracted from the calculation) and the transverse impedance is mainly contributed by the transitions between the beam chamber and the insertion device (ID) section. The longitudinal impedance and the transverse impedance are estimated to be 1Ω and $0.15 \text{ M}\Omega/\text{m}$, respectively.

The coupling impedance of the APS vacuum chamber components was measured with a coaxial wire method, using a synthetic pulse technique [3]. The measurements were done on a section of the beam- and ante-chamber, and a vacuum valve with and without the internal RF screen. A photon absorber is presently under test. The measurements will assist in the design of the various components of the storage ring, especially the type of the RF screen that will be used near the photon absorber.

II. LOSS PARAMETER AND IMPEDANCE

For a given beam bunch with charge, q , the energy loss of the bunch is

$$\Delta E = kq^2 = 2Z_0 c^2 \frac{\int I_1 (I_1 - I_2) dt}{(\int I_1 dt)^2} \text{ (eV)}, \quad (1)$$

where Z_0 is the characteristic impedance of the coaxial wire, I_1 is the current flowing through the reference chamber, and I_2 is the current flowing through the DUT (see Fig.1). Thus the longitudinal loss parameter can be measured by the integration of the current, which is also a function of the beam bunch length, σ . The coupling impedance, Z , can be derived from the wake potential of a beam bunch,

$$W_D(t) = - \frac{2Z_0 [I_1 - I_2]}{q} \text{ (V/pC)}. \quad (2)$$

Transforming eq.(2) into the FD gives the longitudinal impedance as;

$$Z(\omega) = 2Z_0 \frac{[I_1(\omega) - I_2(\omega)]}{I_1(\omega)} \text{ (}\Omega\text{)}. \quad (3)$$

III. EXPERIMENTAL SETUP

As depicted in Fig.1, a Network Analyzer (HP8510B) was used to measure the two-port S-parameters of the DUT. The frequency span is varied from 45 MHz to 18 GHz, depending on the appropriate synthetic pulse length, σ . An HP 9000/308 computer was used for data acquisition and the control of the system. The time domain option computes a synthetic pulse via the Fast Inverse-Fourier Transform (FFT) from the FD data. The temperature in the room was $74 \pm 2^\circ \text{F}$ to get a reliable signal from the DUT.

The test system consists of a piece of the APS beam chamber (50 cm long), the DUT (10 cm) and the transition portions (30 cm each). The transition portion is tapered at 10° to eliminate multiple reflections due to sharp discontinuities. The parameters in the test system and in the APS storage ring are summarized in Table 2. Three different types of center conductors were used: a 2 mm-brass wire, a 9.5 mm-Cu pipe, and an elliptical 50 Ω -matching Al rod.

In the impedance computation, the use of the transmission coefficient (S_{21}) instead of the reflection coefficient (S_{11}) reduces the error in $Z(\omega)$ because the multiple reflections must be considered for the S_{11} :

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TABLE 1 APS impedance budget.

Component	Number	Impedance	
		Z/n (Ω)	Z_l (M Ω /m)
1. RF Cavity (HOM)	15	0.2	0.02
2. Transition between chamber & ID section	34	0.03	0.06
3. Transition between chamber & rf section	3	0.1	0.003
4. Crotch absorber	160	0.01	0.002
5. Shielded bellows	160	0.04	0.007
6. Shielded transitions	80	0.02	0.003
7. Flange full-penetration weldment	480	0.01	0.008
8. Elliptical tube weldment	80	1E-3	1E-3
9. Shielded end contact	80	1E-3	1E-3
10. Valve	80	0.01	0.01
11. Beam position monitor	360	0.02	
12. Transition between chamber w. & w/o ante chamber	120	3E-3	1E-3
13. Resistive wall		0.01	0.01
14. Space charge		1E-5	0.03
15. Others (kickers, bumpers, ion pump ports, etc.)		0.3	
Subtotal		1	0.15
Budget (subtotal X 2)		20	0.3 M Ω /m

Fig.3 The TD transform of the S21 of DUT: the top curve is the reference chamber, the middle is the RF-screened valve, the bottom is the regular valve.

Fig.1 Experimental setup.

Fig.2 The normalized impedance, $Z(\omega)/n$, of the isolation valve with the RF screen.

Frequency (GHz)	0-16	0-10	0-5	2-5
Bunch Length (σ , cm)	1.2	1.8	5.8	9.6
Bunch Length (σ , ps)	37.5	60	192	320
K (Valve w RF)	0.023		0.014	0.008
K (Valve wo RF)	0.123	0.059	0.042	0.039
K (Ante-chamber)	0.002		0.001	
Error in K	6E-04		3E-04	

Table 3. Loss parameters of the various DUTs in different frequency spans.

Fig.4 The loss parameter of the isolation valve, k , vs the bunch length, σ .

Table 2. Test system and APS storage ring parameters

Characteristic impedance of the center conductor,	$Z_0 = 125, 88, 50 \Omega$
Sweep frequency,	$\Delta f = 45 \text{ MHz} \sim 18 \text{ GHz}$
Nominal energy,	$E = 7.0 \text{ GeV}$
Revolution Frequency,	$f_0 = 271.55 \text{ kHz}$
Beam chamber-cutoff freq.	$f_{\text{cut}} = 4.6 \text{ GHz}$
Bunch length, rms	$\sigma_{\text{rms}} = 5.3 \text{ mm}$
Bunch length, FWHM	$\sigma = 27.5 \text{ ps}$
Number of bunch,	$n_b = 20$
Bunch current,	$I_b = 5 \text{ mA}$

$$Z(\omega) = 2Z_0 \frac{[S_{21}(\text{ref}) - S_{21}(\text{DUT})]}{S_{21}(\text{ref})} \quad (\Omega) \quad (4)$$

In order to convert the data into the beam-impedance for a single bunch, the impedance, is normalized:

$$\underline{Z} = \frac{Z(\omega)}{n} \quad (\Omega), \quad (5)$$

where $n = \omega/2\pi f_0$ and f_0 is the revolution frequency of a beam in a storage ring. The total impedance can be obtained by multiplying k by the passage time between bunches in a storage ring, or

$$Z_{\text{tot}} = \frac{k}{n_b f_0} \quad (\Omega), \quad (6)$$

where n_b is the number of bunches in a storage ring.

IV. MEASUREMENTS AND RESULTS

The small section of the beam- and ante-chamber was measured to compare with the previous experiment in the TD [4]. Even though the error of k is as high as 30 %, the resolution is much improved. The TD measurement for the small k -values was repeatable only upto 0.002 V/pC because of the amplitude jitter in the real-time pulse [4]. In the FD measurement, the repeatability error was 6×10^{-4} V/pC in the 0-16 GHz span and the k -value was measured to be 2×10^{-3} V/pC (see Table 3).

For the large value of the k , There are no significant effects of the size of the center conductor. For the small k , the thickest center piece apparently gives more transmission rate (S_{21}), because it gives the exact 50- Ω matching in the DUT.

The typical result of the longitudinal impedance for the vacuum valve with the RF screen is plotted in Fig.2, using the eqns (4) and (5). Some resonant peaks at 2.3, 5.9, and 9.4 GHz are observed, but the Q values are low (≤ 20) so that the contribution to the overall impedance is small. The cause of these are not specifically known, but several possible candidates are obvious and they will be investigated.

The result transformed into the TD is shown in Fig.3, including the S_{21} for the valve with no RF screen. The top curve is for the reference chamber, the middle curve is the valve with the RF screen, and the bottom curve is without the RF screen.

Fig.4 shows the relation of k and σ (the bunch length). The bunch length is varied by changing the frequency span over which the data is recorded. The loss parameter (k) is higher for the shorter bunch and much larger for the valve w/o the RF screen. Table 3 summarizes all the loss parameter measurements.

V. CONCLUSION AND NEAR FUTURE PLAN

Several general conclusions can be made:

- The RF-screened valve has a factor of five improvement over a standard valve and the previous TD measurements with the real-time pulse were correct, but had too a low resolution for the small- k .
- Further measurements will be done on the photon absorber, the 352-MHz cavity, the insertion device, the transition section between various size vacuum pipes.
- It is also planned to determine the type of the RF screen on the photon absorber, the experiment on the aperture coupling is under way and the computer simulation was done [5].

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