THE IMPEDANCE DATABASE AND ITS APPLICATION TO THE APS STORAGE RING *

Yong-Chul Chae[†]
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 USA

Abstract

Since the operation of the APS storage ring, we have observed instabilities of different kinds. Some of them are not well understood and need further investigation; transverse saw-tooth instability and anomalous energy spread are examples. Quantitative understanding of these instabilities requires detailed knowledge of impedance of the ring. For this purpose we developed the concept of the impedance database, where the wake potential of each vacuum component in the ring is deposited and maintained in a standard form. These standardized wake-potentials can be manipulated with high flexibility by utilising the Self Describing Data Sets (SDDS) toolkit developed at Argonne National Laboratory. In this paper we will present the total impedance of the APS storage ring obtained by using the impedance database. Then we report the application of the total impedance to investigate the currently observed instabilities in the APS storage ring.

INTRODUCTION

In the development of the APS storage ring, the information of impedance had been estimated and collected as an Impedance Budget. This tabular data had been not only useful for characterizing the total impedance of the ring but also convenient because of its simplicity.

However, as we installed small-gap chambers for insertion devices (ID) in the ring, we observed that the single-bunch current reduced dramatically. The maximum current we could stably store in the ring is about 5 mA, limited by the mode-coupling instability in vertical plane [1,2,3]. In addition, we also observed saw-tooth excitation in the horizontal plane [2,3] and microwave instability in the longitudinal plane [4]. Understanding these instabilities required a more accurate estimate of the impedance over a broad frequency range because the bunch length in the APS storage ring is as short as 5 mm at low current.

Understanding and curing the instabilities so that we could improve the performance of the ring was the motivation to extend the idea of the Impedance Budget into an Impedance Database, where we collect the impedance function for all impedance elements installed in the ring. The impedance function was used in the simulation by tracking the multiple particles traversing the lattice magnets and impedance elements.

In subsequent sections we introduce the Impedance Database concept and then present highlights of the results including the total impedance of the ring and some of the simulation results. More complete results are presented in the companion papers [5,6,7].

IMPEDANCE DATABASE

Goal

The goal of the Impedance Database is an accurate estimation of the total impedance in the ring. In practice, since we usually obtain the impedance via wake potential, the goal could be expressed as:

$$W_{total} = \sum_{Element} N_i * W_i * \alpha_i ,$$

where

W_{total} = total wake-potential of the ring,
N_i = number of the element in the ring,
W_i = wake-potential of the element,
α_i = weight of the element.

This expression shows that the total wake potential of the ring is the weighted sum of the individual wake potential. A convenient choice of the weight for each element is the lattice function.

Then, the total impedance, Z_{total}, will be obtained via fast Fourier transform (FFT).

Method

We standardize the data format in order to combine and process the wake potentials obtained by the different methods. For this purpose we use the SDDS file format, which is column oriented, and data are accessed by name only for robustness. Standard wake potential requires at least four column data, which are the distance, s, and the wake potentials of three planes, Wx, Wy, and Wz.

We also adopted uniform simulation conditions for all impedance elements in order to assure the even quality for each simulation; those were:

1. bunch length=5 mm,
2. longitudinal mesh size=0.5 mm or smaller,
3. wake length of simulation=0.3 m or longer.

We desire short-bunch simulation because, the shorter the bunch length, the broader the valid frequency range of impedance. However, the numerical instability limits the mesh size depending on the bunch length and the wake length, which in turn is limited by the available computer resources. The above simulation conditions reflect a balancing act of desire and limitations.

We had used LINUX pc-clusters at APS, where we could perform 3-D MAFIA simulation up to 17 million

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[†] chae@aps.anl.gov

mesh points, which was enough to simulate the insertion device chambers for a bunch length of 5 mm.

We used the programs ABCI and MAFIA for calculation of wake potential. Both programs had been modified to be SDDS compliant so that their output is in SDDS format. The wake potential obtained for each impedance element was deposited in the designated directory within the APS computer network.

Since the Impedance Database should be available to all APS personnel, we developed a script to add and remove the impedance elements easily so that whoever has access to the Impedance Database directory can construct the total wake potential and its impedance at any time for his/her own use.

Results

We recently completed building the first phase of the Impedance Database for the storage ring. Some of the results and highlights are summarized here.

The Impedance Database includes ID chambers with 5 mm and 8 mm gap, rf sectors including rf cavities and chamber transitions, three types of beam position monitors installed at the regular chambers and ID chambers, six types of shielded bellows, five types of synchrotron radiation absorbers, flag chambers for the fluorescent screens, vertical scrapers, horizontal scrapers, and strip line monitors.

The Impedance Budget showing the contributions of each impedance element is shown in the Table 1. Impedance in the table is an absolute value at the low-frequency near origin. In the table we used an average value for an element having multiple types.

Table 1. Impedance Budget of the APS storage ring.

Name	**Qty**	**Z_x (kΩ/m)**	**Z_y (kΩ/m)**	**Z/n (Ω)**
Absorber	200	4.00E+01	4.00E+00	5.00E-03
Bellow	240	0.00E+00	4.80E+01	4.20E-02
BPM	400	6.40E+01	4.00E+01	2.00E-02
BPM-P05mm	2	8.00E+00	4.00E-01	1.00E-04
BPM-P08mm	22	4.40E+01	1.76E+01	1.10E-03
Flag Chamber	10	1.00E+01	1.50E+02	2.00E-02
ID-5mm	2	1.20E+00	2.20E+02	2.40E-03
ID-8mm	22	4.40E+00	6.16E+02	2.20E-02
RF-sector	4	5.20E+01	6.00E+01	2.00E-01
Scraper-H	2	1.50E+01	1.40E+01	3.20E-02
Scraper-V	2	3.20E+00	4.00E+01	7.50E-02
Strip line	4	8.00E-01	1.20E+00	6.00E-03
Total		**2.43E+02**	**1.21E+03**	**4.20E-01**

The major contributors to the total impedance were identified. The ID chambers dominate vertical impedance with 80% contribution, rf sectors and flag chambers containing fluorescent screens contribute 50% of longitudinal impedance, and the beam position monitors (BPM) and synchrotron radiation absorbers contribute the most to horizontal impedance.

The total impedance of the ring, which is the Fourier transform of the total wake potential divided by the bunch spectrum, is shown in Fig. 1. The result shown was obtained with the unit weight for every impedance element. Horizontal, vertical and longitudinal impedances of both real and imaginary parts are shown from top to bottom. For the longitudinal impedance, Z/n are presented, where n is the harmonic number.

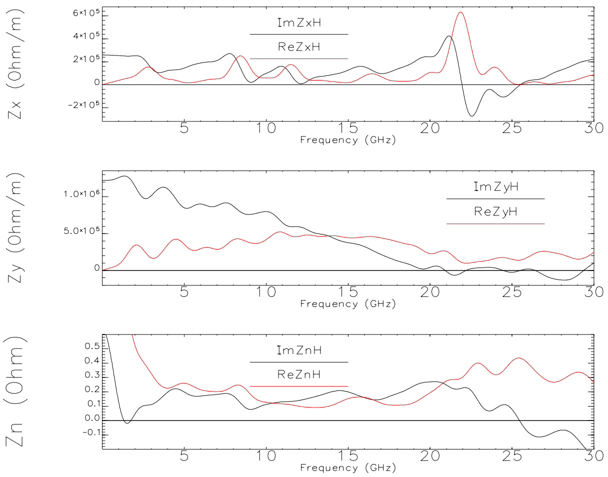

Figure 1: Total impedance of the ring.

We used a broadband resonator (BBR) model in order to parameterize the total impedance. The results are shown in Table 2. In the table, Z/n has two values; one is 0.22 Ohm without rf sector, and the other is 0.42 Ω, which includes 0.2 Ω from higher order modes (HOMs). This is discussed more in ref. 5.

Table 2: Broadband Resonator Model.

	R_s (Ω)	Q	f_r (GHz)
Zx	0.6e6	4.0	22
Zy	0.5e6	0.4	20
Z/n	0.22/0.42	2.0	25

APPLICATION

As the initial application of the Impedance Database, we carried out multiparticle tracking with a goal of reproducing the beam behaviors observed in the ring. The program elegant [8] was used for all tracking simulations, and some of the results are presented.

Longitudinal Phenomena

We observed microwave instability in the ring characterized by bunch lengthening, energy spread, and the coherent signal excitation at $4*f_s$ above the threshold current [4].

We used the 7.5 nm lattice whose natural bunch length is 20 ps, and natural energy spread is 1×10^{-3}. The 10,000 particles were initially loaded in the equilibrium phase space and then tracked 10,000 turns. After 2000 turns of initial transient, we took an average of 5000 turns. The average value of bunch length and energy spread together with standard deviation are shown in Fig. 2. The results in Fig. 2 are in good agreements with experiment [4], however, we had to increase the impedance in Fig. 1 by 80%.

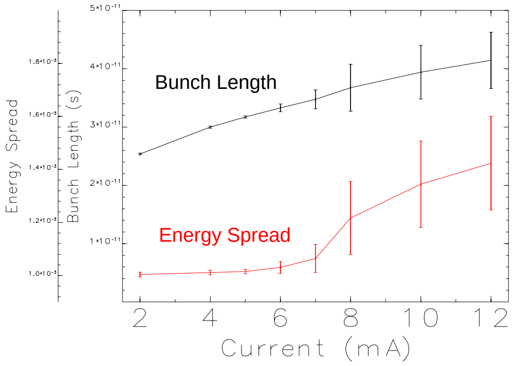

Figure 2: Bunch length and energy spread.

Vertical Phenomena

In the APS storage ring we observed mode-coupling instability in the vertical plane [2,3]. The observations include the modes couple at about 3 mA, the beam is vertically stable up to 5 mA, and we could accumulate a single bunch up to 8-10 mA.

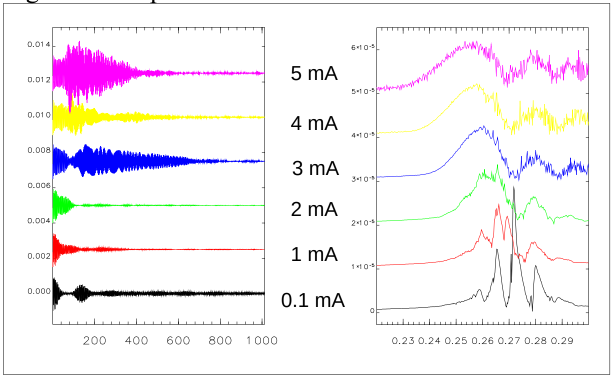

Figure 3: Turn-by-turn history of vertical beam center (left); its Fourier transform (right).

In the simulation we used a 7.5 nm lattice whose chromaticities were set to 4 and 7 in the horizontal and vertical planes, respectively. We used the BBR impedance with R_s=0.9 MΩ, Q=0.6, f_r=20 GHz. Compared with the most up-to-date parameters in Table 2, this resulted in a larger wake potential by 20%. We show the beam history and its Fourier transform of several currents in Fig. 3. We find that the beam centroids are stable up to 5 mA, the modes couples at 3 mA. In a companion paper [6], we show the beam size blowup after mode coupling, which could reduce the lifetime.

Horizontal Phenomena

In the horizontal plane, a saw-tooth instability was observed in the ring [2,3]. One of the characteristics was the sequence of stable, steady state, bursting, and steady state as the single bunch current increased.

The simulation study of this phenomenon is still in its infancy, but we made some progress to report. We found two types of impedance sources that could excite the bursting mode, namely, a narrowband source and a broadband source.

The resistive wall impedance was used as a narrowband source. The horizontal excitations of different currents are shown in Fig. 4. On the left are the traces excited by the narrowband impedance. As the current increases, the amplitude of bursting increases too. On the right are the traces excited by the broadband impedance, which is offset by 1 mm horizontally. Even though the bursting modes are not as clean as observed in the experiment or in the narrowband simulation, the characteristic mode changes are well reproduced.

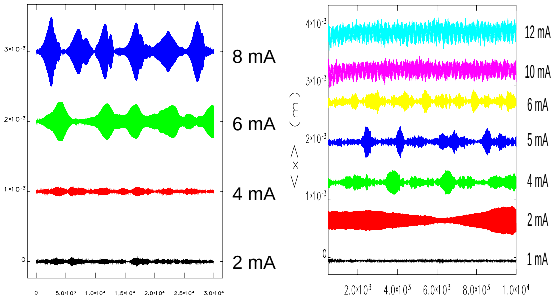

Figure 4. Turn-by-turn history of horizontal beam center excited by narrowband resistive-wall impedance (left) or by broadband impedance (right).

CONCLUSION

The Impedance Database was useful in constructing the total impedance of the ring. When it was applied to the APS storage ring, the initial simulation results showed good agreement with measurement, encouraging a more realistic simulation for the real machine.

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