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BEAM COUPLING IMPEDANCE STUDY AND ITS DATABASE OF SIAM PHOTON SOURCE STORAGE RING

N. Juntong*, T. Chanwattana, S. Jummunt, K. Kittimanapun, T. Pulampong, T. Phimsen, W. Promdee, Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand

Abstract

Since the Siam Photon Source (SPS) had an electron beam energy upgraded from 1.0 GeV to 1.2 GeV in 2005, the storage ring impedance measurements were done once in 2007. Two insertion magnet devices have been installed in the SPS storage ring during June to August 2013. There are several vacuum components added to the storage ring; these affect the ring impedance. Quantitative understanding of instabilities requires detailed knowledge of the impedance of the ring. For this purpose, the development of an impedance database is a necessity, where the wake potentials of each vacuum component are kept and maintained in a standard format. The self-describing data sets (SDDS) file format will be utilized to record components wake potentials. The wake potentials of each vacuum component can be obtained from a particle tracking simulation; a CST particle studio program will be used in the simulation process. The wake potentials can also be included in a beam dynamic tracking program such as ELEGANT to observe beam behaviours with these instabilities and find a curing means. The study results will be presented.

INTRODUCTION

The SPS storage ring has 81.3 m circumference. It accommodates different types of vacuum components such as beam position monitor (BPM), bellows, pumping ports, vacuum beam ducts, and radio frequency cavity. Group and number of components are summarized in Table 1. These components affect the stored beam inside the ring in term of longitudinal and transverse instabilities. These instabilities caused by the wakefield, a scattered electromagnetic fields induced by electron beam itself.

Integration of wakefield over the path of electron bunch will get wake potentials. Taking Fourier transform of wake potentials divided by a bunch charge spectrum will give a beam induced impedance of that vacuum component. Wake potential is sum of electromagnetic force of wakefield inside vacuum component acting on a bunch charge travels in z direction [1] as

$$\vec{W}(s) = \frac{1}{Q}\int_{-\infty}^{\infty}(\vec{E} + c\vec{e}_z \times \vec{B})_{t=(z'+s)/c}dz' \tag{1}$$

where Q is total charge of electron bunch, c is light velocity, $\vec{E}$, $\vec{B}$ is electric and magnetic fields of wakefield inside vacuum component, respectively.

Loss and kick factor can be calculated from wake potentials. Integration of wake potentials longitudinal component over bunch charge density will give a loss factor. With the same calculation on the transverse components will give a kick factor as

$$k_{\parallel} = \int_{-\infty}^{\infty} \rho(s) \cdot W_{\parallel}(s)ds \tag{2}$$

$$k_{\perp}(s) = \frac{1}{Q}\int_{-\infty}^{\infty} \rho(s) \cdot W_{\perp}(s)ds \tag{3}$$

where ρ is normalized bunch charge density, $W_{\parallel}$ and $W_{\perp}$ is a longitudinal and transverse components of wake potential, respectively.

Loss factor is a quantitative number of longitudinal effects to the beam of the wakefield. Longitudinal components can affect electron bunch such as the potential well bunch lengthening, bunch threshold current decreasing, and beam energy spread. In the same aspect, kick factor is a quantitative number to measure transverse effects to the beam of the transverse components of wakefield. It can cause a transverse beam instabilities or lead to a beam loss in a severe case.

Table 1: Vacuum Components in the SPS Storage Ring

Vacuum components	Number of components
BPM	26
Bellow	4
L42 bellow	12
L71 bellow	4
L72 bellow	4
VP1 upstream bellow	4
VP1 downstream bellow	4
VP1 pump port	4
Pump port - short	12
Short duct	8
L1000 duct	9
L1400 duct	12
Bump duct	3
RF cavity	1
Bending duct	8

WAKEFIELD SIMULATIONS

The wakefield and wake potentials of vacuum components can be obtained from electromagnetic field solvers in connection with particle tracking simulation. Wakefield module of CST Studio Suite ®will be used in the simulation process. The simulation will give wakefield, wake potentials, and impedances of the input geometry of each frequency in a study range. The longitudinal broadband impedance ($Z_{\parallel}/n$)

* nawin@slri.or.th

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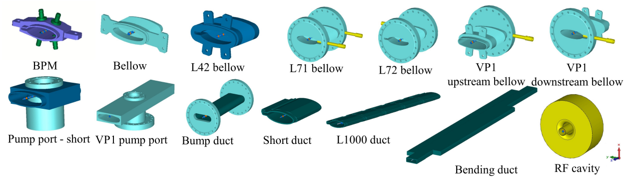

Figure 1: The 3G geometries of vacuum components of the SPS storage ring (not to scale).

can be obtained by a normalized integration of longitudinal impedance over a study frequency range [2] as

$$Z_{\parallel}/n = \frac{1}{f_{cut} - f_c} \cdot \int_{f_c}^{f_{cut}} Z_w(f) \frac{f_0}{f} df \qquad (4)$$

where Z_w is the simulation results of wake impedances, f_0 is the revolution frequency of electron beam inside the storage ring, f_c is the frequency at the minimum between the first and the second resonances, and f_{cut} is the maximum cut off frequency of the electron beam spectrum.

Wakefield from the beam induced electromagnetic fields inside vacuum components depends on materials and shapes of that components. Each of vacuum component has been 3D modelled in engineering software and then exported into file format that can be imported back in CST Studio Suite ® [3]. Examples are illustrated in Fig. 1. Materials of components should be defined properly together with mesh size and boundary conditions.

Simulation were performed using the present electron bunch length in storage ring. Gaussian distribution of beam is assumed with a beam sigma of 30 mm. This will give a maximum beam spectrum frequency of f_{cut} = 3.413 GHz. The longitudinal broadband impedance $Z_{\parallel}/n$ was obtained from simulated wake impedance $Z_w(f)$ with the Eq. 4 (taking $f_c = 0$), the loss factor values were directly calculated by the code. All simulations were performed for a 30 mm bunch and wake lengths s = 1000 mm. The revolution frequency of electron beam f_0 is 3.6875 MHz.

Impedance, loss factor and kick factor form simulation are summarized in group of components as listed in Table 2. The broadband longitudinal impedance of all vacuum components is 5.93 Ω. This results is different from 12.0 ± 4.2 Ω of the measurement done in 2007 [4] by using method described in [5]. Those measurements has a large variation and there were several improvements of vacuum components in the storage ring. There were also the installation of three insertion devices in the ring [6, 7]. These may cause the discrepancy of impedance values. The study indicated that bellows are main contribution to the impedance with 52 % and the pumping ports is the second contribution of 36 % as illustrated graphically in Fig. 2. This is similar to other light sources [8–12].

IMPEDANCE DATABASE

The wakefield impedance were exported to store in a self describing data sets (SDDS) format [13] to construct

Table 2: Impedance of Vacuum Components Groups of the SPS Storage Ring

Components Groups	$Z_{\parallel}/n$ (Ω)	$k_{\parallel}$ (V/pC)	k_x (V/pC)	k_y (V/pC)
BPMs	0.0312	2.62E-3	1.04E-2	3.01E-3
Bellows	3.2352	6.05E-1	2.29E-1	1.29E-1
Pump ports	2.1428	4.15E-1	9.60E-2	1.43E0
Beam ducts	0.0258	1.12E-2	2.77E-3	1.90E-3
RF cavities	0.3927	8.58E-2	2.20E-5	2.41E-4
Others	0.1017	4.26E-2	3.23E-3	1.72E-2
Total	5.9294	1.16E1	3.41E-1	1.59E0

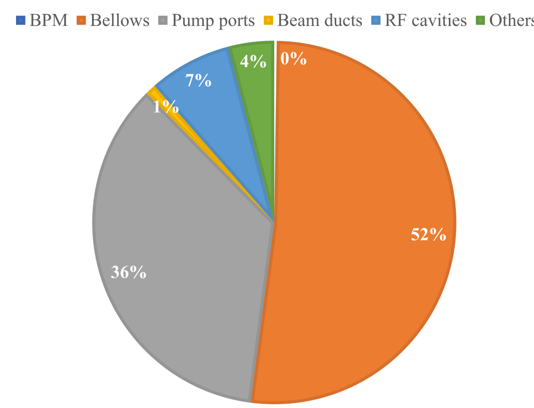

Figure 2: Contributions of vacuum components to the beam impedance of the SPS storage ring.

impedance database. This impedance database will be used with a particle tracking code, ELEGANT [14], to study effects to electron beam inside the storage ring.

Preliminary ELEGANT simulation results showed that the total impedance from the constructed database affects the longitudinal bunch length (σ_s) by factor of two. It also makes an energy spread (σ_δ) increase by 60 %. Results are shown in Fig. 3 and Fig. 4 for bunch length and energy spread, respectively. This illustrates that the constructed database can be called and used in ELEGANT. The total impedance of the ring has a strong effects to an electron beam inside the SPS storage ring. Means to reduce or to mitigate the impedance need to be studied and implemented.

CONCLUSION

The vacuum components of the SPS storage ring has been categorized into groups. The wakefield module in CST Studio Suite ®was used to simulate for the wakefield and wake impedance of each vacuum components. The longitudinal broadband impedance was calculated from the simulated wake impedances. The loss factor and kick factor were obtained directly from the simulation. Major contribution to the storage ring impedance is the bellows, while the pumping ports is ranked the second.

The wakefield and wake impedances were exported from simulations to construct the impedance database with the SDDS file format. ELEGANT code was used to study the

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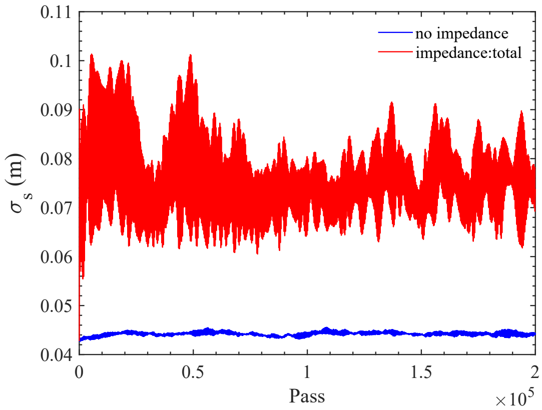

Figure 3: The impedance effects to an electron bunch length in the SPS storage ring.

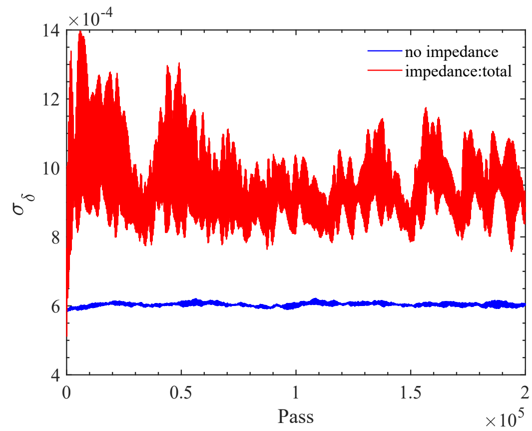

Figure 4: The impedance effects to an electron beam energy spread in the SPS storage ring.

impedance effects. Preliminary results shown that the total impedance makes an electron bunch lengthen by factor of two, and a 60 % increased in beam energy spread. In depth study is required to find means of reducing or mitigating this impedance effects. This remains a further investigation.

REFERENCES

[1] E. Gjonaj, T. Lau, T. Weiland and R. Wanzenberg, "Computation of short range wake field with PBCI", *ICFA Beam Dyn. Newslett.*, vol. 45, pp. 38–52, 2008.

[2] V. P. Androsov, P. I. Gladkikh, A. M. Gvozd, I. M. Karnaukhov and Y. N. Telegin, "Broadband impedance of the NESTOR storage ring", *Prob. Atomic Sci. Technol.*, vol. 3, pp. 60-67, 2011. `arXiv:1006.4846`

[3] CST Studio Suite, `https://www.cst.com/`

[4] P. Sudmuang and C. Kwankasem, "Measurement of the variation of the betatron tunes with the beam current", SLRI, Nakhon Ratchasima, Thailand, Note. NSRC-TN-2007/03, May 2007.

[5] A. W. Chao, *Physics of Collective Beam Instabilities in High Energy Accelerators*. New York, USA: Wiley, 1993, pp. 185–187.

[6] P. Sunwong *et al.*, "Commissioning and Operation of Superconducting Multipole Wiggler at Siam Photon Source", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 2398–2400. `doi:10.18429/JACoW-IPAC2021-TUPAB375`

[7] P. Sudmuang *et al.*, "Commisioning of the 2.4T Multipole Wiggler and the 6.5T Superconducting Wavelength Shifter at the SIAM Photon Source", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2014, pp. 1192–1194. `doi:10.18429/JACoW-IPAC2014-TUPRO068`

[8] Y.-C. Chae and Y. Wang, "Impedance Database II for the Advanced Photon Source Storage Ring", in *Proc. PAC'07*, Albuquerque, NM, USA, Jun. 2007, paper FRPMN104, pp. 4336–4338.

[9] Y.-C. Chae, "The Impedance Database and its Application to the APS Storage Ring", in *Proc. PAC'03*, Portland, OR, USA, May 2003, paper RPPB004, pp. 3017–3019.

[10] R. T. Dowd, M. J. Boland, G. LeBlanc, M. J. Spencer, and Y. E. Tan, "Impedance and Beam Stability Study at the Australian Synchrotron", in *Proc. EPAC'06*, Edinburgh, UK, Jun. 2006, paper THPCH031, pp. 2844–2846.

[11] A. Rusanov, "Preliminary Impedance Budget for the TPS Storage Ring", in *Proc. EPAC'08*, Genoa, Italy, Jun. 2008, paper TUPP025, pp. 1586–1588.

[12] A. Rusanov, "Impedance Study for the TPS Storage Ring", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper TUPD057, pp. 2060–2062.

[13] M. Borland, "A Self-Describing File Protocol for Simulation Integration and Shared Postprocessors", in *Proc. PAC'95*, Dallas, TX, USA, May 1995, paper WAE11, pp. 2184–2186.

[14] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation", in *Proc. ICAP2000*, Darmstadt, Germany, Sep. 2000, paper LS-287, pp. 1–11.