THE COLLECTIVE EFFECTS OF THE SHORT PULSED X-RAY (SPX) SYSTEM IN THE ADVANCED PHOTON SOURCE UPGRADE*

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Abstract

The Advanced Photon Source (APS) is a 7-GeV hard x-ray synchrotron light source. The APS Upgrade specifies a short-pulse x-ray (SPX) system as well as additional beamlines delivering higher brightness and flux. The SPX system will use S-band superconducting cavities. The performance of such a system based on the zero-current simulation is well established [1]. Here, we include the effect of wakefields generated by the SPX system. When the SPX system is off, we are interested in how much current we can store in the single bunch, because the SPX contributes significantly to the broadband impedance of the ring. With the SPX system on, we are interested in how much the vertical emittance will increase, which in turn will enlarge the x-ray pulse length.

INTRODUCTION

Collective effects related to the deflecting cavities can be separated into short- and long-range effects. The former act within a single bunch, whereas the latter act over one or more turns. Depending on the detailed resonant properties (i.e., frequencies and shunt impedance) of the cavities, there may or may not be an undesired beam oscillation known as coupled-bunch motion. Calculation methods can determine the safe range of cavity properties for an arbitrary bunch pattern against this instability. One only needs to specify the cavity resonant properties required for stability for all desired bunch patterns. This has been investigated using the methods described in [2] and found acceptable.

The single-bunch limit is determined by the sum total of all short-range wakefields produced in the storage ring vacuum-chamber components. The deflecting cavities and the pipes connecting them to the standard chamber thus contribute additional short-range wakefields. The goal is to make an accurate estimation of the impact of the SPX cavities on single-bunch properties, including the single-bunch current limit.

COMPUTATION OF WAKE POTENTIAL

The layout of the long-straight section where the SPX system will be installed is shown in Figure 1. The SPX system in the storage ring will have a short-range wakefield effect on the beam very much like other impedance sources. The system has two different impedance elements, namely, the SPX chamber, which includes the extrusion for insertion devices (IDs); a straight round pipe where the cavities would go; and three taper transitions and deflecting cavities. Compared to the standard long-straight section (LSS), the SPX will have extra transitions connecting the deflecting cavity pipe to the regular chamber.

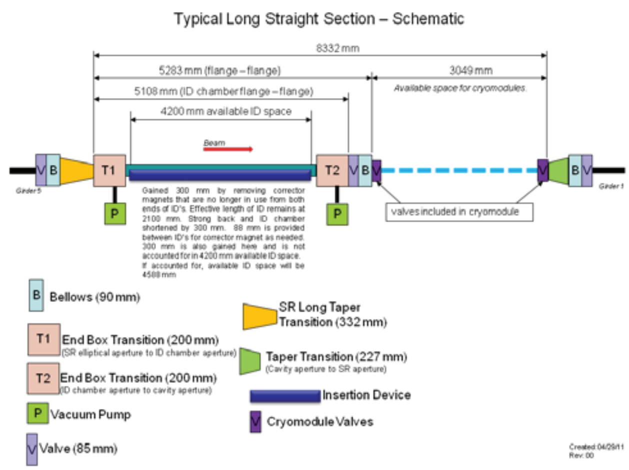

Figure 1: A long-straight section for the SPX system.

The detailed 3-D computation by GdfidL [3] shows that the vertical wake of the SPX chamber excited by a bunched beam is almost the same as for the LSS chamber, as shown in Figure 2.

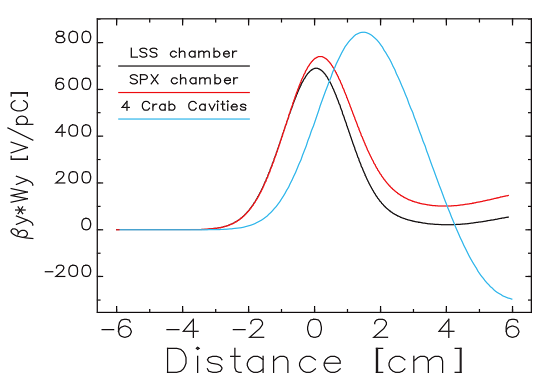

Figure 2: The vertical wake potential of eight deflecting cavities excited by a bunched beam with σ_z = 1 cm, compared with those of the LSS and SPX chambers.

The additional impedance source is the deflecting (or crab) cavity itself. Two cavity designs considered for the project are shown in Figure 3. The cavity in 3(b) has much improved de-Qing of dangerous HOMs compared to the cavity in 3(a). The cavity aperture is 50 mm, a compromise between the desire to minimize wakefields and maximize the effectiveness of waveguide HOM damping (motivating a larger aperture) and the desire to improve deflecting performance (motivating a smaller aperture). With this aperture choice, four cavities at each end of the SPX zone will be needed to generate 2 MV, for a total of eight cavities.

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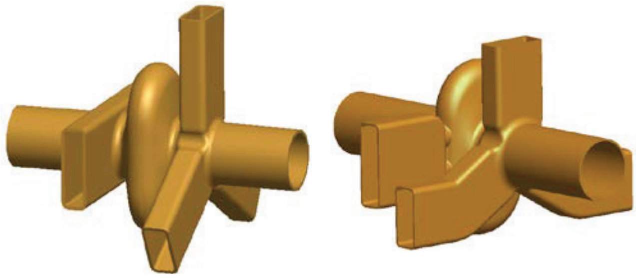

Figure 3: Models of superconducting deflecting cavities.

The vertical wake potential was computed by GdfidL modeling the cavity in 3(a). The result of a set of four cavities is compared with the SPX and LSS chambers in Figure 2, which shows that the cavity can significantly impact the vertical kick to the beam in the SPX zone in addition to the one from the SPX chamber.

IMPEDANCE EFFECT ON THE BEAM

Following the same simulation method used in establishing the APS impedance model [4, 5], 200,000 macro particles were tracked using ELEGANT [6] with the deflecting cavity impedance included. We compared the injection loss simulation with three different configurations: 1) ring without SPX cavities, 2) ring with two sets of four SPX cavities totaling 2 MV, and 3) ring with two sets of eight SPX cavities totaling 4 MV of deflecting voltage. The circles in Figure 4 indicate the accumulation limit of single bunch at the chromaticity set at 9 in both planes. Interestingly the more SPX cavities installed in the ring, the higher the accumulation limit, as shown in Figure 4, which is opposite to the result reported for the pulsed crab cavity [7].

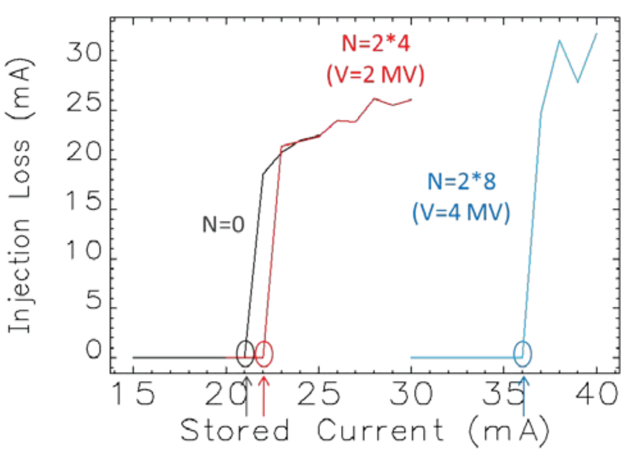

Figure 4: Injection loss simulation result, which determines the single-bunch current limit.

In the previous study [7], we investigated the effect of transverse impedance only. When the same method was applied to the SPX system, we observed a similar current reduction. However, as shown in Figure 5, with the full 3D impedance including the longitudinal impedance, we found that the bunch was lengthened, which reduces the peak current. As a result the transverse mode-coupling instability (TMCI) in the vertical plane was reduced in strength, leading to a small net increase in the single-bunch current for the 2-MV cavity system envisioned for the APS Upgrade. Thus, 16 mA can be delivered in a hybrid fill with the SPX system installed in the ring.

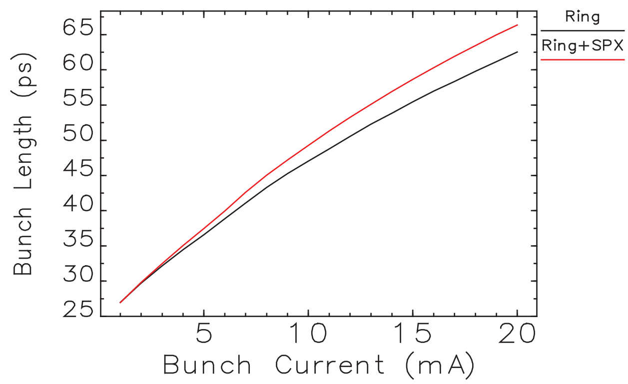

Figure 5: Bunch lengthening with and without deflecting cavities in the ring, assuming a total of eight deflecting cavities.

In the low-current regime below 6 mA, the increase in bunch length by deflecting cavities is not significant. This is compatible with the short-pulse operation of the SPX system in the 24-bunch mode, in which each bunch has 4-6 mA, below the microwave threshold.

Hence, the intensity of short pulses available in 24-bunch mode from SPX will not be affected much by collective effects introduced by the cavities. On the other hand, 16-mA operation in hybrid-fill mode may not be compatible with short-pulse x-ray operation because the coherent motion excited by the microwave instability will make it difficult to produce a precise chirp along the bunch. There are other challenges for SPX operation in hybrid mode, including the phase slew along the 56-bunch train. For these reasons, operation in hybrid mode is not contemplated.

In summary, with up to eight deflecting cavities installed in the ring, more than 16 mA can be stored in a single bunch. Hence, installation of the cavities will not jeopardize hybrid-mode operation. Collective effects with the presence of the cavities should not degrade SPX performance in 24-bunch operation at 150 mA.

Discussion of Bunch Lengthening

Because the deflecting cavities lengthen the bunch, they might be seen as having a helpful effect for other upgrades. For example, we might be able to make other changes in the ring that increase the transverse impedance, without jeopardizing the ability to achieve 16-mA single-bunch current. One obvious possibility would be inclusion of several in-vacuum undulators (IVUs). However, we have elected not to pursue this possibility, for three reasons. First, the lengthening is not significant for the eight cavities included in the upgrade. Only with a much larger number of cavities would an appreciable benefit be seen. This is illustrated in Figure 4. Second, we do not wish to link the success of one upgrade (insertion devices) to the implementation of another (SPX), since in principle the SPX component of the upgrade could be removed. Third, operation at higher single-bunch current would be a significant benefit to timing experiments, which are emphasized in the mission needs statement.

Hence, the upgrade mission would benefit from any improvement resulting from the combination of SPX installation and careful preservation of the transverse impedance.

EMITTANCE DEGRADATION DUE TO IMPEDANCE

The performance of deflecting cavities generating short x-ray pulses has been investigated based on the single-particle dynamics. However, collective effects occurring within these two sectors may alter the beam dynamics in all planes in a significant way.

The vertical betatron phase, for example, may need to be readjusted because the (small) transverse impedance will detune the phase advance somewhat depending on the charge and shape of bunched beam. Such consideration will make simulations more realistic.

A preliminary simulation of multiparticle dynamics was performed using ELEGANT with an emphasis on vertical emittance degradation. The transverse impedances were added in three stages to the otherwise magnet-only lattice with full linear and nonlinear elements for canonical tracking. At each stage the effect was assessed:

- Impedance of two sets of SPX cavities, each consisting of four deflecting cavities at Sectors 5 and 7. Each cavity impedance kicks the beam in both the x and y planes.
- In addition, chamber impedance of Sector 6 and Sector 7 between the SPX cavities, where the sector impedance was lumped at S6A:Q1 and S6B:Q1 for Sector 6 and at S7A:Q1 and S7B:Q1 for Sector 7.
- In addition, the chamber impedance of remaining sectors outside SPX, where the sector impedance was lumped at the center of each straight section.

Inside the SPX, the bunch will get an impedance kick proportional to the slice offset in the deflecting plane y. Outside the SPX there will be no impedance kick to the beam in an ideal machine because of the cancellation. However, if there will be any residual oscillation in the transverse plane, the emittance may be further degraded because of the impedance. In order to see such effects quantitatively, we tracked 30000 particles over 4000 turns following the same method described in [7]. The result was compared with the reference emittance, which was obtained over the 5000 turns without impedance; any increase in emittance then was attributed to the impedance effect.

We used the same lattice with 2-MV deflecting voltage. The current was 6.25 mA with 41-ps rms bunch length. For the simulation parameter consistent with the APS Upgrade, we could not resolve any impedance effect on the vertical emittance, as evidenced in Figure 6.

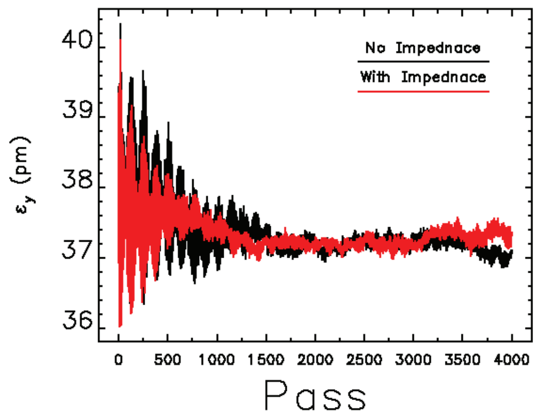

Figure 6: The vertical impedance measured at the straight section outside of SPX sectors with and without impedance effects.

In the work just reported, we did not include the effect of longitudinal impedance, which would require a nominal simulation condition of 200000 particles and 10000 turns, taking a week on a 100-core cluster. However, we believe that the self-consistent simulation is important in predicting the SPX performance, so we plan to continue these simulations using larger computing resources.

SUMMARY

The collective effect simulations for SPX were mainly developed in the context of instability modeling and are believed to give accurate predictions on single- and coupled-bunch effects. Usually, the study of collective effects stops here. However, for unconventional situations, such as the APS Upgrade with SPX, the performance-related simulation of emittance degradation is an important issue. For this purpose we will need to simulate the ring as closely as possible to the situation found in realistic operation, which will require large-scale computation on 1000s of cores.

REFERENCES

[1] M. Borland, Phys. Rev ST Accel. Beams **8**, 074001 (2005).

[2] L. Emery, Proc. PAC2007, p. 4348 (2007); http://www.JACoW.org.

[3] W. Bruns, Proc. LINAC2002, p. 418 (2007); http://www.JACoW.org.

[4] Y. Chae, ICFA Beam Dynamics Newsletter 45, (2008).

[5] Y. Chae and L. Morrison, WEPPR082, these proceedings.

[6] M. Borland, APS Light Source ANL/APS/LS-287 (2000).

[7] Y. Chae, G. Waldschmidt, V. Dolgashev, Proc. PAC2007, p. 4339 (2007); http://www.JACoW.org.

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