TOP-UP OPERATION AT SPRING-8 - TOWARDS MAXIMIZING THE POTENTIAL OF A 3RD GENERATION LIGHT SOURCE

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Abstract

Since 1999 we have been improving the SPring-8 accelerators aiming at "ideal top-up operation." The ideal operation demands not only steady stored current but also a stored beam oscillation-free and loss-free injection process and low impurity in a beam filling with isolated single-bunches. As a result of 6-years' R&D we have overcome all the difficulties. The top-up operation has been started at SPring-8 since May 20, 2004 after users confirmed that the beam injections do not disturb the experiments seriously. At the moment a prepared gate signal synchronizing to the beam injections is unused for any experiments. Here, we present our approach to and current status of the top-up operation at SPring-8 focusing on what we have devised.

INTRODUCTION

Recent performance improvements of synchrotron radiation (SR) sources make density of a bunched beam high. The high density shortens beam lifetime due to electron-electron scattering in the same bunched beam even in high-energy SR sources such as the 8-GeV storage ring. Thus, further low emittance or increment in bunch current is inconsistent with required long beam lifetime. The so-called top-up operation is a way to manage both the high beam density and the short beam lifetime. In top-up operation, continuous beam injections at short intervals keep the current approximately constant. The beam lifetime averaged over the period longer than the injection interval is, in a sense, equal to infinity. However, the beam injection is a transitional process and easily disturbs a pseudo-equilibrium state in the ring. Although the top-up operation has no intrinsic limit, it is difficult to attain the ideal operation without a remarkable disturbance for any experiments.

GOAL

Our goal is the ideal top-up operation satisfying the following conditions. Firstly beam injection never disturbs user experiments. The beam injection must not affect major characteristics of a photon beam and users can continue their experiments across the beam injections without any gate- signals. Secondly beam injection never causes injection beam loss at all. The loss-free injection is important to prevent field-degradation of in-vacuum insertion devices (IDs) with narrow gap-heights and hence for stable operation of the SR facility over a long time-span. Thirdly impurity in a beam filling with isolated single-bunches is kept under a sufficiently low-level over one operation period. Fourthly constancy of 0.1% or less in the stored beam current must be regularly achieved to keep thermal equilibrium of X-ray optics and remove ambiguity of the photon beam intensity.

APPROACH

To solve the four problems described in the previous section, we have taken the following approaches.

Suppression of Stored Beam Oscillation

The stored beam oscillation is mainly induced in a horizontal plane by leakage of the horizontal injection bump orbit. In the common case where sextupole magnets are located within the bump orbit, the condition for the bump closure depends on the amplitude of the bump due to the nonlinear kicks by the sextupole magnets. To reduce the bump leakage we used a minimal condition for emittance of the leakage in the lowest order of the nonlinear perturbation. This condition potentially reduces the leakage by about two order, down to a few tens micron [1].

To suppress the horizontal oscillation by field errors of the bump magnets, the waveforms of four bump magnet-fields were adjusted. We reduced eddy current in the end plates of the bump magnets by changing their material from stainless steel to glassmat laminated sheets and adjusted the impedance of bump magnets including power cables. We also adjusted the excitation timing of each bump magnet to synchronize four bump fields. A counter-field generated with a single correction pulse-magnet downstream of the injection point was used to correct the remaining oscillation. By all the above countermeasures,

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the horizontal oscillation finally reached to one-third of the horizontal beam size [2].

The vertical oscillation was suppressed by adjusting tilt errors of the bump magnets and suppressing the field leakage of septum magnets. The remaining oscillation was further suppressed with a correction pulse-magnet. The vertical oscillation was finally reduced to one-half of the vertical beam size [2]. Figure 1 shows the X-ray intensity reductions measured with a silicon photodiode in the photon beam line. The users confirmed that the effect of the remaining reduction on the experiments is negligible.

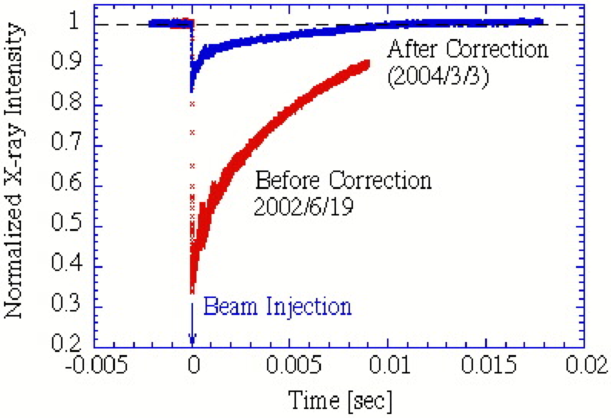

Figure 1: Reductions of X-ray intensity at the beam injection before and after the leakage suppression.

Suppression of Injection Beam Loss

Particle tracking revealed that amplitude reduction of the injection beam is effective for reducing the injection beam loss [3]. Since natural emittance of the booster synchrotron is large, being 230nm.rad, the horizontal rms size (3.4mm) of the injection beam is not negligibly small compared with the coherent injection amplitude (~10mm). To reduce the total amplitude we cut the lateral tail of the injection beam distribution by installing a collimation system composed of double scrapers upstream of a beam transport line from the booster synchrotron to the storage ring (SSBT). The two scrapers have an orthogonal phase relation in a horizontal betatron oscillation and can reduce the injection beam emittance [4]. The tail cut enables to bring the injection beam near to the septum wall and this further reduces the total amplitude.

The simulation also showed that low chromaticity-operation is effective for the reduction of the injection beam loss [3]. However, high chromaticity was necessary for suppressing various kinds of beam instabilities. At the end of 2003, both the horizontal and vertical chromaticities were +8 and these high operating chromaticities enhance the injection beam loss. To lower the chromaticities, a bunch-by-bunch feedback (BBF) system was developed, which is characterized by low signal noise, fast data processing with FPGA, stable 9-tap FIR filters, etc [5]. This BBF system assures the stable operation under the lower chromaticity value of +2. Combining the low chromaticity and the collimation system, the high injection efficiency of 80%~90% was achieved with all the ID gaps closed.

Formation of Purified Single Bunch

In order to inject a highly purified single bunch into the storage ring we have developed an RF-knock out (KO) system in the booster synchrotron [6]. The RF-KO system kicks out stray electrons found around the target bunch. Through tuning and stabilizing the timing of RF-KO signal, the RF-KO frequency, parameters of the RF acceleration system and the betatron tune, the impurity of 10^{-9} or less has been constantly achieved in the user operation [7].

In the 8-GeV storage ring, the radiation damping is strong due to the large radiation loss per turn and hence the diffusion path to nearby RF buckets is hardly formed in the longitudinal phase space. This is because the diffusible electrons having the large energy deviation are immediately lost due to the limitation of dynamic aperture or the physical aperture of the vacuum chamber. The impurity thus scarcely increases as far as the pure single bunch is injected into the ring.

Injector Upgrade for Constant Stored Current

To achieve the constant stored current with the variation of 0.1% or less, stability of the injectors, a 1GeV-linac and an 8GeV-booster synchrotron, have been improved. To stabilize shot-by-shot intensity of the beam injected into the storage ring, beam energy and current in the linac was stabilized by introducing an energy compression system, developing a new synchronous timing system [8], and improving the linac RF system for the RF power and phase stability [9]. Aiming at the top-up operation of two rings in the same site, the SPring-8 storage ring and NewSUBARU [10], a switching magnet in the beam transport line just downstream the linac was replaced by a lamination type magnet driven by a patterned current of 1Hz.

OPERATION RESULTS

Based on the experimental verification of the operation performance, the top-up operation of the SPring-8 storage ring has been started since May 20, 2004. Presently the beam is injected at 1- or 5-minute interval to keep the stored current at 99mA. The injection current for refilling is 30~40 μA. The temporal variation of the stored current is about 0.1%. Figure 2 shows the obtained current variation for six days from the start of the top-up operation. The large current drops seen in the figure were caused by the interruption of refilling for about 30 min to inject the beam into NewSUBARU. In this autumn fast switching of the injection path will be introduced to realize the flexible beam injection for the top-up operation of two rings and these drops will disappear.

To keep the filling pattern in the storage ring, we built the bunch current measurement system based on a fast oscilloscope with 20-GS/s. The bunch current distribution is measured after each beam injection to decide to which bunch and how much the beam is injected in the next. Presently it takes about 25-sec to measure the currents of 2436 bunches with the accuracy of 5%.

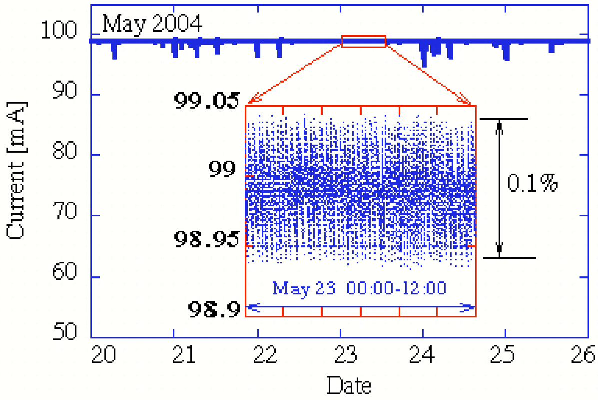

Figure 2: Variation of the stored beam current for six days. The variation for 12 hrs from 10:00 PM May 23 is magnified and shown in the center of the figure.

To monitor the injection beam loss during the top-up operation, beam charge monitors (BCMs) are installed downstream of the collimation system and upstream of the ring injection point. By using the BCMs and the DCCT in the booster and in the storage ring, the transmission charge through the SSBT, the total charge ejected from the booster and the charge increment in the ring are measured shot by shot with a synchronized measurement system. Figure 3 shows the statistics of the injection efficiency calculated with these data for one day. The injection efficiency goes beyond the present target of 80%.

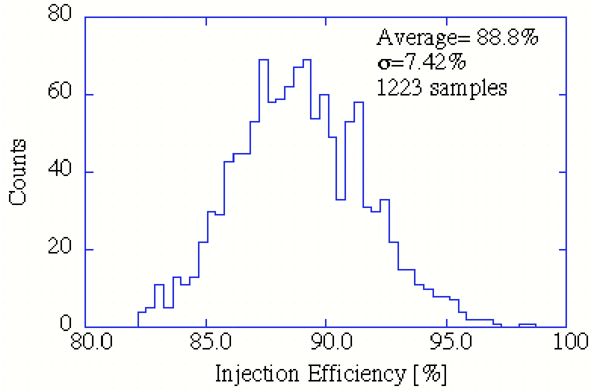

Figure 3: Injection efficiency statistics for one day

Growth of the impurity during the top-up operation was measured by a photon counting system with fast light shutters [11]. Figure 4 shows the ratio of the number of electrons in the bucket adjacent to the target bucket on the trailing time side to that in the target bucket. Here, background noise was assumed to be zero and the error bar shows a statistical error in the measurement. We saw that the impurity increased up to 2×10^{-9} for one week operation. Since the target bunch current was 1.5 mA, corresponding to 4.5×10^{10} electrons, we found that the number of electrons in the adjacent bucket increased from 40 to 90 in one week. In this period, the number of beam injections into the target bucket was 500. The averaged impurity of the injection single bunches is 1×10^{-10}, which is a sufficient level.

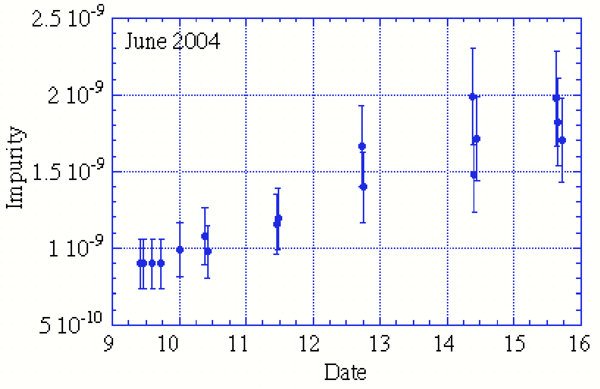

Figure 4: Variation of impurity during the top-up operation

CONCLUSION

The top-up operation of the SPring-8 storage ring has been started achieving the target performances required by the experimental users. This operation is expected to contribute to further innovative experiments in SPring-8.

REFERENCES

[1] H. Tanaka et al., submitted to PRE.
[2] T. Ohshima et al., “Suppression of Stored Beam Oscillation Excited by Beam Injection,” these proceedings.
[3] M. Takao et al., “Injection Beam Loss at the SPring-8 Storage Ring,” these proceedings.
[4] K. Fukami et al., “Beam Collimation System for the SPring-8 Top-up Operation,” presented at APAC'04, 22 to 26 Mar., Gyeongju, Korea.
[5] T. Nakamura et al., “Transverse Bunch-by-bunch Feedback System for the SPring-8 Storage Ring,” these proceedings.
[6] H. Suzuki et al., Nucl. Instr. and Meth. A, **444** (2000) 515-533.
[7] T. Aoki et al., PAC’03, Portland, May 2003, p. 2551.
[8] T. Asaka et al., Nucl. Instr. and Meth. A, **516** (2004) 249-269.
[9] S. Suzuki et al., “Improvements of SPring-8 Linac towards Top-up Operation,” these proceedings.
[10] A. Ando et al., J. Synch. Rad., 5 (1998) 342-344.
[11] K. Tamura et al., to be submitted elsewhere.