Multi-bunch injection for SSRF storage ring postprint

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Date: 2023-06-18T00:00:00+00:00

Abstract

The multi-bunch injection adopted at Shanghai Synchrotron Radiation Facility (SSRF) increases the injection rate greatly, with much less injection time than that of single bunch injection. It reduces massively the beam failure time during users' operation and prolongs the pulsed injection hardware lifetime. In this paper, the scheme to produce multi bunches for the RF electron gun is described. The filling result and beam orbit stability for top up operation is discussed.

Full Text

NUCLEAR SCIENCE AND TECHNIQUES 26, 050101 (2015)

Multi-bunch injection for SSRF storage ring

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(Received August 24, 2015; accepted in revised form September 9, 2015; published online October 20, 2015)

The multi-bunch injection scheme adopted at the Shanghai Synchrotron Radiation Facility (SSRF) substantially increases the injection rate, achieving significantly shorter injection times compared to single-bunch injection. This approach dramatically reduces beam failure time during user operations and extends the lifetime of pulsed injection hardware.

This paper describes the scheme for producing multi-bunches using an RF electron gun and discusses the filling performance and beam orbit stability during

top-up operation.

Keywords: Multi-bunch, Injection, Shanghai Synchrotron Radiation Facility (SSRF)

DOI: 10.13538/j.1001-8042/nst.26.050101

INTRODUCTION

Third-generation light sources serve as workhorses for X-ray science, with advanced facilities achieving beam availability times up to 98%. Considerable effort has been devoted to increasing mean time between failures (MTBF) and reducing mean downtime (MDT) to meet user requirements. An effective method for decreasing MDT is to increase the injection rate.

Table 1 summarizes the injection status of seven third-generation light sources. Six facilities employ single-bunch injection, which offers the advantage of highly uniform bunch charge during top-up operation—beneficial for beam orbit stability. When orbit stability approaches the sub-micron level, beam position monitors (BPMs) become sensitive to the filling pattern [1].

TABLE 1. Injection status of third-generation light sources [2–8]

Facilities	Injection mode	Booster repetition rate (Hz)
Diamond	Top-up, single bunch	10
Soleil	Top-up, single bunch	1
Spear 3	Top-up, single bunch	2
Spring8	Top-up, multi bunches	1
SSRF	Top-up, single bunch	2
APS	Top-up, single or trains	2
ESRF	Top-up, single bunch	10

The Shanghai Synchrotron Radiation Facility (SSRF) is an advanced third-generation light source featuring a 432 m circumference storage ring operating 3.5 GeV electron beam bunches with a natural emittance of 3.9 nm·rad. The injector consists of a 150 MeV linac and a 3.5 GeV booster operating at a repetition rate of 2 Hz. Single-bunch injection typically requires approximately 20 minutes to fill the storage ring from 0 mA to 240 mA, limited by the beam charge emitted from the RF gun cathode and the booster repetition rate. For top-up operation, filling 1 mA requires 15 seconds.

II. MULTI-BUNCH GENERATION FOR THE LINAC

To generate multi-bunches, the pulsed voltage of the grid cap has been extended from 3 ns to 12 ns using reflecting cables. This method is both simple and economical. The measured voltage pulse is shown in Fig. 1 [Figure 1: see original paper]. The stretched pulse creates a 12-ns long electron bunch from the electron gun. This long bunch is subsequently sent to a 500 MHz subharmonic buncher, where 5–6 bunches are formed with a bunch length of 300 ps at an energy of 10 MeV. The bunches are then accelerated to 157 MeV by the linac through four traveling wave tubes.

The energy divergence of the bunches is 0.74% (Fig. 2 [Figure 2: see original paper]). Although this is larger than the 0.5% achieved in single-bunch mode, the booster injection energy acceptance of 2.0% readily accommodates this energy divergence, ensuring high injection efficiency into the booster.

III. TOP-UP INJECTION EFFICIENCY AND BUNCH CHARGE UNIFORMITY

Injection efficiency from booster to storage ring is a critical parameter for dosimetry concerns. The interlock threshold for SSRF is 50%, below which top-up injection is halted. For multi-bunch injection, the situation is not significantly different from single-bunch injection. Energy deviations among bunches from the linac are fully damped during the booster energy ramping process. The quality of bunches extracted from the booster depends on booster conditions. The booster extraction kicker pulses and storage ring injection kicker pulses feature wide flat tops of approximately 125 ns, while the multi-bunches occupy only 10 ns in time duration. Consequently, the multi-bunches receive a uniform kick strength, ensuring injection efficiency equivalent to single-bunch injection. The measured top-up injection efficiency exceeds 85%, with a representative snapshot shown in Fig. 3 [Figure 3: see original paper].

Maintaining uniform bunch charge in multi-bunch injection mode presents greater challenges than in single-bunch mode, where the lowest-charge bucket can be identified using a bunch current monitor (BCM). However, since the top-up injection control system directs injected bunches to specific buckets, point-to-point filling is not feasible. Current filling methods include random shooting, sequential bucket injection, and targeting the lowest-charge bucket. The injected charge distribution for multi-bunches is shown in Fig. 4 [Figure 4: see original paper]. It is crucial to shift the top-up timing controller by 2 ns later to inject the highest-charged bunch into the target bucket with the lowest charge.

The bunch charge deviation for multi-bunch injection is 3.3%, as shown in Fig. 5(a) [Figure 5: see original paper]. Bunches at the two ends of bunch trains are excluded from this calculation as they are uncontrollable in multi-bunch injection and do not significantly affect BPMs. For comparison, the bunch charge deviation for single-bunch injection is 5.0% [9] (Fig. 5(b) [Figure 5: see original paper]). The improved charge deviation in multi-bunch injection results from the smaller charge of individual bunches compared to single-bunch injection.

IV. ORBIT STABILITY

BPM readings are sensitive to beam current and filling patterns. To provide stable photon beams to users, light sources implement top-up operation to maintain constant beam current and filling pattern. As demonstrated in Section III, the filling pattern remains constant during top-up operation, minimizing BPM noise from pattern variations.

The SSRF orbit feedback systems employ the SVD algorithm [10], also used at other light sources. At SSRF, not all SVD singular values are utilized, which enhances system stability. BPM reading errors from filling patterns are minimized through the methods described in Section III. The 24-hour orbit stability of the storage ring (measured at the end of a straight section) is shown in Fig. 7 [Figure 7: see original paper], with RMS values of 0.35 µm horizontally and 0.13 µm vertically. In comparison, single-bunch injection achieves 0.26 µm and 0.25 µm in the horizontal and vertical planes, respectively.

For multi-bunch injection, the injection rate can exceed 1.6 mA/s (Fig. 6 [Figure 6: see original paper]), compared to only 0.3 mA/s for single-bunch injection. The filling time to 240 mA is reduced from 20 minutes to 5 minutes. For top-up filling, single-bunch injection requires 15 seconds, while multi-bunch injection needs only 4 seconds (for top-up injection, the bunch charge is reduced by the focusing solenoid after the RF electron gun). Since local closed-bump injection orbit distortion is inevitable, shorter injection times are advantageous for user experiments.

V. CONCLUSION

The multi-bunch injection scheme implemented at SSRF substantially shortens injection time, thereby decreasing MDT and reducing the orbit distortion period during top-up operation. This approach undoubtedly extends the lifetime of the septum, kickers, and other pulsed injection components whose longevity is related to trigger frequency.

Orbit stability is crucial for light sources. The filling pattern must be carefully arranged in multi-bunch injection to maintain uniform bunch charge and minimize BPM noise. As most performance metrics of multi-bunch injection are comparable to or better than those of single-bunch injection, the scheme has been implemented for routine user operation.

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Note: Figure translations are in progress. See original paper for figures.