ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM061

SEXTUPOLE INJECTION AT TPS

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Abstract

The feasibility of performing sextupole injection at TPS (Taiwan Photon Source) storage ring has been demonstrated in this study with 300 mA stored electron beam. In order to carry out the experiment, a sextupole and its associated pulser were fabricated according to the specifications required. The sextupole was installed during a short break in September 2021 by making use of a ceramic unit located between kicker-3 and kicker-4. Moderate adjustment of the beam injection trajectory at the BTS (booster-to-storage ring) transfer line is needed so as to avoid beam scraping off at the injection septum. This study provides potential option of transparent injection for TPS users.

INTRODUCTION

A TPS sextupole injection trajectory has been theoretically analyzed previously and experimentally demonstrated using a couple of tuning knobs in the booster to storage ring (BTS) transfer line with minor adjustments [1]. These results were further explored by incorporating with a recently installed sextupole at injection straight section to test sextupole injection at TPS storage ring. A 300 mA stored beam was achieved. In this report, we summarize the related technical information and facts collected in the machine study shifts for possible improvement in the future whenever the sextupole injection scheme is taken into consideration. Although only few machine study shifts were made available for this study, the results indicate that the sextupole injection is doable at TPS. Electron beam accumulation at the storage ring can be readily obtained. This report concludes with a brief outline in terms of improving injection efficiency and reducing the observed stored beam orbit disturbance during beam injection.

BEAM TRAJECTORY OF SEXTUPOLE INJECTION

The schematic layout of the beam trajectory at injection straight section is given in Fig. 1. The newly installed sextupole kicks the injected electron beam onto the storage ring orbit.

THE SEXTUPOLE PULSER OF 1.6 MICROSECOND HALF_SINE BASED

The existing kicker pulsers were designed for multi-turns injection scheme with 5 μs half_sine based [2]. They do not fit into the sextupole injection requirement that the kick field shall turn off before the injected electron beam circulating the TPS storage ring for one turn of 1.7 μs. The remaining field strength of using a 5 μs half_sine based pulser will knock the circulating electron beam several times and causing beam loss, as illustrated in Fig. 2.

Comparison of the newly fabricated 1.7 μs pulser with the existing 5 μs pulser is shown in Fig. 3. Since the sextupole required drive current is much higher than the existing kicker pulser can provide, a test unit of oil-insulated pulser module is adopted so as to overcome the potential arcing issue observed at the test bench during the preparation period.

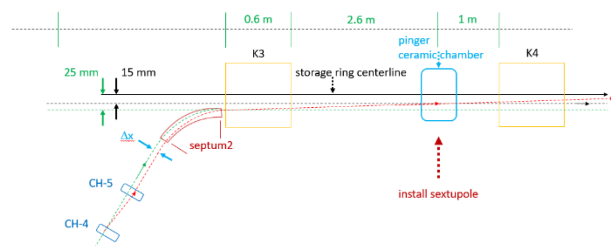

Figure 1: Applying a set of tuning knobs (CH-4, CH-5, septum2) at BTS transfer line for downstream sextupole injection. CH: horizontal corrector.

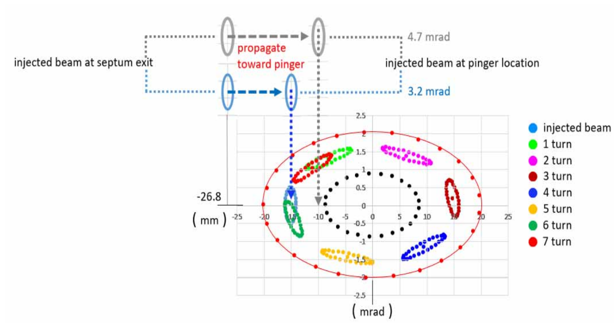

Figure 2: The calculated turn-by-turn phase-space illustration of the electron beam using sextupole injection.

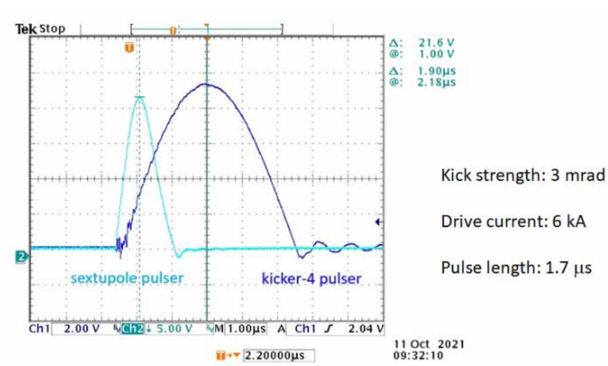

Figure 3: The half-sine base of the sextupole pulser is only one-third of that existing kicker pulser.

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14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM061

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EXPERIMENT

Preparation

Since the available machine study shifts were limited due to practical consideration of TPS operation, the sextupole injection experiment was carried out in few shifts. The complete experimental setup was done on the first run of the granted machine study shifts. At the beginning of the experiment, the trajectory of kicker-4 on-axis injection was reconfirmed by using previously saved operation (OP) file. Then, the sextupole was initiated and increased its drive current gradually while turning off the kicker-4. Tuning of the associated BTS knobs noted in Fig. 1 was exercised during this process as well in order to shift the BTS injection trajectory from kicker-4 to sextupole. In addition, sextupole strength was adjusted accordingly for optimization purpose. A 1.15 mA stored beam current was obtained before terminating this study shift due to the radiation ceiling limit, as shown in Fig. 4.

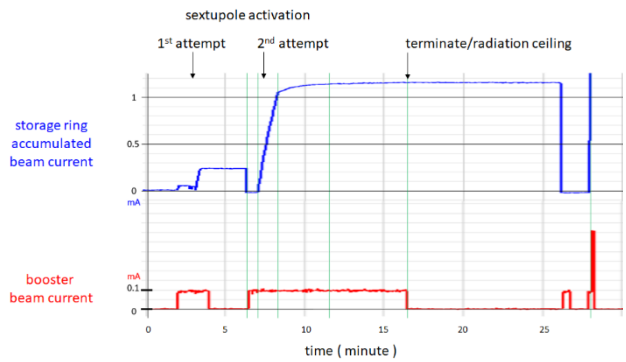

Figure 4: A 1.15 mA stored beam current was obtained after initiating the sextupole.

TPS 300 mA Stored Beam Current using Sextu-Pole Injection

In the follow up machine study shift, the sextupole injection process had brief pauses at stored beam current of 30, 60, 90, 120, 190, 235 mA to take turns for various trials. A 300 mA stored beam current was achieved before terminating the experiment, as shown in Fig. 5. The injection efficiency was about 20%. On the other hand, the routine-OP injection efficiency is usually better than 90%. The achieved 300 mA stored beam demonstrated that the sextupole injection at TPS storage ring is practically doable with limited tuning knobs required at BTS transfer line.

The Observed Filling Pattern

The observed filling pattern of the stored 300 mA beam current is given in Fig. 6 together with the filling pattern in routine user shifts using 4-kickers injection for comparison purpose. Since these two cases use the same routine injection menu of setting length of bunch train, the electrons loss at the leading edge and falling tail of bunch train is inevitable and yet improvable.

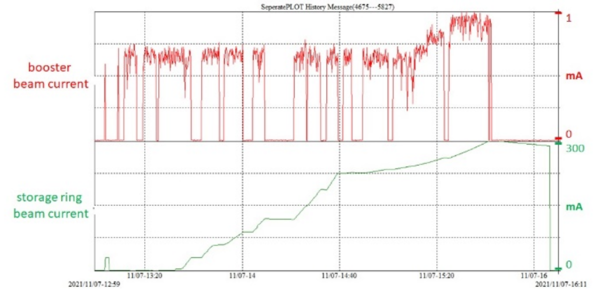

Figure 5: Storage ring beam accumulation in the sextupole injection experiment.

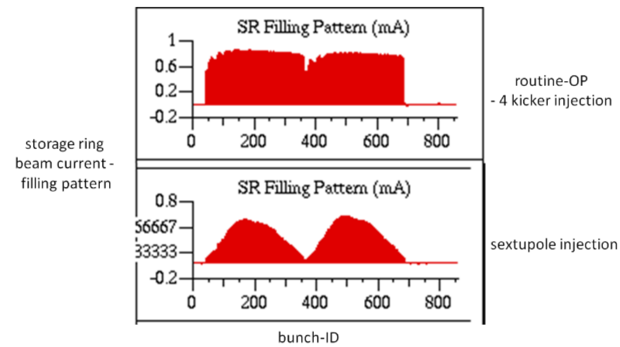

Figure 6: The stored beam filling pattern using (a) routine 4-kickers injection (500 mA); and (b) sextupole injection (300 mA).

DISCUSSION

Optimization of Injection Efficiency

A routine-OP injection file and filling pattern control package are usually used in routine user shift operation. As shown in the case of Fig. 7, it provides a controlled bunch train (300 bunches, 600 ns) at the booster. During the injection process, the booster bunch train switches to the next consecutive buckets, back and forth, based on the command signal provided by a storage ring current incremental monitor. A uniform bunch current distribution at the storage ring of two consecutive bunch trains is subsequently obtained.

The optimized 600 ns bunch train extends over 0.4% (peak-to-peak) kick strength variation in using 4-kickers routine injection process, as illustrated in Fig. 8. If one assumed that the 0.4% kick strength variation fits the injection allowance for both cases, only one-third of this preset bunch train could be kicked properly onto the storage ring acceptance while using sextupole injection. The rest of bunches would be lost in the injection process presumably. It is obvious that the injection efficiency would be greatly improved if the injection control package shorten the booster bunch train to one-third of its preset value. On the other hand, it will prolong the associated injection duration accordingly. One could possibly increase booster beam current to cope with this issue.

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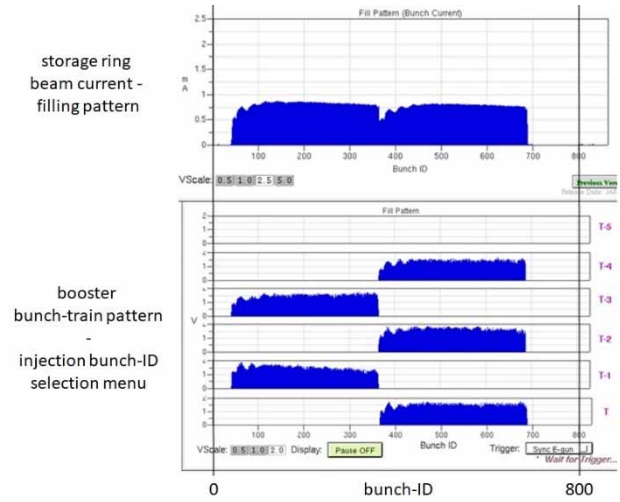

Figure 7: A typical 500 mA stored beam filling pattern in routine operation.

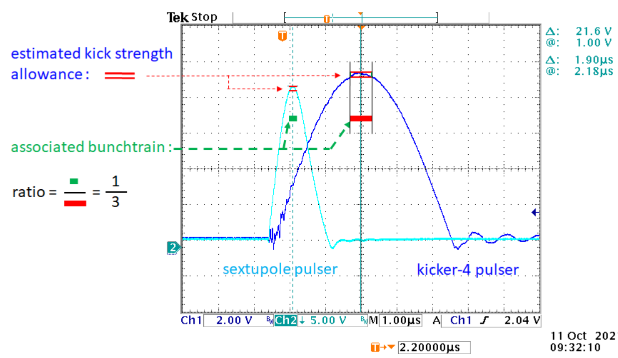

Figure 8: The 0.4% kick strength allowance is given by the ratio of = [(kick strength variation over the 600 ns bunch train)/(kicker peak field strength)].

As for the triangle shaped filling pattern given in Fig. 8 is concerned, one could examine its associated kick strength variation range of the sextupole pulser in Fig. 8. A 30% difference is obtained. This implies that the actual kick strength the electrons experienced spans over 3.2 mrad to 2.2 mrad. It matches well with the given acceptance illustrated in Fig. 2 that the required nominal kick strength of sextupole is 3.2 mrad. Notice that the acceptance gives x_{max} = ±20 mm and x'_{max} = ± 2 mrad, as shown in Fig. 2. The electrons along increasing bunch-ID, from 150 to 300 (and decreasing bunch-ID, from 150 to o as well), are lost in the injection proportionally and a triangle shaped filling pattern is observed.

Orbit disturbance during injection

In order to verify whether the sextupole injection does give less disturbance to the stored beam during injection, the injection pulsers of 4-kickers and sextupole were initialized alternatively with stored beam current of 500 mA. Their associated beam disturbance signals at selective beam position monitor (BPM) were recorded turn-by-turn. One would expect that using sextupole shall give zero disturbance to the 500 mA stored beam. However, the observed horizontal beam disturbance (BPM-X) of using sextupole does not vanish. Moreover, the observed disturbance (1 mm) is larger than that of using 4-kickers in routine user shifts (0.5 mm).

It is obvious that the routine orbit of 500 mA stored beam in user shift does not sit at the center of the sextupole. One could easily verify this sextupole character by applying local orbit bump technique at the injection straight section to steer the orbit horizontally such that minimization of beam disturbance can be readily obtained.

It is worth of noting that the sextupole inducing horizontal orbit disturbance of 1 mm would require an estimated 0.2 mrad net kick to produce. It implies that the routine orbit of 500 mA stored beam, in the case of Fig. 8, is sitting 1.4 mm sideway from the sextupole center [3].

SUMMARY

A sextupole has been fabricated and installed at TPS injection straight section to examine the feasibility of applying sextupole injection at TPS. The test result shows that a 300 mA stored beam is demonstrated with few available study shifts. Suggestions to improve poor injection efficiency are proposed. Methods to reduce the disturbance on the stored beam orbit using local bump technique is briefly described. Recently, the success of implementing a multipole injection kicker (MIK) to create a B_y-free region around kicker center so as to eliminate the beam disturbing source [4], and a proposed metal shielded kit on a conventional kicker [5] would certainly broaden the problem-solving aspects in this respect.

We note in conclusion that the sextupole injection at TPS storage ring is practically doable using sextupole located at 1 meter upstream of kicker-4. Later on, the sextupole can move to existing kicker-4 location such that the operational sextupole strength can be further reduced effectively.

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