EXPERIMENTAL TEST ON THE TPS BOOSTER INJECTION SCHEME EXPLORATION AND THE ASSOCIATED BUNCH TRAIN ANALYSIS

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Abstract

In order to explore the tuning range of injection septum and kicker for TPS booster operation, an experimental test on the designed injection scheme has been performed. Tuning of these injection units is based on the top-up operation process for storage ring vacuum cleaning purpose. It is set for a fast beam accumulation in the storage ring where the stored beam variation range is selected for efficient operation consideration. The measurement results of booster beam current variation while tuning of injection septum and kicker are presented. A preliminary analysis concerning the observation of deteriorated phase space acceptance in the TPS booster is given in this report. This study also includes an effort to extend the present available operation bunch train for TPS booster. It shows that the increase of the booster beam current by bunch train tuning indicates an upper bound of about 400 ns.

INTRODUCTION

TPS linac relocation and beam test of the LTB (linac to booster) transfer line for the TPS phase I commissioning had been reported [1]. It indicates that the beam transfer rate was limited partly due to the small entry/exit apertures of the LTB bending chamber, as shown on the upper chamber in Fig. 1. For the TPS phase II commissioning, the beam transfer efficiency of LTB has been reexamined after the bending chamber is rebuilt for a wider exit channel, as shown in the lower chamber in Fig. 1. It was installed in July 2015. The beam transfer ratio monitoring at the entrance and exit of the bending chamber has been improved from 0.85 to 1. The overall transfer efficiency given by the ICTs (integrated current transformer), located at the linac exit (ICT1) and at upstream of the booster injection septum (ICT2), is raised from 65~70% to about 85%, as illustrated in Fig. 2. In order to provide further improvement options for raising booster injection efficiency, the proper tuning of the injection units involved in the process are systematically examined. The experimental details are described in the following sections.

The designed beam injection scheme and its detailed geometric arrangement of septum and kicker are depicted in Fig. 3 for illustration purpose [2, 3]. The 150 MeV electron beam from the linac travels through LTB transfer line is injected on-axis to the booster beam centreline [4]. Since the tuning range exploration of the injection septum and kicker in this study involves horizontal plane only, therefore Fig. 3 shows only the corresponding horizontal phase space evolution of the injected electron beam at kicker location for the following discussion.

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Figure 1: The TPS LTB bending chambers are arranged in parallel for comparison purpose. The upper chamber was built with small entrance/exit apertures while the lower newly build chamber is equipped with wider entrance/exit channels.

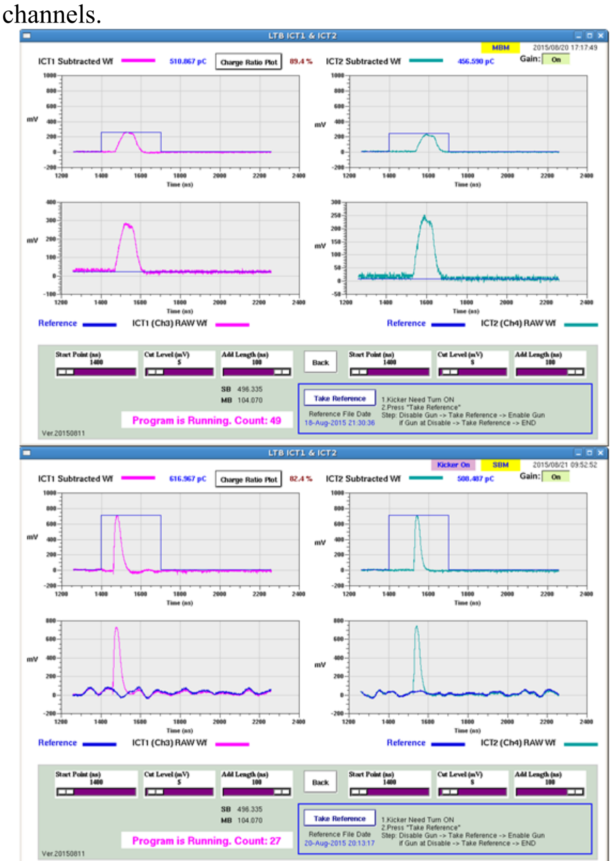

Figure 2: The transfer rate (ICT2/ICT1) of LTB has been improved up to ~85%. The upper one is the multi-bunch mode and the lower is the single-bunch mode.

It is worth of testing the operational injection scheme in order to compare with the calculated expectation [5]. A preliminary experimental test-run for this tuning range exploration has been carried out during a top-up operation for storage ring vacuum cleaning process. The measured results are presented in the following sections and a primitive analysis on the injection phase space acceptance is discussed. In addition, measurement on the available bunch train information is also briefly described.

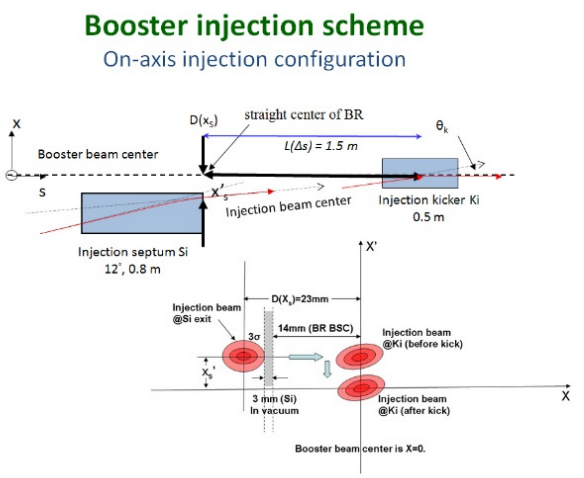

Figure 3: The LTB-to-booster beam injection scheme and its corresponding horizontal phase space evolution.

TUNING PRACTICE AND THE RESULTS

Exploring the tuning range of injection septum and kicker during top-up operation could only be performed effectively when the differential step of the stored beam current is large enough for this exercise. For the experiment carrying out at this particular top-up operation case, the stored beam current varies between 160 mA and 210 mA. The filling time for each beam accumulation step is about 2 minutes.

Tuning range of injection kicker

A quick check on the possible tuning range of the injection kicker has been performed during the said top-up operation. The beam current in the booster was monitored while varying the kicker strength with respect to the nominal setting. A typical measurement result is shown in Fig. 4. The available range given in the figure, i.e. ±2.5%, is taken at the FWHM (full width at half maximum) of the associated booster beam current. This indicates that the kicker strength variation of ±2.5% is acceptable at this particular routine top-up operation.

Injection septum tuning range

The tuning range of the injection septum has also been experimentally tested in a sequential manner at this top-up operation working point. It is worth of noting that the kicker tuning range at its corresponding septum setting reveals a drifting trend of the nominal kicker setting as the septum strength is varied. This implies the fact that varying the septum strength does not only change the bending angel of the electron beam but also its displacement at the septum exit. The beam on-axis injection kick has to respond accordingly for optimization purpose. The measured tuning range of the injection septum is shown in Fig. 5.

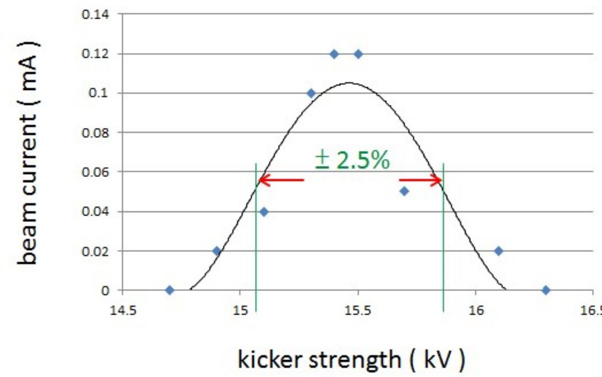

Figure 4: The tuning range of the injection kicker in a typical top-up operation.

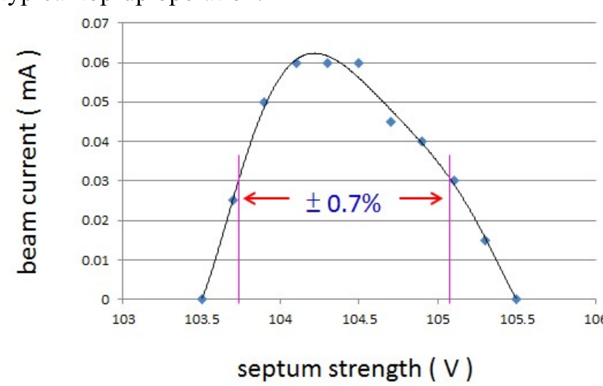

Figure 5: The tuning range of the injection septum in a typical top-up operation.

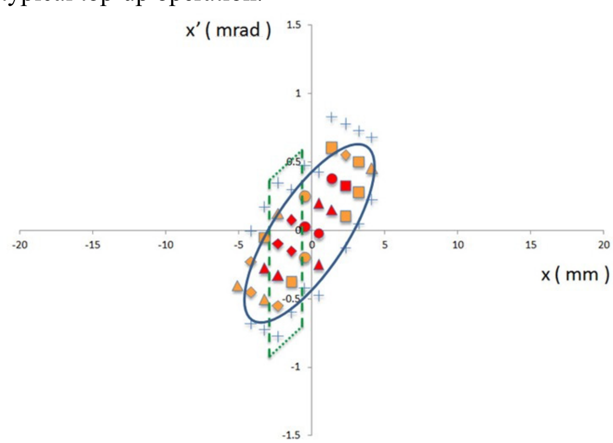

Figure 6: The measured horizontal phase space acceptance of the TPS booster at injection kicker. The green dash line circled region is depicted here for comparison purpose based on an independent measurement result given in [6].

As shown in the figure, the asymmetry of the septum tuning range indicates that the injected beam trajectory at this top-up working point is close to the septum plate at its exit. As the septum setting becomes smaller, the de-

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creasing rate of the successfully injected beam drops faster in comparison with the beam current decreasing rate when the septum setting becomes larger.

The experimental results of exploring the tuning range of septum and kicker are summarized in Fig. 6. The observation dots in horizontal phase space are obtained by tracing each data pair of the septum and kicker settings through the designed injection scheme illustrated in Fig. 3. A green dash line region shown in the figure is also given for illustration purpose. It coincides with the septum and kicker settings for bunch train experiment [6].

ANALYSIS

Phase space acceptance

The horizontal phase space tracking of the TPS booster bare lattice at straight section has been reported in its design phase [5]. However, the challenges encountered in the early phase of its commissioning imply that its corresponding acceptance is worth of re-examining [7].

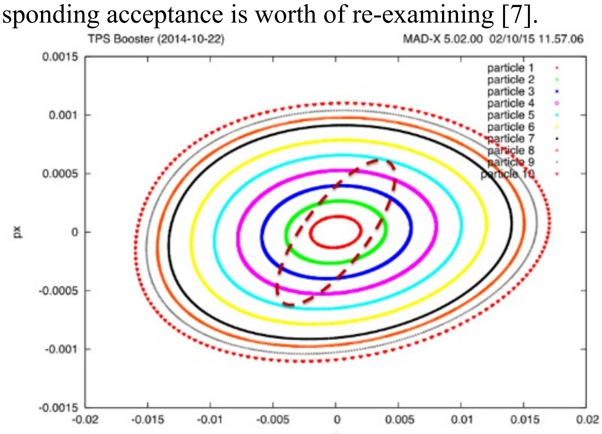

Figure 7: The phase space particle tracking of the designed TPS booster observed at the injection kicker location. The operational horizontal phase space given in Fig. 6 is depicted here, i.e. the brown dash line circled region, for comparison purpose.

A reproduced horizontal phase space tracking of the TPS booster lattice at the injection kicker location is shown in Fig. 7 in order to compare with the measurement results. The tracking region has been selectively reduced, in comparison with the tracking plot of ±40 mm in design study [5], due to the physical aperture limitation set in the calculation, i.e. ±17.5 mm. This beam stay clear constrain given by the vacuum chamber aperture appears to be the major limiting factor in the tracking study.

The calculated tracking result given in Fig. 7 indicates that the linear lattice behaviour is dominated within the given physical aperture for the circulating electron beam in the booster. The experimental test result of the operational horizontal phase space given in Fig. 6 is also depicted here for comparison purpose. Considering the limited available tuning range of the injection septum and kicker observed in this experiment, it implies that the injection phase space acceptance is deteriorated to an extent that would not be expected in the design study.

Since this experiment is constrained within a top-up operation for storage ring vacuum outgas processing, the available tuning range of the injection septum and kicker is limited so as to confine its disturbance to the routine operation at all possible minimum levels throughout the experiment. Further exploration concerning the booster phase space acceptance should be given in order to improve the overall operation efficiency especially on the beam injection related items.

Operational bunch train

The available bunch train for routine top-up operation has been explored. A typical measurement result is given in Fig. 8. It shows that the booster beam current is increased while lengthening the injected bunch train. A slight adjustment of the injection kicker timing is also performed for beam current optimization purpose. The result indicates that the increase of the booster beam current is proportional to the length of the bunch train applied up to 400 ns. Then, the beam current reveals a saturation feature with respect to the increased bunch train. This indicates that no further injected electron bunches over 400 ns would be captured and accelerated in the booster. Detailed analysis suggests that the extension of bunch train tuning is dominantly limited by the long falling tail of the kicker pulse [7, 8].

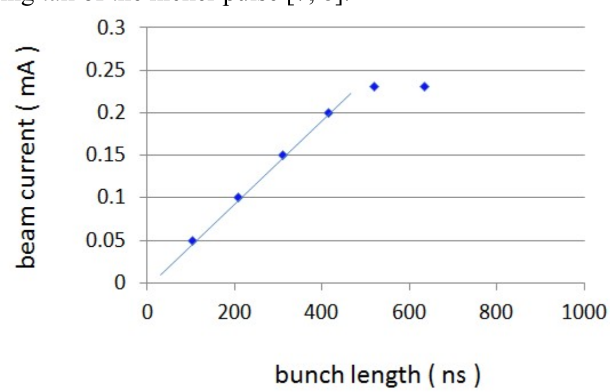

Figure 8: Typical measurement of the booster beam current as a function of the length of bunch train applied.

SUMMARY

The tuning range of injection septum and kicker for TPS booster at top-up operation for vacuum outgas processing has been performed. The analysis of the experimental results is in line with the injection scheme design in order to explore the corresponding phase space acceptance. The measured results indicate that their tuning ranges are limited within this selected operation constrains. The analysis on the injection phase space acceptance implies that it has been deteriorated in comparison with the designed expectation. Further investigation should be continued in order to improve the operation efficiency.

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