PULSE-TO-PULSE MODE SWITCHING OF KEKB INJECTOR LINAC

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Abstract

Electron and positron injections from the KEKB injector linac to storage rings have been switched in a typical cycle of five minutes. The switching involves a mechanical movement of a positron production target from and to a beam line. It prevents from faster switching, like pulse-to-pulse switching. A target assembly with a small hole beside a target material and four pulse steering magnets are installed. For positron injection pulses, the pulse steering magnets are off and electron beams irradiate the target to produce positrons. While, for electron injection pulses, the pulse steering magnets are excited to create a orbit bump in order for the electron beams to go through the hole and bypass the target. This paper describes details of a system for the pulse orbit bump and results from recent beam studies.

INTRODUCTION

The KEKB injector linac supplies electron and positron beams to the KEKB storage rings HER (8.0 GeV e-), LER (3.5 GeV e+) and to the two synchrotron radiation facility rings PF (2.5 GeV e-) and AR (3.1 GeV e-) as well. Each ring requires different beam properties; a time-structure, a particle charge, an energy and an intensity. Parameter setting of the linac, called as ”injection mode”, is switched for an appropriate beam to be generated, accelerated and sent into a selected ring. In this mode switching, parameters like a choice of the pre-injector, electron gun settings, magnet currents, acceleration phases, rf pulse timings and so forth are changed. Mode switching between the electron and the positron injection for HER and LER rings is frequent in typically 5 minutes cycle. Each switching takes 30 seconds in completing to change parameters. Most of the linac operation time is occupied for KEKB continuous injection. It is interrupted by injections to PF (once a day) and to AR (twice a day), each takes 15 minutes to fill up the storage ring. Switchings from KEKB to PF or AR and its reverse have taken a few minutes until recently, since it needed to change a current slowly for a large bending magnet to keep its hysteresis cycle. However, recently, a demand of continuous PF injection was brought up for keeping its storage current constant. It is beneficial for some synchrotron radiation users, but it was not compatible with the KEKB continuous injection. To solve this issue, much efforts have been made to realize quasi-simultaneous electron injection to KEKB HER and to PF [1]. It can be achieved by injecting both beams from the same pre-injector, installing a pulse bending magnet and a new beam transfer line for PF, pulse-to-pulse switching of acceleration rf phases for 8.0 GeV and 2.5 GeV beam energies, setting up focusing and steering magnets compatible for these different beam energies [2]. This unification of these two injection modes has almost been completed and it will be used for an autumn run this year (2008).

Next step of the unification is that of the KEKB electron and positron injections. Positrons are produced by irradiating a metal target with electron beams. A target is placed on a beam line halfway across the KEKB linac. The target is retracted from the beam line during an electron injection and inserted during a positron injection. Mechanical movement of the target takes a few seconds. It is desirable keep constant storage currents in both of electron ring and positron ring for a beam collision tuning to achieve superior luminosity. To realize pulse-to-pulse switching of the electron and positron injection modes, it was proposed to use a target assembly with a small hole beside a target material in order to fix it on a beam line and to let electron beams bypass through the hole with pulse steering magnets only for electron injection pulses.

In the following chapters, details of the target assembly, the pulse steering magnets and recent results of beam studies are given.

TARGET BYPASS ORBIT FOR PULSE-TO-PULSE MODE SWITCHING

Target bypass orbit

In designing a bypass orbit to avoid the target retraction, first considered has been a large orbit bump to bypass not only the target but positron focusing solenoids and a capture system. It needed an independent bypass beam line apart more than 300 mm from the original beam line and also huge pulse magnets to bend 4-GeV electron beams in large angle. Thus, it was too costly. More practical and economical solution was to make a small hole in a target assembly beside the target material and to make a bump orbit of only some millimeters height. This small orbit bump can be contained in a present beam ducts and in apertures of accelerating structures. Fig. 1 shows a bypass orbit bump and a beam line layout around the positron production target. A component denoted as PT21T in the figure is a positron production target and the thick green lines show an aperture of the target hole. Center of the hole is 5.2 mm aside horizontally from a beam line center. Focusing quadrupoles setting is based on a candidate beam optical calculation which is compatible for HER and PF injections. A purple line shows a bump orbit and red

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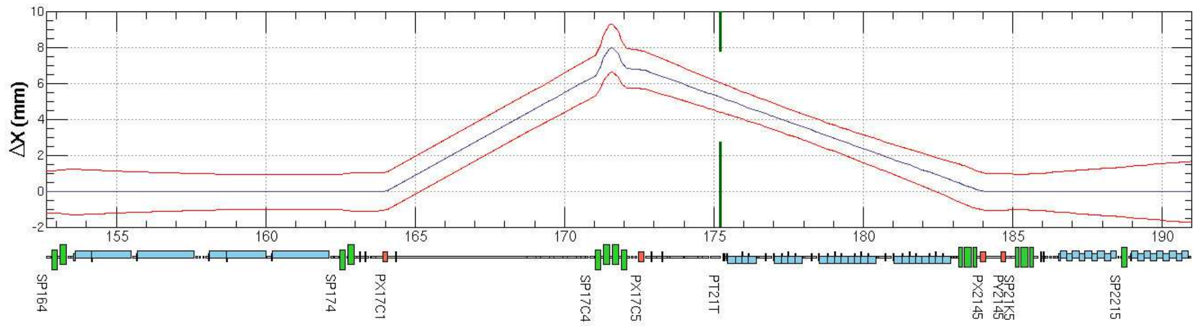

Figure 1: Target bypass orbit and beam-line component layout around the positron production target.

lines show a beam envelope in 3-sigma extent assuming a design emittance of electron beam for HER injection: $\gamma\epsilon = 1.0 \times 10^{-4} m$. A envelope of PF injection beams is not described here since its size is typically much less than that of HER beam. About 3 meters upstream of the target, there is a quadrupole quartet (illustrated in green rectangles) to focus electron beam onto the target. At just downstream of the target, there is a positron-focusing solenoid region in 8 meters long and capture accelerating structures (blue rectangles) in it. Three horizontal pulse steering magnets (PX17C, PX17C5, PX2145) and a vertical steering (PY2145) are installed (orange rectangles). Horizontal steering magnets make a closed orbit bump to let electron beams go through the hole. Since the focusing quadrupole quartet is inside the bump, it contributes to kick the beam toward the beam line center and help the second steering magnet. The vertical steering magnet is used to compensate a vertical kick from edges of the solenoidal field.

Target assembly with a small hole

For positron production, 4.0-GeV electron beam (beam intensity 10 nC/bunch, 1 or 2 bunches/pulse, maximum pulse repetition 50 Hz) irradiates a tungsten target. A 14-mm thick amorphous tungsten had been used as a target material. Recently, a 10-mm thick crystal tungsten has been developed for practical use, which resulted in 25% increase of the positron intensity [3]. Transverse cross section of the crystal tungsten is a square in shape, 4.5 mm on a side. The target is combined in a copper support by the hot isostatic pressing method. Cooling water pipe is wound around the support and connected by brazing. In a present injection mode switching, the target assembly is mechanically moved. The target is retracted from a beam line for electron beams to pass through during electron injections, and it is inserted in the beam line for positron production during positron injections. The target is driven by a pressurized air and it takes a few seconds to complete the movement. A cycle period of the retraction and the insertion is limited to be longer than 5 minutes for avoiding a breakage of a vacuum bellows in a long-term operation. To realize a beam mode switching without moving the target, a hole 5.0 mm in diameter is penetrated beside the target as shown in Fig. 2.

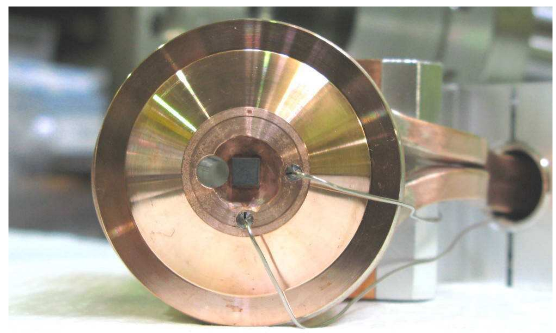

Figure 2: Positron production target assembly with a hole.

Pulse steering magnets

To make a bump height of the target bypass orbit sufficient for the target hole, pulse steering magnets should generate 1.0-mrad transverse kick angle for the 4-GeV electron beam. To achieve this specification, modification of used magnets in the TRISTAN accelerator was considered. The candidate magnet has dimensions of 330 mm in yoke width, 280 mm in yoke height and 170 mm in pole length. This size is suitable for installing into available spaces in the linac beam line. It could generate 0.0593 Tesla dipole field with a maximum DC current of 10 A, which corresponds to 0.56-mrad kick angle for 4.0 GeV beam. To meet the specification requirement on the field strength, a pole gap of the magnet was modified from 70 mm to 35 mm, by fabricating additional pole head and welding to an existing pole. It doubled the field strength at the same current to meet the specification. This modification resulted in significant increase of a coil inductance from 32 mH to 57 mH. In this situation, the maximum current which can be supplied to the magnet is limited by a induction voltage a power supply can manage. We use a sine-like pulse shape with a offset to make an initial and a final time derivates of the supplied current to be zero, because an edged shape of the pulse current give larger induction voltage. Bipolar pulse power supplies, BP4610 and BP4620 of the NF corporation are used as amplifiers of input pulses from function generators. The power supplies can tolerate an induction voltage by a pulse longer than 40-ms cycle. Thus, it can excite a bump orbit at maximum repetition of 25 Hz. In a case of 50 Hz injection, we will switch the power supplies to a DC mode. A timing of the orbit bump excitation with respect to beam arrival has 0.5 ms jitter from a constraint in bucket selection.

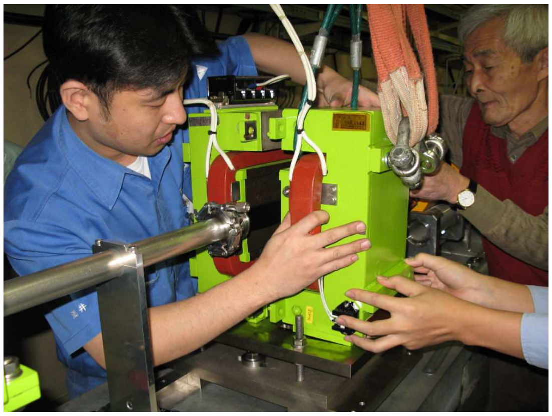

Figure 3: Pulse steering magnet for target bypass orbit

Beam transmission studies

Preliminary beam studies have clarified some issues on this scheme of mode switching using a bump orbit through the target hole:

- When the bump height is large, certain beam loss occurs because some fraction of electrons hit vacuum ducts around the region of the quadrupole quartet. Vacuum ducts whose inner shape was a circle of 10.0 mm in radius was replaced by that of elliptical shape whose major axis is 14.5 mm.
- Preliminary target hole diameter 3.0 mm was not sufficiently tolerant for beam transmission. It was enlarged to 5.0 mm in the most recent target.
- Setting of the pulse steering magnets for the bump orbit and beam transmission performance are dependent upon a focusing strength of the quadrupole quartet. In the most promising optical setting in views of beam transmission and matching to a downstream optics, the quadrupole strength was set to a medium value between that for an previous HER injection optics and that for optimum focusing onto the target [2].

Beam studies are performed quite recently to measure a beam transmission performance after these improvements. Fig. 4 shows beam transmission ratios for 1st and 2nd bunches of the HER injection beam and for the PF beam. We define a standard charge by a beam charge measured at a downstream of the bump orbit when bump height is zero and the target extracted. The transmission ratio in vertical axis of the figure is calculated as a measured beam charge divided by the standard charge. The bump height in horizontal axis is defined as a difference of an orbit position at the target from that when pulse steering magnets are off. It should be noticed that these values are not absolute orbit position. Dashed the blue and aqua lines show measured beam transmission ratio of two bunches of a HER beam with the target extracted. Degradation in a right-hand shoulder is caused by beam loss at vacuum ducts. While, the solid lines in same colors are those for the case the target is inserted. At each bump height of the maximum transmission for the first and second bunches, differences of the values for the cases with and without the target is less than 5%. Thus, it shows that 95% of the beams can be pass through even with an aperture limited by the hole. Optimum bump heights for the first and second bunches of the HER coincides in a range of 0.1 mm. It shows that the orbits for them are very close in 0.1 mm and a common bump height can achieve a transmission close to the optimum. Dashed and solid red lines show the transmission for PF beams. The optimum transmission for PF beam is better than 95%, but the optimum bump height differs about 0.6 mm from those of HER beams. This significant orbit difference forces a compromised bump height in order to make it common for the HER and PF beams. It results in slightly degraded transmission. It need more careful tuning to make these orbit to be closer for better tranmission. If the tuning cannot improve the situation, pulse-to-pulse variation of the bump height will be necessary and requires some upgrades in the pulse power supply control system. After all, even in a compromised bump height, 90% transmission is achieved both for HER beams and for PF beam.

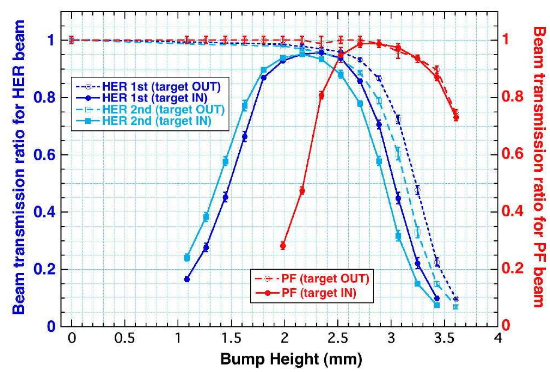

Figure 4: Measured beam transmission performances.

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