

CONSTRUCTION AND COMMISSIONING OF DIRECT BEAM TRANSPORT LINE FOR PF-AR

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Abstract

PF-AR was constructed as an accumulator ring for TRISTAN, and in the KEKB era it has been revitalized as a 6.5 GeV synchrotron radiation source. The injection energy was 3 GeV and the beam was accelerated to 6.5 GeV prior to the user run. The original beam transport line (BT) from the LINAC to the PF-AR shared its upstream part with the the BT line of KEKB High Energy Ring (HER). The injection-mode change from PF-AR to HER or vice versa needs about 10 minutes for the magnet cycling procedure of the shared part. In SuperKEKB, the upgrade of KEKB, the lifetime of HER is about 10 minutes. The mode-switch operation of the BT is, therefore, not allowed for maintaining the highest luminosity of the SuperKEKB. In order to avoid this problem, a new 6.5 GeV BT line dedicated to PF-AR has been constructed. This also enables the top-up injection for the user run. The commissioning of the new BT line has been completed in this March, and now the first user run has been operated successfully.

INTRODUCTION

The Photon Factory Advanced Ring (PF-AR) is a storage ring light source of Hard X ray region dedicated to the single bunch operation. With the old beam transport (BT), 3 GeV electrons were injected and accelerated to 6.5 GeV before the user run. KEK LINAC provides injection beams for four rings; 7 GeV electron for SuperKEKB HER (High Energy Ring), 4 GeV positron for LER (Low Energy Ring) [1], 2.5 GeV electron for PF ring, and 6.5 GeV electron for PF-AR now. Since the pulse-to-pulse switching of LINAC and the beam switching yard had been made for three rings of PF, HER and LER for old KEKB, PF-AR injection interrupted it for about 10 minutes at least due to the magnet cycling procedure for the upstream part of the old BT that is used not only for PF-AR but also for HER. Since SuperKEKB requires a continuous injection of 50 Hz for HER and LER because of their short Touschek lifetime of about 10 minutes [2], the 10 minutes interruption is very critical for SuperKEKB. Thus a new independent BT for PF-AR that enables the pulse-to-pulse injection for all four rings has been constructed [3] [4]. The new BT is designed for 6.5 GeV and enables the top-up operation that will begin in autumn 2018 after the comple-

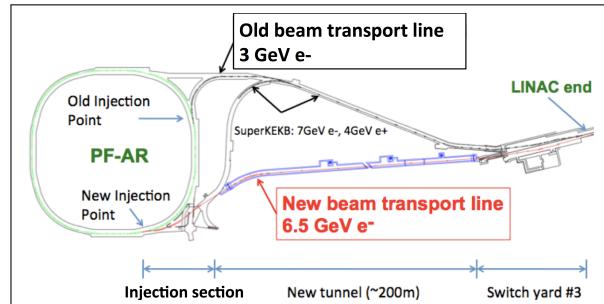


Figure 1: The schematic view of the old and the new direct beam transport line of PF-AR.

tion of Phase 2 operation of SuperKEKB. The construction of a new tunnel for the independent BT began in 2012 and finished in 2015 with the infrastructure. The installation of accelerator components of magnets and vacuum ducts finished in 2016. In order to reuse all bending magnets, the removal and the installation were conducted in parallel. Finally the commissioning began in February 2017. Here, we report the construction and commissioning of the new BT for PF-AR.

CONFIGURATION OF PF-AR DIRECT BEAM TRANSPORT LINE

The new BT transport is about 320 m long from the exit of the pulsed bending magnet at the end of LINAC to the new injection point of PF-AR (Figure 1). The optical functions are shown in Figure 2. We describe the configuration of the new BT in three parts; LINAC Switch Yard #3 (SY3), new tunnel, and ring injection section.

Switch Yard #3

As shown in Figure 3, SY3 hall is located at the exit of LINAC to switch electron and positron beams for HER (purple line), LER (blue), PF (green) and PF-AR (red). The beam is kicked by the pulsed bending magnet with the maximum repetition rate of 25 Hz for PF and PF-AR. With the same magnetic field of the magnet for different beam energies, BTs for PF and PF-AR can be separated. This section is the most crowded and complicated area in this construction. The geometrical design of the BT, the hardware design and alignments have overcome many difficulties.

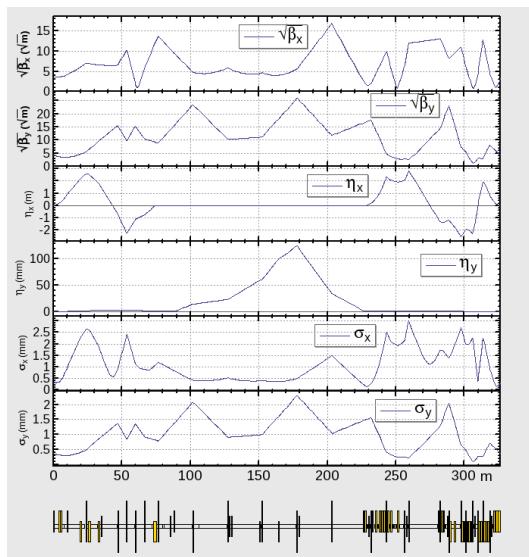


Figure 2: Optical functions from the end of the injector linac to the injection point of the PF-AR. In order to calculate the beam size, we supposed that the normalized emittance is 100×10^{-6} mrad, and the energy spread is 1.0×10^{-3} as the 1σ of Gaussian distribution at the initial point of the BT.

New Tunnel

The new BT tunnel is about 200 m straight line divided by an existing utility conduit (Figure 4). The upstream and downstream tunnels are connected to each other to prevent geometrical fluctuation without fixing the utility conduit. In order to make the vacuum duct pass through the conduit without interference with existing utility racks, the beam trajectory is bumped to +60 mm using four vertical bending magnets. The level adjustment between LINAC and PF-AR is made with this bump. The height of the trajectory at the exit of the bump is -28 mm. The optics is designed as achromatic for this vertical asymmetrical bump.

Injection Section

Behind the new tunnel, the new BT crosses the existing SuperKEKB BTs that is 0.6 m below (Figure 5). The BT for PF-AR is 2.4 m high from the floor of the SuperKEKB BTs and thus the three new 4 m vacuum ducts are hanged on the ceiling of the SuperKEKB BT tunnel.

For the injection system of PF-AR, three pulsed kicker magnets and two pulsed septum magnets are newly manufactured for 6.5 GeV [5] [6] [7]. In order to install these new kickers, vacuum ducts are renewed in the range of 25 m.

COMMISSIONING

The beam commissioning began on February 13, 2017. The beam passed through the new BT and reached the injection point on the first day. The beam storage was observed on the second day. However, a large loss occurred in the accumulation, and the injection efficiency was suppressed below only 1 %. This problem was resolved with the precise

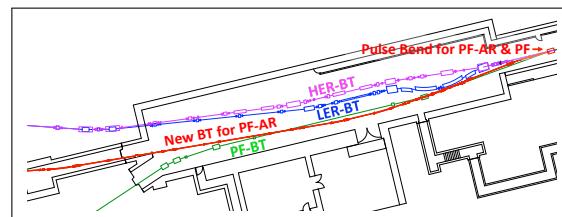


Figure 3: Four beam transport lines in LINAC Switch Yard #3.

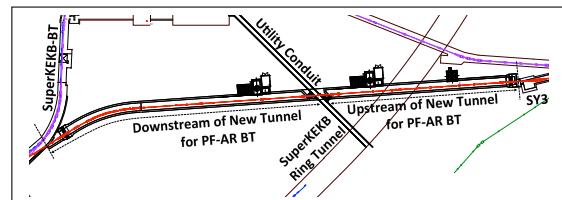


Figure 4: The new tunnel section of the direct beam transport line for PF-AR.

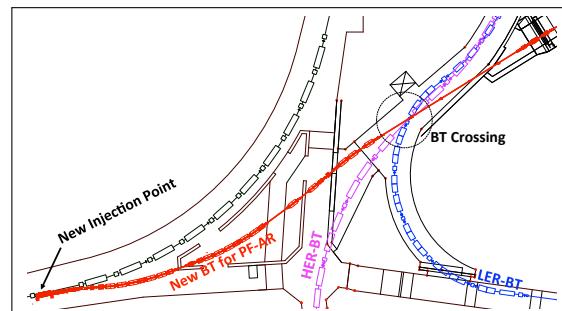


Figure 5: The injection section of the direct beam transport line for PF-AT.

measurement and adjustment of the timing of the injection kickers, and the beam injection efficiency was drastically improved to about 80 % on the fifth day. This was calculated as the ratio of the increase of the accumulated beam current detected by the DCCT of PF-AR ring to the charge amount detected by the CT at the end of LINAC (Figure 6). After this adjustment, the injection efficiency got stable around 84 - 88 % through the commissioning.

Figure 7 shows the BPM measurement results for the new BT with the very rough first calibration. Figure 8 shows the history of the maximum stored current of the day and typical lifetime during the commissioning period. The stored current already reached 60 mA, the design goal¹. The vacuum pressure and beam lifetime is almost recovered as shown in Figure 9. On March 1, the facility inspection by Nuclear Safety Technology Center was implemented and on March 16, the notification of the acceptance was made. From April 2017, PF-AR successfully operates the user run with the new BT and injection system.

¹ After confirming the accumulation of 60 mA, the current was lowered to 50 mA for the device protection.

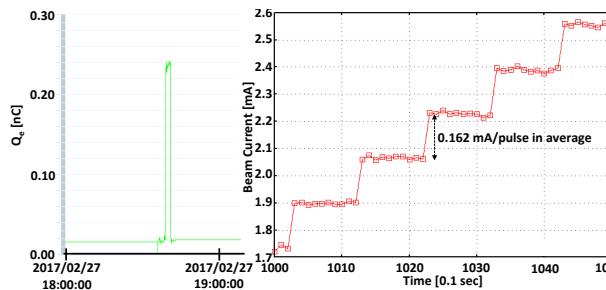


Figure 6: (Left) Charge amount detected at the end of Linac. (Right) Accumulated beam current of PF-AR ring.

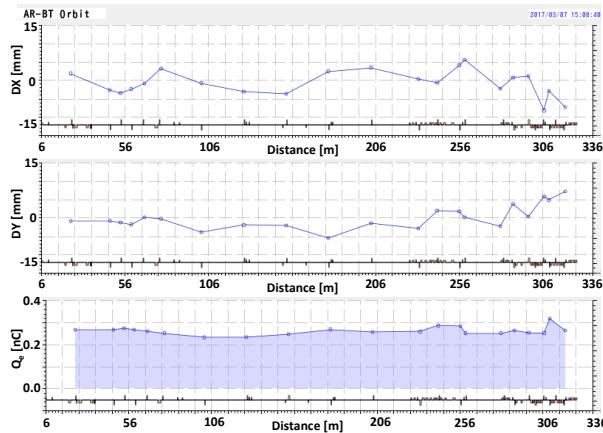


Figure 7: A example of the beam position and charge amount through the new direct beam transport line, measured by BPMs with the very rough first calibration. The starting point of “Distance” is the pulsed bending magnet in SY3, indicated in Figure 3.

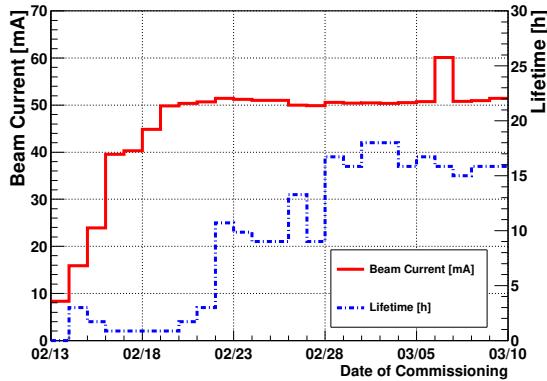


Figure 8: The history of the beam current and the lifetime. The displayed values of the beam current are the maximum ones, and those of the lifetime are the typical ones recorded for each day.

FUTURE WORK

The upgrade of LINAC for Phase 2 operation of the SuperKEKB is scheduled from this June for five months [8]. LINAC finally enables the continuous injection for four rings

ISBN 978-3-95450-182-3

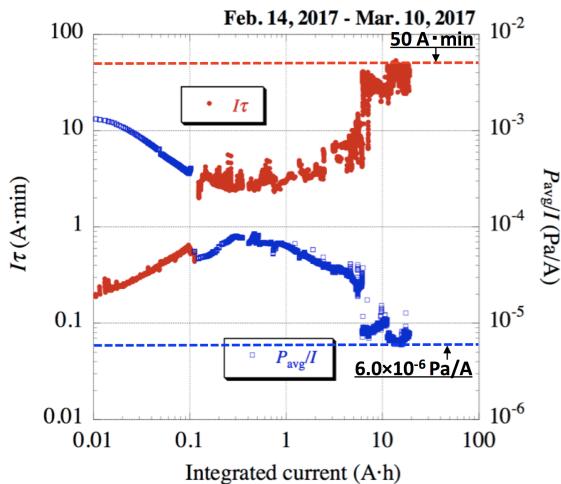


Figure 9: The state of the vacuum scrubbing of the PF-AR ring. Each dashed line indicates the goal estimated from the past results before the construction of the new BT.

with the positron damping ring in autumn 2017. After the commissioning for SuperKEKB and beam study for PF and PF-AR, the user run with the top-up injection for PF and PF-AR will begin in autumn 2018.

Also, the full energy injection resolves the problem of the very severe beam instability effect at 3 GeV which occurs due to the strong HOMs excited by the comparatively short bunch. We will begin the machine study for the lower emittance optics with the careful hardware protection in the next step.

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