MODIFICATION OF BEAM TRANSPORT LINE DESIGN FOR SIMULTANEOUS TOP-UP INJECTION TO PF AND PF-AR

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Abstract
The High Energy Accelerator Research Organization (KEK) has two light sources: Photon Factory (PF, 2.5 GeV) and Photon Factory Advanced Ring (PF-AR, 6.5 GeV). In 2017, the operation of a new beam transport line (BT) of PF-AR was started, and the simultaneous top-up injection for both PF and PF-AR was realized. These days, there have been strong demands for the reduction of the operating cost of accelerators, and its importance is greater in PF-AR with higher ring-energy of 6.5 GeV. In 2019, the 5 GeV operation was started in PF-AR. However, the new BT of PF-AR (ARBT) was designed for the energy of 6.5 GeV, then the simultaneous top-up injection is no longer available under the condition of 5 GeV operation of PF-AR and 2.5 GeV operation of PF. In order to mitigate this impact, the pseudo-top-up injection has been employed by fine-tuning the current of a common DC bending magnet placed at the intersection of ARBT and the BT of PF (PFBT) within a given time frame. However, this scheme reduces the flexibility of the operation schedules, and will not be able to respond adequately to low emittance optics of PF-AR that may bring the shorter beam lifetime. In order to realize true-top-up injection, a modification of BTs’ optics design was carried out to add new horizontal steering magnets and a flattened-duct. The beam commissioning succeeded and the application to the user-run will start in this May. This time, details of modification and its extended plan will be presented.

INTRODUCTION

New BT of PF-AR
The High Energy Accelerator Research Organization (KEK) has two light source accelerators, Photon Factory (PF) and Photon Factory Advanced Ring (PF-AR), with the energy of 2.5 GeV and 6.5 GeV, respectively. In 2017, with the upgrade of KEKB to SuperKEKB (placed at the KEK Tsukuba campus, same as PF-AR and PF), the BT of PF-AR (ARB) became independent from the BT of KEKB. Until 2017, 3 GeV electron beam was transported through the old ARBT, and after the injection, the beam was ramping up to 6.5 GeV of the operation energy. The new ARBT was designed for 6.5 GeV, then the top-up injection was realized in PF-AR. The top-up injection in PF was already accomplished, therefore the simultaneous top-up injection of PF and PF-AR was realized (Fig. 1) [1].

Pseudo-top-up operation
These days, the demand to reduce the operation cost is getting larger, and that is relatively strong with PF-AR compared with PF with 2.5 GeV. In order to respond to this, the 5 GeV operation was suggested. However, the new ARBT was designed for 6.5 GeV, and there is a common DC bending magnet (called BPFS) at the intersection of ARBT and the BT of PF (PFBT) (Fig. 2). Therefore, the orbit of the 5 GeV electron beam accompanies the deviation from the designed orbit downstream of BPFS. In order to resolve this, ‘pseudo-top-up operation’ was introduced [2]. This scheme has the each injection time (150 sec. for PF and 90 sec. for PF-AR), and in this given time frame, the exciting current of BPFS is changed finely for each energy. In this scheme, the reduction of the stored beam current in each ring occurs, however that is so little and can be ignored from the light source users’ perspective. The user-run with 5 GeV was started in 2019, and the operation keeps stable.

Figure 1: New beam transport line for PF-AR.

Figure 2: Layout around the intersection of PFBT and ARBT. Beams comes from the right side to the left. Orbits of PF-AR and PF are isolated at the pulse bending magnet, and after that, intersects twice. The common DC bending magnet is placed at the first intersection.
DEMANDS FOR THE TRUE-TOP-UP INJECTION IN PF-AR AND PF

By the realization of the pseudo-top-up operation, the stored current values of PF and PF-AR can be almost kept at the designed values. However, “true-top-up injection” is still desired from the following points of view.

The first is the constraint of the operation schedule. PF employs “hybrid operation”, that supplies a high current single bunch and the normal current multi bunches. In this operation, the beam lifetime is shorter than the normal multibunch operation, and true-top-up injection is necessary. For this reason, the hybrid operation in PF could be operated only behind the 6.5 GeV operation of PF-AR.

The second is the need for the immediate response to the shorter lifetime and unexpected beam losses. Recently, the new $e^+, e^-$ irradiation test beamline was constructed at PF-AR, and the commissioning is started [3]. In parallel with that, the application of a low emittance optics is considered in PF-AR [4]. These may bring the shorter lifetime or unexpected beam losses. Therefore, the true-top-up injection is desirable.

MODIFICATION OF OPTICS DESIGN TO REALIZE TRUE-TOP-UP INJECTION

The budget for the realization of the true-top-up injection was approved in FY2021, and the practical modification was carried out last summer (FY2022).

Our modification plan is to set the magnetic field of the common DC bending magnet close to the design value of 5 GeV ARBT, and absorb the orbital deviation in 2.5 GeV PFBT. This time, the energy is changed in ARBT from 6.5 GeV to 5 GeV. However, ARBT has little space to install additional instruments, then we decided to modify PFBT.

The deviation that occurs in PFBT is absorbed by using three additional horizontal steering magnets (Fig. 3). The quadrupole magnet “QPFA1” placed where new three horizontal steerings were set was moved to the downstream.

This modification employs only DC magnets so that the cost and the efforts to install and operate can be suppressed. In addition, the scope of the modification is narrow and does not include any existing beam position monitors (BPMs) and screen monitors that are relatively expensive.

New optics of PFBT and ARBT are shown in Fig. 4 and Fig. 5 respectively. In new PFBT (Fig. 4), the excess kick angle by BPFS is 12.6 mrad. This could lead the large orbital deviation that is proportional to the distance from BPFS. In order to avoid this, HS2, 3 are placed very close to BPFS.

In new ARBT (Fig. 5), the excess kick angle by BPFS gets practically small by the pulse bending magnet and BPAPS1, 2. The kick amplitude of the pulse bending magnet could not change in between ARBT and PFBT, then we change the phase (delay) of the pulse. This practically works to reduce the kick angle of the pulse in ARBT. The naked excess kick angle by BPFS is 6.66 mrad and mitigated angle by the pulse bending magnet and BPAPS1, 2 is 4.30 mrad. This is 64.6 % of the original angle.
COMMISSIONING

We conducted beam commissioning with new PFBT last October and November. The most respected rule is not to change the current of the common DC bending magnet “BPFS” as a tuning nob. As long as this is followed, the tuning of ARBT and PFBT is independent, each other.

As the first step, we confirmed that the transportation is successful in ARBT. This was carried out in last May, because new ARBT optics could be tested without any hardware modifications, as mentioned above.

After the practical modification in last summer, we tried to establish new optics in ARBT and PFBT at the same time. As the result, it was confirmed that the comparable injection rate was achieved in both ARBT and PFBT.

We have several horizontal steering magnets in each BT. However, if we employ all of them as the tuning nobs to reduce the difference between the practical orbit and the design, the adjustment will not converge. Ideally, We need only two nobs to set the position and angle: BPAA1 and BPAA2 in ARBT and HS3 and HS4 in PFBT (Fig. 3). One example is depicted in Fig. 6 as the tuning process in ARBT.

FUTURE PLAN

As mentioned above, we have already succeed in the commissioning of the true-top-up injection simultaneously for both PF-AR and PF. The application into the practical user-run is scheduled in next May (FY2023).

In addition, We will continue the modification to Phase 1.5 (what we carried out in last summer is called as Phase 1). In Phase 1, three new horizontal steering magnets (HS2, 3, 4) were installed. HS1 is the existing one, and has relatively weak kick angle. This time, we manufactured four new steering magnets with same specifications, then it is expected that the beam operation will become more stable by replacing HS1 with the fourth horizontal steering magnet (Fig. 7). For the replacement, it is necessary to fabricate and install a new flat duct to match the gap of the new steering magnet, as was done in Phase 1.

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REFERENCES


