Realization of True-Top-Up Operation of PF-AR with 5 GeV

The 6.5 GeV light source PF-AR at KEK uses a direct beam transport line (BT) newly constructed in 2017. It has achieved simultaneous injection to PF-AR, another light source PF, and Super-KEKB collider. However, due to an operating budget cut, PF-AR started 5.0 GeV operation in 2019. The simultaneous top-up operation of PF-AR and PF was no longer possible due to the direct BT of PF-AR (ARBT) designed for the energy of 6.5 GeV and the existence of a common DC bending magnet at the crossing of ARBT and PFBT. Thus, in the current user-operation, the pseudo-top-up operation of PF-AR and PF was adopted by finely switching the magnetic field strength of the common bending magnet. This paper considers the modifications to BTs required to realize true-top-up operation instead of the current pseudo-top-up operation. We will compare some options and explain the characteristics of each.

PF-AR (Photon Factory Advanced Ring) is a light source facility in the hard X-ray region specialized for single-bunch operation. In 2017, the new beam transport line (BT) of PF-AR became available, then the simultaneous injection (top-up) of PF-AR and PF, another light source in KEK with energy of 2.5 GeV, was realized (**Fig. 1**) [1]. The new BT of PF-AR (ARBT) was designed for the energy of 6.5 GeV, the same as the ring-energy, and starts from a pulse bending magnet with the BT of the PF-ring (PFBT). After that, they cross each other twice. At the first crossing, there is a DC bending magnet, and the electron beams with energies of 6.5 GeV and 2.5 GeV are kicked out by the same magnetic field strength at its own fixed angle (**Fig. 2**).

Although the new ARBT was designed for 6.5 GeV operation, operation at 5 GeV was considered after construction due to budget cuts. The 5 GeV operation started in FY 2019, however, the simultaneous injection (top-up operation) with 5 GeV ARBT and 2.5 GeV PFBT was no longer available because of the common DC bending magnet. In the actual operation, the injection times of 150 s and 90 s are given to PF and PF-AR respectively, and the top-up operation is carried out within each assigned time. During the PF-AR injection, the electric current of the common DC bending magnet and the upstream pulse bending magnet are adjusted to the energy of 5 GeV, which we call “pseudo-top-up operation” [2].

In this study, we investigated the possibility of simultaneous top-up operation of PF and PF-AR with 5 GeV operation. In order to realize the simultaneous top-up injection of PF-AR (5 GeV) and PF (2.5 GeV), a hardware modification such as the addition of magnets is required. However, ARBT does not have enough space to install additional magnets compared to PFBT, thus it is more appropriate to modify PFBT instead. First, we considered reducing the magnetic field strength of the common DC bending magnet by 7% in order to make the 5 GeV ARBT, then adding magnets to PFBT. Two options are described below.

1) 4HS option

In this option, one horizontal steering (HS) will be installed between the pulse bending magnet and the common DC bending magnet, and three HSs will be installed downstream of the common DC bending magnet. In addition to these four new HSs, a new vacuum duct with larger inner diameter will be installed (**Fig. 3**). The maximum kick angle of HSs is about 8 mrad, and the replacement of the vacuum duct will be limited to the section from the quadrupole magnet of QPFA1 to QPFA2 (**Fig. 2**). Thanks to this limited modification of the vacuum duct, only the gate valve and the vacuum duct connected to the pump need to be replaced, and there is no interference on the beam position monitor (BPM) or the screen monitor, and so the cost can be reduced.

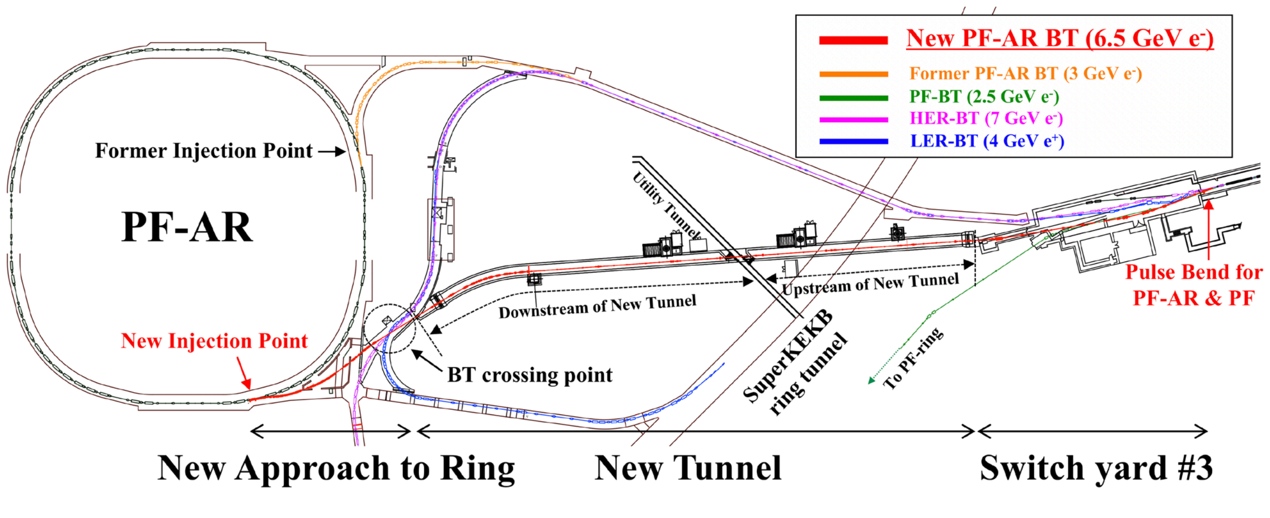

Figure 1: Layout of transport beam lines.

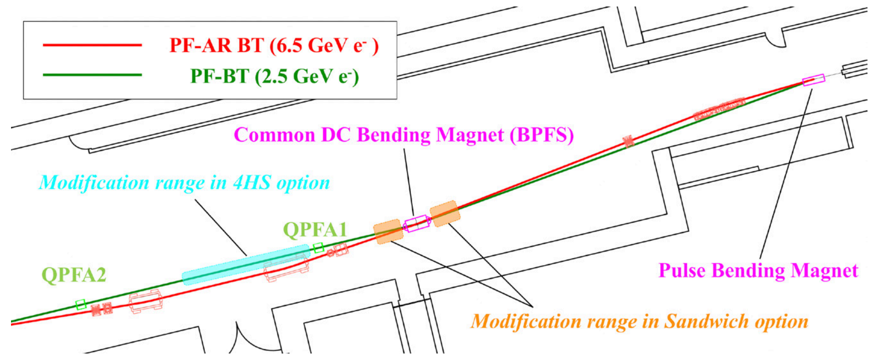

Figure 2: Present geometry of BTs, and the range of modification for the 4HS option (blue shaded area) and the sandwich option (orange shaded area).

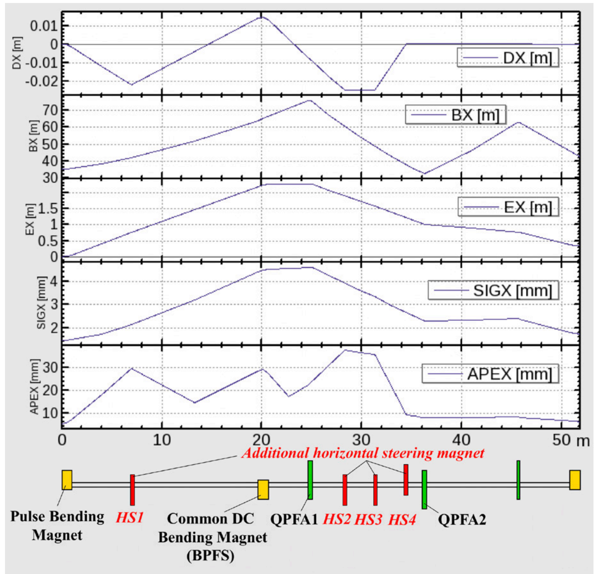

Figure 3: Optics of modified PFBT in the 4HS option. DX, BX, EX and SIGX indicates a deviation from the designed orbit, beta function, dispersion function and beam size in the horizontal direction, respectively. APEX is the space occupied by the beam in the horizontal direction, and equals to |DX| + 3 SIGX + 1 mm.

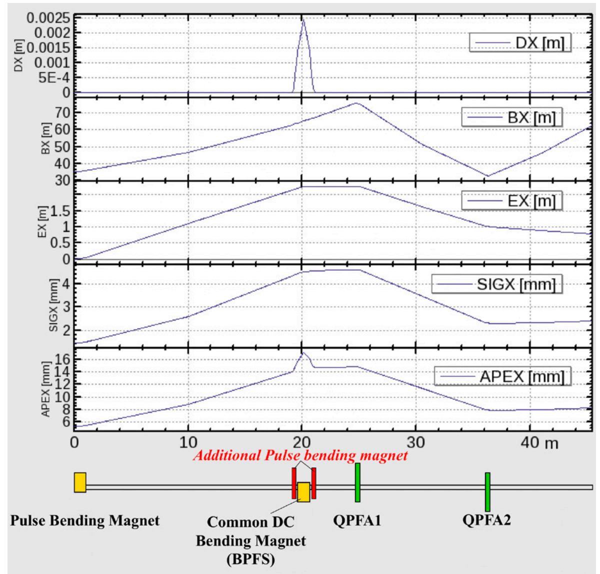

Figure 4: Optics of modified PFBT in the sandwich option.

2) Sandwich option

This proposal involves sandwiching the common DC bending magnet BPFS, which generates excess kick to the PFBT electron beam, with two new pulse bending magnets. The range of this modification is smaller than that of the 4HS option, because the modification will be completed by a local correction around the magnet BPFS (**Fig. 2** and **4**). The kick angle of the additional pulse bending magnets is about 4 mrad. The common DC bending magnet is placed at the intersection of PFBT and ARBT, where an X-shaped duct is installed. In order to install new pulse bending magnets, it is necessary to redesign the vacuum duct in a wide range upstream of BPFS, and the increased cost for introducing a ceramic duct for the pulse magnets must also be considered.

We are currently examining these two proposals from various points of view, such as cost and operation, and are conducting a specific design and selection of the additional magnets and magnet power supplies. In addition, a more detailed design study of the vacuum duct will be necessary in the near future.

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N. Higashi[1, 2], C. Mitsuda[1, 2], S. Nagahashi[1], K. Harada[1, 2], T. Nogami[1], T. Uchiyama[1], T. Obina[1, 2] and N. Nakamura[1]
([1]KEK-ACCL, [2]SOKENDAI)