BEAM-BASED OPTICS CORRECTION FOR NEW BEAM TRANSPORT LINE FROM LINAC TO PHOTON FACTORY IN KEK

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Abstract

The 8-GeV electron Linac in KEK supplies four storage rings with requested beam having specific energies, charges and bunch structures, changing sequentially its operation mode. In order to shorten the switch-time of Linac from KEKB to PF and vice versa, a new beam transport line for PF (PF/BT) has been constructed [1]. In this paper we describe on the beam commissioning and the operational status of the new PF line, with emphasis on the beam-based improvement of optics.

INTRODUCTION

The Linac in KEK provides beams for four rings, i.e., Low Energy Ring (LER: 3.5 GeV, e^+) and High Energy Ring (HER: 8.0 GeV, e^-) of KEKB, Photon Factory (PF: 2.5 GeV, e^-) and Advanced Ring for pulse X-rays (PF-AR: 3.0 GeV, e^-). The Linac continuously injects beams into LER and HER alternatively every about five minutes, and both of KEKB rings maintain almost full operating currents. The PF or PF-AR, on the other hand, had need of about 20 minutes several times a day, for topping off the current or from scratch, including 5 minutes for changing the parameters of Linac. During this, the stored currents in KEKB rings significantly decreased, and the optimum point of luminosity tuning was lost. It had taken more than two hours to recover the luminosity. It is therefore important for maximizing luminosity of KEKB to shorten the switch-time of Linac from KEKB to PF or PF-AR. In summer of 2005, a transport line from Linac to PF were renewed, in which a new DC bend deflects the electron beam from the end of Linac to the new line. We have succeeded in reducing the occupancy time of PF injection to about five minutes, and there has been almost no significant interference to the luminosity. In the near future the DC bend is envisaged to be replaced with a pulse-bend, which will make it possible to deliver the beams to the PF and KEKB in pulse to pulse basis. To this end the PF will also enjoy the top-up injection to keep brilliant high. In this paper we describe on the operational status of the new PF line, with emphasis on the optics improvement based on the beam-based measurements.

NEW PF/BT LINE

Fig. 1 shows a layout of the beam-switch yard (BSY) at the end of Linac. The thick black(red) line designates the old(new) line to PF. In the old system all beams had shared the first bend of Energy Compression System (ECS) of KEKB positron line as a common magnet and it had played a role of switch-bend. Two beams for KEKB are designed to be guided to their own transport lines without changing the ECS-bend, owing to their different charge and energy. Mode-change between KEKB and PF, however, needs to turn off/on the first bend of ECS. Since the ECS bends are heavily saturated it requires about three minutes to recover the magnetic fields. In the new system, the PF beam is extracted at the upstream of ECS through a new switch-bend (BM581), which is dedicated for PF, and guided to the existing line at the downstream of BSY. BM581 is able to be set up the magnetic condition within about a half a minute. The new line rejoins the exiting line at a bend, BH12.

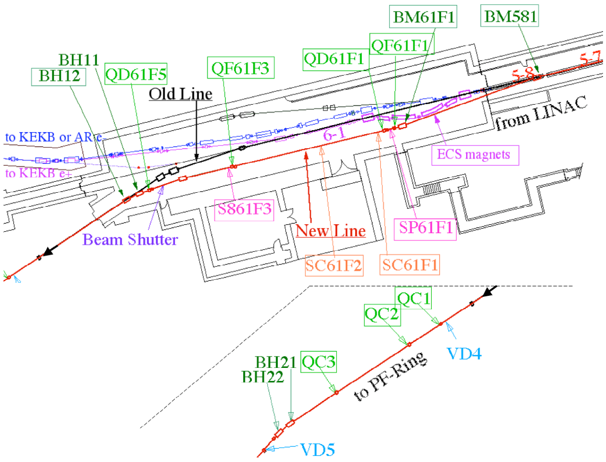

Figure 1: Layout of Beam Transport Lines.

The new system has successfully commissioned without major difficulties [2]. The elapsed time in mode changing from KEKB to PF, for go-and-return, was 2.6 minutes, while it was 5.3 minutes in the old system. Thus the mode-switch time is successfully made almost a half of that of the old system. Orbit deviations were 4 mm and 2 mm at maximum for horizontal and vertical plane, respectively, which is small enough to accommodate the beam (3 mm in horizontal and 1 mm in vertical beam sizes in 1σ) in the chamber aperture of 57.2 mm. The injection rate for PF ring surpassed 2 mA/sec at a repetition rate of 25 Hz, which is very good values compared to that in the old system.

LEAKAGE FIELD FROM ECS BENDS

The beam line is designed such that the beam is bent by bends BM581 and BM61F1 by the same quantity in opposite direction. In the initial stage of commissioning, however, we could not steer the beam without changing the strength of BM581 by 1.5 % higher than that of BM61F1. It was found that this was due to the magnetic leakage field originated from ECS-bends. The magnets of ECS consist of six bends in which the first and the sixth magnets are H-type whereas the second to the fifth ones are C-type. The third bend was closest to the PF beam and direct field of their coils had caused sizable orbit change.

Measurement of Leakage Fields using Beam

On a profile monitor (SC61F2), the difference of the horizontal position with the ECS on and off was measured to be about 12 mm. Assuming that an hypothetical magnetic field exists at a point where the beam is closest to ECS bends, kick angle and integrated field should be about 0.80 mrad and 67 Gm. The quadrupole component of the leakage field is estimated as follows; Variations of the horizontal positions on a BPM (SP61F1) changing strength of BM581 are fitted to linear function to obtain the slope or R_{12} component of transfer matrix. We measured the R_{12} component under the conditions that ECS bends were on and off. The difference of the two R_{12}'s is attributed the quadrupole component originating from leakage field of ECS-bends. Measured value of B'L is 0.0025$\pm$0.0060 T and the quadrupole component can be ignored within an error.

Measurement of Leakage Field using Hall-probe

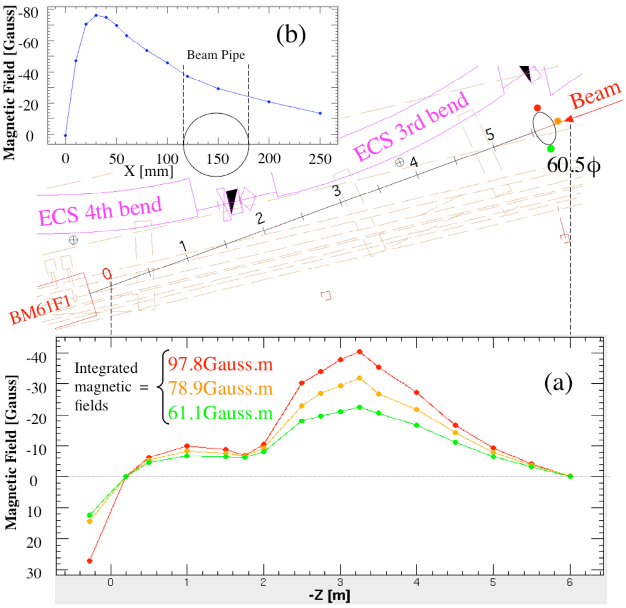

Figure 2: Measurements of magnetic leak from ECS.

We measured leakage field from ECS bends by using a Hall-probe. The positive field refers to the upward direction. Fig. 2(a) shows the measured magnetic field in the vicinity of ECS along the beam line. The red, yellow and green lines indicate the measured values on the right, upper and left sides of the beam pipe, respectively. The leakage field from the third and fourth bends are observed. The other source of leakage field can be seen around z=0, which arises from direct field of BM61F1, though this field is contained in the strength of BM61F1. Integrated fields along the beam line are 97.8, 78.9 and 61.1 Gm for the right, upper and left sides of the pipe, respectively, being consistent with the value obtained from beam measurement.

We estimated an integrated quadrupole component of the leakage field using difference of integrated fields at the right and left sides of the beam pipe. With a outer diameter of the pipe is 60.5 mm, we obtained 0.0060 T, being consistent with the beam-based measurement.

We have measured transverse profile of the field at the closest point to ECS. The results are shown at the inset of Fig. 2(b). The outside edge of the coil of magnet is defined as X=0. The strength of magnetic field is zero around X=0, where the upward leakage-field from the gap cancels the downward field arising from a coil of ECS. At the region X>0, the gap field diminished and the coil field dominates.

Design of Magnetic Shield

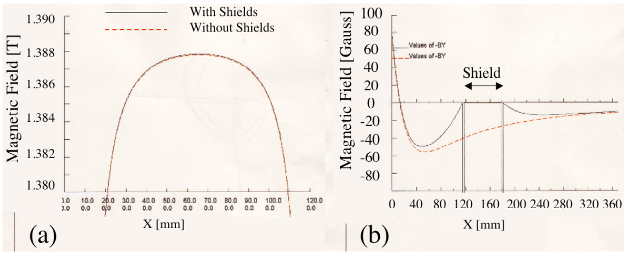

Figure 3: Calculations of magnetic fields of the ECS bend.

In order to design magnetic shielding, we made a field calculation using code OPERA-2D. In the calculation a shield that is made of steel of 0.6 mm in thickness was placed at the closest position in the beam line. The field inside the gap is shown in Fig. 3(a) while the field outside of coils is shown in Fig. 3(b). The direction of X-axis is taken from gap to coil as positive. It is seen from Fig. 3(a) that the field change due to shield is 0.0036%, which does not give any effects to the KEKB-beam line. Fig. 3(b) indicates that the direction of the field outside of coils is opposite to that inside of coils and that the field at the PF/BT line decreases from 37 G to 0.25G with the iron shield.

Magnetic Shielding and its Effect

We have made a shield around the beam pipe in the whole region from the vicinity of the third bend of ECS to the BM61F1. The beam pipes are wrapped with double μ-metal sheets of 0.35 mm thick and boarded up with galvanized steel sheets whose cross sections are square-bracket shape of 0.6 mm thick. With this structure, we expected that the leakage field greater than 10 G is shielded by steels and the minute fields like 0.25G which remained in the Fig. 3(b) are shielded by μ-metals.

After installing the magnetic shield, we observed orbit change in the profile monitor (SC61F2) with ECS on and off, which was less than 1 mm and dramatically reduced, compared with the value of 12 mm before the shielding. The remnant orbit change could be attributed to leakage from the first ECS bend because the same amount of orbit-change was observed when only the first bend was on and off. Although this orbit-change has practically no problem, we added μ-metal shields to the PF/BT line in the close vicinity to the first and second ECS bend. After making shields, no orbit distortion was observed even with the two upstream bends (BM581 and BM61F1) set to the design values.

DISPERSION CORRECTION

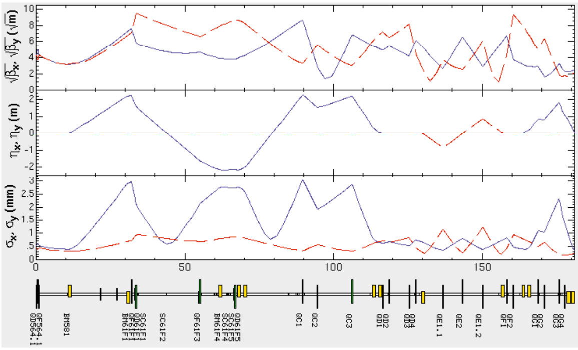

Figure 4: Design Optics Parameters of PF/BT.

All calculations for optics were done with SAD code [3]. The design optics of β-functions, dispersion functions and beam sizes with an energy spread of 0.125% are shown in Fig. 4. The blue and red lines refer to the horizontal and vertical plane, respectively. The dispersion function at a profile monitor (SC61F2) is zero in design. In the actual operation, however, with a beam energy changed, orbit-shift of a few mm was observed on SC61F2. Observed dispersion error could be attributed to strength error of quads in the region where the horizontal dispersion functions are not zero. We made measurements of the correction factors of quads using beam. Measurements were divided into two groups of quads, i.e., quads installed in the upstream of BH12, for which we call Group-1 and the others (Group-2). Because the currents of quads in the two groups are set using the different excitation curves, which are not cross-calibrated, there should be at least two independent correction factors for the quads.

Measurement for Group-1

There are four quads (QF61F1, QD61F1, QF61F3 and QD61F5) upstream of BH12. BPM's are installed adjacent to the quads. To prevent scaling errors of BPM's from affecting the results, we employed a special optics where the horizontal dispersion function at a BPM (S861F3), which is just downstream of QF61F3, is zero. The dispersion function at S861F3 depends on the three quads upstream of it. Varying a correction factor which is common to the three quads, we measured the dispersion at the BPM. We obtained the correction factor of 0.9536 for the quads, with which measured dispersion is -0.0041 $\pm$0.002. Without correction factor, it was -0.178$\pm$0.002. The correction factor of QD61F5 was assumed to be the same value as the others.

Measurement for Group-2

There are three quads (QC1, QC2, QC3) downstream of BH12 in the region where the horizontal dispersion function is not zero. Prior to the measurement we set up the initial design-optics (Fig. 4) with a correction factor applied to the quads of Group-1. Varying beam energy within $\pm$0.2%, we measured BPM responses against the beam energy, thus dispersion function at BPM's. We made a least-square fit to minimize the difference of measured dispersion and the design value, taking the correction factor of the quads as free parameters. Because the three quads are cross-calibrated, correction factors are considered to be identical. We tried to make a fitting with a constraint of equal correction factors but we could not find realistic solution. Note that the present method depends on the BPM scaling error. We assumed that the three quads have independent correction factors. The results are summarized in Table 1. We did not make any corrections about quads downstream of QC3 this time, because the dispersion function is zero in the region.

Table 1: Correction Factors of Quads

	Correction Factors
Quads of Group-1	0.9536
QC1	1.0127
QC2	0.9845
QC3	1.0782

The measured dispersion function after the correction factors are applied is shown in Fig. 5. The measured horizontal dispersion functions (EX in the top row) are good in agreement with the design values (ηx in the third row).

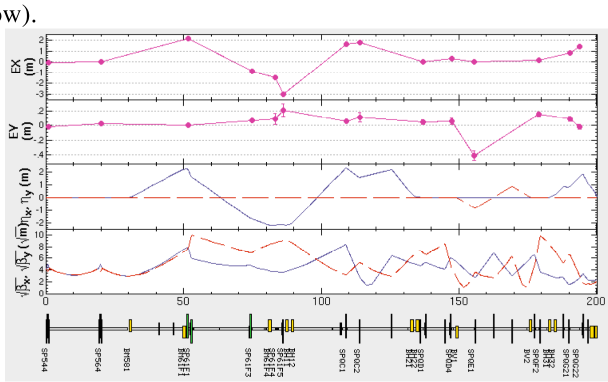

Figure 5: Measured dispersion functions after setting the correction factors in Table 1 to the quads.

SUMMARY

We have made improvement of the optics of the new PF/BT transport line based on the measurements using beam. First we found imperfections originating from leakage field from ECS magnets, and made magnetic shielding. Second we decided correction factors for quads using special optics and least-square fit. After these corrections beam performance has been greatly improved.

REFERENCES

[1] N.Iida, et al., "New Beam Transport Line from Linac to Photon Factory in KEK", Proceedings of EPAC06.

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