Direct Beam Injection Lines to PF and AR Rings

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Abstract

When the KEKB experimental operation becomes routine, it will require a frequent injection of both electron and positron from a linac. It will interfere with the injection to PF and AR rings taking a lot of time for converting the injection modes at different energies. To accomplish all injections in a short possible time, a new injection beam lines are investigated.

1 Introduction

With the onset of the KEKB routine operation frequent electron and positron injections will be required to make up for a short beam life time at the high luminosity run more than ~10^{32} $s^{-1}cm^{-2}$. At present both AR and PF rings are filled with electrons at 2.5 GeV and KEKB with electrons of 8 GeV and positrons of 3.5 GeV. An injector linac, formerly built for PF ring and also served as an injector to an accumulation ring (AR) of the TRISTAN main ring (MR), has been modified greatly to inject electrons and positrons at their full energies. As a result an electron gun, pre-buncher and buncher for 2.5 GeV to PF and AR injections are installed at an intermediate position of the linac. During injection to PF or AR, most of linac sectors are suppressed of the accelerating voltage except for required ones to attain an injection energy. The PF injection is few times a day, about 10 min for each fill, but the AR injection many times a day at present because of its short beam lifetime.

To overcome the complex and time-consuming mode exchange, the direct beam injection lines to PF and AR are considered. Installing a new beam transport line parallel to linac, the electron beam extracted at 2.5 GeV with a kicker magnet is transported along this new line and switched to PF or AR with a bending magnet at the beam switch yard. The electron beam switched to PF is transported through the present beam lines. But to AR several dipoles and quadrupoles need to be manufactured to guide the beam to the last curved transport section which is available by changing the excitation parameters.

2 Extraction from Linac and Transport to Switch Yard

The pre-buncher and buncher at the sector C-8, just downstream of quadrupole QF-C7-4 (see Fig.1), are replaced with a kicker magnet whose excitation duration is short enough to allow for an extraction of one beam pulse from 50 Hz pulse train without effecting rest beam pulses to KEKB. At this point the beam energy should be adjusted to 2.5 GeV for every injection mode (the present value is 2.85909 GeV). This energy reduction can be compensated by the following sectors. A trigger signal to fire the kicker magnet can be supplied by the existing timing system allowing the beam injection to a selected bucket of the PF or AR ring. A diagnostic beam energy measuring device can be provided after the kicker magnet to feedback for the beam energy regulation. One electron bunch is extracted horizontally and bent back to a straight beam transport line parallel to linac. Distance of the new beam line from the linac axis is assumed as 2.3 m for the present study. The linac beam level from the floor is 1.2 m. If the higher beam level is required to make the stay clear space under the new beam line, the vertical beam offset is possible using the vertical bending magnets following the horizontal bending magnets. The beam level is assumed as 1.8 m by the vertical offset of 0.6 m so as to maintain this level halfway to the PF injection line and to the beginning of the existing last curved section of the AR injection line.

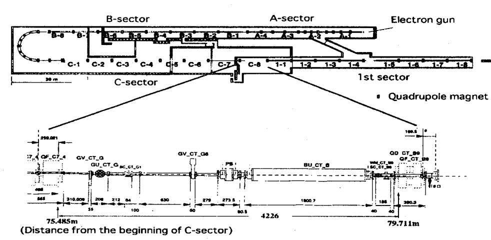

Fig.1 Section of the electron beam extraction. PB (pre-buncher) and BU (buncher) are replaced with a kicker magnet (about 2 m long). An available space is 4.2 m.

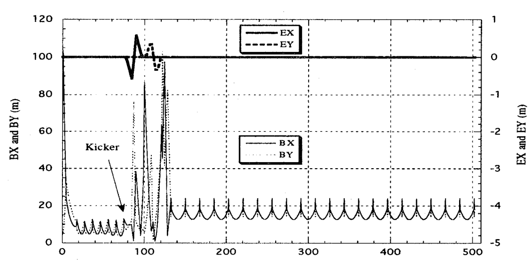

Fig.2 Twiss parameters of a new beam transport line along linac. A cell length of the regular section is 17.6 m (21 triplets in total).

After the beam is elevated, the irregular section containing the horizontal and vertical dipoles is connected to the regular section through the transition section. As the regular section is very long (about 370 m), a compact regular cell of a quadrupole triplet is considered to accommodate one beam position monitor per cell enabling both horizontal and vertical readings at the center of the middle focusing quadrupole. Twiss parameters of the beam transport line (about 500 m long) is shown in Fig.2 which are obtained by TRANSPORT code. All magnet elements of this transport line is given in Table 1, where B1 is the kicker magnet and BV1~2 are the vertical offset magnets.

Table 1
MAGNET PARAMETERS OF NEW BEAM TRANSPORT LINE ALONG LINAC. FIGURES FOLLOWING THE ELEMENT NAME ARE THE NUMBER OF MAGNETS.

Element	K-value	Ang (deg)	Length (m)	Grad (T/m)	Field (T)
(1) Horizontal offset section					
QF1 x 2	0.551	-	0.20	22.971	-
QD1	-0.502	-	0.20	-20.944	-
B1	-	-6.871	2.00	-	-0.500
B2	-	6.871	2.00	-	0.500
(2) Vertical offset & transition section					
QD1	-0.260	-	0.20	-10.820	-
QF1	0.388	-	0.20	16.197	-
QD2	-0.462	-	0.20	-19.247	-
QF2	0.500	-	0.20	20.857	-
QD3	-0.462	-	0.20	-19.248	-
QF3	0.374	-	0.20	15.603	-
QD4	-0.500	-	0.20	-20.841	-
QF4	0.353	-	0.20	14.731	-
QD5	-0.226	-	0.20	-9.439	-
BV1 x 2	-	-4.096	1.20	-	-0.497
BV2 x 2	-	4.096	1.20	-	0.497
(3) Regular section (21 triplets)					
QF6 x 22	0.670	-	0.40	13.971	-
QD6 x 43	-0.340	-	0.20	-14.193	-

3 PF Beam Injection Line

At the beam switch yard the first dipole magnet following the last quadrupole triplet of the linac beam line serves as a beam switching element. It is operated as a bipolar mode and the beam is dumped when it is not excited or in the case of power supply faults. If it is excited in either polarities, the beam is deflected to the PF or AR injection line. Fig.3 gives the location of the beam switch magnet.

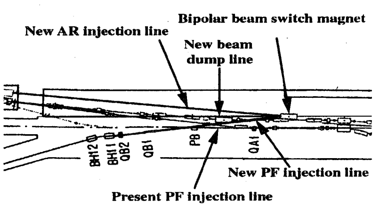

Fig.3 Location of the beam switch magnet at the switch yard.

To the PF injection line, the beam passes over the KEKB injection lines with the vertical separation of 0.6 m. The PF ring beam level is higher than the linac axis by 3.5 m and the beam is vertically translated along the slope as shown in Fig.4. The 1.8 m beam level, therefore, will be maintained to the first vertical bending magnet (BV1).

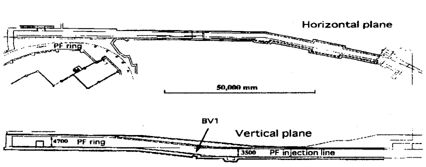

Fig.4 FP injection line. BV1 is the location of the first vertical bending magnet. Difference of beam level between linac and PF ring is 3.5 m.

Twiss parameters and beam sizes from the beginning of the C-sector to the PF injection septum through the new beam line is shown in Fig.5 and Fig.6, respectively.

As the effect of the momentum dispersion is not considered, $\eta_x(\Delta p/p_0)$ and $\eta_y(\Delta p/p_0)$ must be added to the beam size in Fig.6. The maximum η_x is about 3.8 m, so the maximum half beam size increases to ~9 mm assuming the momentum spread of ±0.2%. The normalized horizontal and vertical emittances are assumed as 800 and 820 mm mrad, respectively. Magnet parameters of PF injection line are given in Table 2 with the present data. The beam switch magnet is given by the name of BSW.

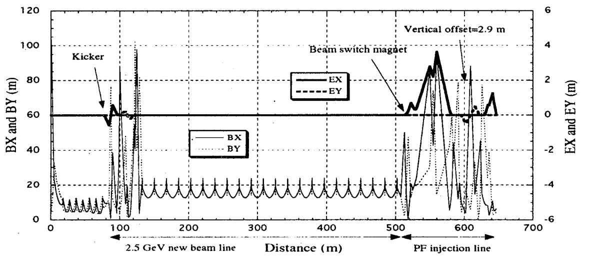

Fig.5 Twiss parameters to the PF ring from the beginning of the C-sector through the new beam line.

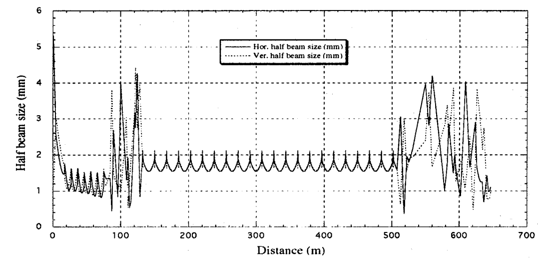

Fig.6 Beam size from the beginning of the C-sector to the PF ring through the new beam line. The effect of the momentum compaction is not considered.

Table 2
MAGNET PARAMETERS OF PF INJECTION LINE.

Element	K-value	Angle (deg)	Length (m)	Gradient (T/m)	Field (T)	Present (T/m or T)
(1) First section						
QAD1	-0.186	-	0.20	-7.761	-	-
QAF1	0.271	-	0.20	11.306	-	-
QA1	-0.281	-	0.30	-7.817	-	2.865
QB1	0.291	-	0.30	8.084	-	-5.347
QB2	-0.056	-	0.30	-1.551	-	6.155
QC1	0.088	-	0.30	2.447	-	3.030
QC2	-0.188	-	0.30	-5.212	-	-5.596
QC3	0.130	-	0.30	3.612	-	3.218
BSW	-	5.000	2.00	-	0.364	-
BH1 x 2	-	7.506	1.05	-	1.040	1.040
BH2 x 2	-	7.501	1.05	-	1.039	1.040
(2) Second section						
QD1	-0.174	-	0.30	-4.827	-	-2.449
QD2	0.270	-	0.30	7.493	-	2.604
QD3	0.300	-	0.30	-8.340	-	-7.260
QD4	0.262	-	0.30	7.279	-	6.153
QE1	-0.303	-	0.30	-8.423	-	-8.432
QE2	0.212	-	0.30	5.903	-	5.087
QE1	-0.303	-	0.30	-8.423	-	-8.432
QF1	0.270	-	0.30	7.493	-	7.896
QF2	-0.313	-	0.30	-8.712	-	-8.879
QG1	0.269	-	0.30	7.480	-	7.514
QG2	-0.275	-	0.30	-7.655	-	-7.517
QG3	0.352	-	0.30	9.785	-	9.605
QG4	-0.200	-	0.30	-5.565	-	-5.152
BV1	-	-6.211	1.05	-	-0.860	-1.037
BV2	-	6.211	1.05	-	0.860	1.037
BH3 x 2	-	6.002	0.84	-	1.040	1.040
BSP1	-	-7.000	1.50	-	-0.679	-0.679
BSP2	-	-5.000	1.00	-	-0.728	-0.728

4 AR Beam Injection Line

As shown in Fig.3, the beam is guided by the alternate excitation of the beam switch magnet. As the present injection line is common to the KEKB electron transport line except for the last curved section, this switch magnet has to be followed by a new 2.5 GeV AR beam line which is connected to the existing last curved section at 1.8 m beam level. Twiss parameters and beam sizes are given in Fig.7 and Fig.8, respectively, from the beginning of the C-sector to the end of the AR injection line. Also in Fig.8, $\eta_x(\Delta p / p_0)$ and $\eta_y(\Delta p / p_0)$ are not considered.

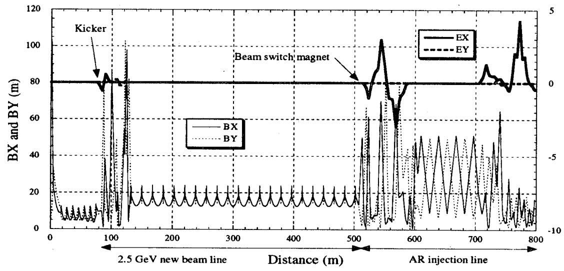

Fig.7 Twiss parameters of the AR injection line from the beginning of the C-sector of linac.

The AR injection line is divided into 3 sections (Fig.9), curved section-1, straight section and curved section-2. As the curved section-2 (last curved section) is independent of the KEKB injection lines, it is used by adjusting the excitation parameters so as to connect twiss parameters at both ends as given in Table 3, where the first two quadrupoles (QAD1 and QAF1) and the beam switch dipole (BSW) are same as in Table 2.

The straight section has enough length (about 100 m) to accommodate several regular cells. Although it is possible to use quadrupole triplets, a small number of FODO cells is adopted allowing larger betatron function.

Table 3
MAGNET PARAMETERS OF AR INJECTION LINE.

Element	K-value	Ang (deg)	Length (m)	Grad (T/m)	Field (T)
(1) Curved section-1					
QAD1	-0.186	-	0.20	-7.761	-
QAF1	0.271	-	0.20	11.306	-
QD2	-0.346	-	0.35	-8.255	-
QF2	0.400	-	0.35	9.524	-
QD3	-0.470	-	0.35	-11.202	-
QXF1	0.130	-	0.50	2.169	-
QXD2	-0.332	-	0.50	-5.543	-
QXF2	0.234	-	0.50	3.895	-
QXD3	-0.256	-	0.50	-4.267	-
QXF3	0.320	-	0.50	5.338	-
QXD4	-0.279	-	0.50	-4.652	-
QXF4	0.232	-	0.50	3.871	-
QXD5	-0.198	-	0.50	-3.295	-
QXF5	0.133	-	0.35	3.173	-
BSW	-	-5.832	2.00	-	-0.424
BA x 5	-	-5.832	2.00	-	-0.424
(2) Straight section					
QXD6	-0.272	-	0.50	-4.545	-
QXF6	0.443	-	0.50	7.380	-
QXD7	-0.377	-	0.50	-6.282	-
QFA1	0.274	-	0.50	4.562	-
QDA1	-0.125	-	0.50	-2.076	-
QWF x 4	0.097	-	0.50	1.615	-
QWD x 3	-0.109	-	0.50	-1.813	-
(3) Curved section-2					
QRD1 x 2	-0.128	-	0.36	-2.955	-
QRF2	0.256	-	0.36	5.926	-
QRF3	0.173	-	0.36	4.004	-
QRD4 x2	-0.219	-	0.36	-5.077	-
QRF5	0.227	-	0.36	-5.259	-
QRF6	-0.310	-	0.36	-7.172	-
QFO1 x 3	0.309	-	0.36	7.166	-
QDO1 x 2	-0.285	-	0.36	-6.600	-
QDO2 x 2	-0.296	-	0.36	-6.864	-
QFO2	0.288	-	0.36	6.681	-
QFO3	0.354	-	0.36	8.208	-
QDO3	-0.318	-	0.36	-7.372	-
BHR1 x 4	-	5.384	1.00	-	0.783
BVRU x 2	-	-4.779	1.00	-	-0.695
BVRD x 2	-	4.779	1.00	-	0.695
BHR2x 14	-	6.429	1.00	-	0.936
BHR3	-	7.558	1.00	-	1.100
BR2E	-	4.368	1.20	-	0.530
BR1E	-	2.406	1.20	-	0.292

5 Effects of Random Alignment and Excitation Errors

To estimate the orbit deformation due to the quadrupole misalignment and excitation error, random error are given to all quadrupoles. Ten cases were treated for different random numbers.

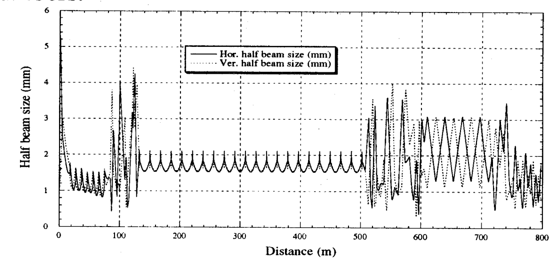

Fig.8 Beam sizes of the AR injection line from the beginning of the C-sector of linac.

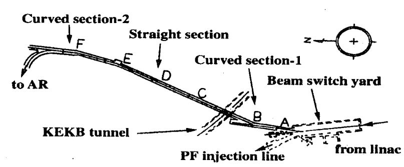

Fig.9 Layout of the AR and KEKB injection tunnel.

5.1 Quadrupole Misalignment

It is assumed that every quadrupole has alignment error in all directions between -0.3 ~ 0.3 mm. The rms orbit distortions are given in Fig.10 for the PF injection line and Fig.11 for the AR injection line. Large misalignment effects are expected from these figures.

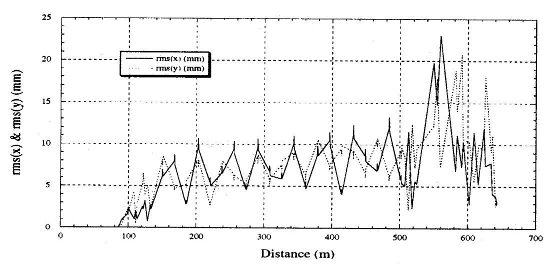

Fig.10 Orbit distortion due to the random quadrupole misalignment for the PF injection line including new linac beam transport line.

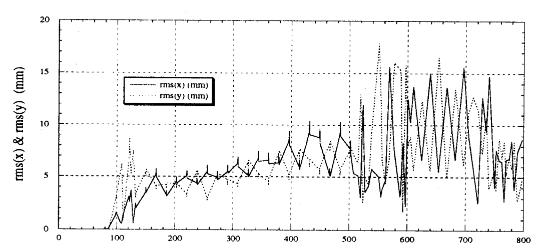

Fig.11 Orbit distortion due to the random quadrupole misalignment for the AR injection line including new linac beam transport line.

5.2 Quadrupole Gradient Error

Under an assumption that every quadrupole has a random gradient error between -0.01~0.01 T/m (percent error depends on the excitation level), effects on the betatron and dispersion functions are examined. According to the computer simulations, effects of the random gradient errors are very small for above error range.