BEAM OPTICS MATCHING IN THE KEKB INJECTOR LINAC

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Abstract

The upgrade of the KEK electron/positron linac for the KEK B-factory project is proceeding. The beam commissioning of the first 1.5-GeV section of the linac and the 180-degree arc section has been performed. This paper reports on the beam optical matching in the linac and the optical parameter tuning of the arc for the achromatic and isochronous conditions.

INTRODUCTION

The KEK B-factory is an asymmetric collider of 8.0-GeV electrons and 3.5-GeV positrons. For full-energy injection into the storage rings, the original 0.25-GeV positron generator linac and 2.5-GeV electron/positron injector linac were upgraded to 1.5-GeV and 6.5-GeV energies respectively and connected by a 180-degree arc [1]. The positron production target has been moved to a position where the electron beam energy is 3.7 GeV. The designed beam intensities are 1.2 nC/pulse for injection into the electron storage ring and 10 nC/pulse for positron production. One of the most important issues in the beam commissioning of the KEKB injector linac is the transport of the intense electron beam from the bunching section through the linac and the 180-degree arc to the target. In the fall of 1997, the beam commissioning of the 1.5-GeV linac commenced. The beam optical matching in the 1.5-GeV linac has been performed. We measured the emittances at three points along the linac. Though the observed Twiss parameters agreed well with the designed values, a large emittance growth was observed. The measured data were compared with the preliminary results of a particle-tracking simulation. For beam transport through the arc with minimum degradation of beam quality, achromatic and isochronous conditions have to be satisfied. An extensive survey of the beam optical parameters tuning of the arc was performed. For the calculation of beam optics, the TRANSPORT [2] and SAD [3] codes were used.

1.5-GEV LINAC OPTICS

The 1.5-GeV linac (130 m long) is composed of a pre-injector and 11 accelerator units. Each unit has four 2-m accelerating structures (21 MV/m) fed by a 50 MW S-band klystron. In the pre-injector, the electrons from the 200-kV electron gun are compressed to a single-bunched beam by two sub-harmonic bunchers, a pre-buncher and a buncher [4]. During rf-bunching, the beam is focused by a 1.0-kG solenoidal field supplied by Helmholtz coils. At the exit of the bunching section, it has an energy of 19 MeV. The latter part of the pre-injector is used for acceleration up to 70 MeV, for beam diagnostics (emittance, energy distribution, bunch time structure) and for matching to the downstream lattice. Quadrupoles are placed every 3 to 6 meters in the first three units and every 10 meters in the subsequent eight units. Focusing strengths were set to achieve almost 90-deg betatron phase advance per cell. The calculated beta functions and beam envelopes are shown in Fig.1.

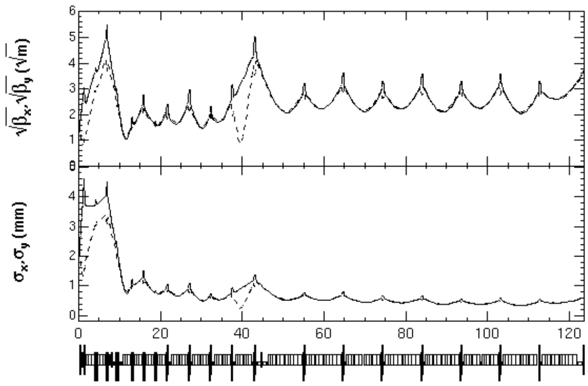

Figure: 1 Calculated beta functions and beam envelopes of the 1.5 GeV linac. (Solid: horizontal, Dashed: vertical)

For matching of the beam from the solenoidal focusing system to the periodic quadrupole cells, the emittance just after the buncher was measured by scanning the quadrupole strength and observing the beam spot size on the screen monitor. To reduce errors in the beam size measurement, we used a CCD camera which can be triggered in synchronization with the beam arrival [5]. The data points for the different quadrupole strengths were fitted to evaluate the emittance and the Twiss parameters. Based on the measured results, the quadrupole strengths were calculated to achieve matching. To compare the beam emittances along the linac with the designed optics, we measured them at the 0.5-GeV point and at the end of the 1.5-GeV linac. An example of the measured data is shown in Fig.2. Though the result of the matching was good, the emittance was observed to grow along the length of the linac, as shown in Fig.3. The effects of the chromaticity and of wake fields were expected as causes of the growth. To evaluate the effect of chromaticity, particle tracking simulations were performed. One thousand macro particles were tracked along the linac with the designed optics in six dimensional phase space. The variation of the r.m.s. emittance calculated by the transverse distribution of the macro-particles are plotted in Fig.4. A large emittance growth occurred when a large energy-spread at the pre-injector was assumed. However, the expected emittance growths were much smaller than the measurements. Further simulation studies including wake field effects is necessary and will be performed later.

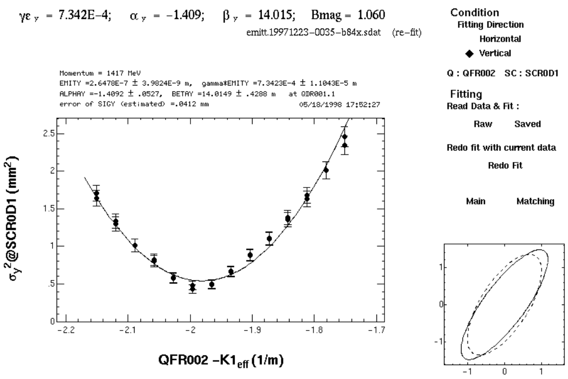

Figure: 2 Emittance estimated from the measured beam sizes while scanning quadrupole strengths. Observed phase ellipse (solid) is compared with the designed optics (dashed).

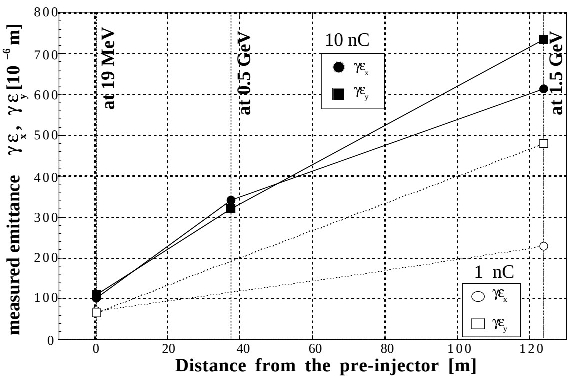

Figure: 3 Observed emittance growth for 10 nC and 1 nC beams.

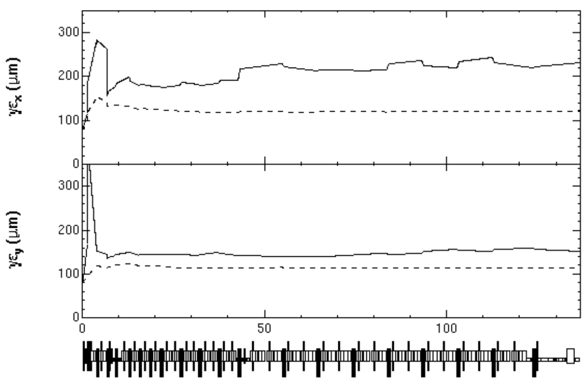

Figure: 4 Simulated emittance growth (Solid:dE/E = +/-30%, Dashed:dE/E = +/-20% after the buncher. Initial emittance = 85 μm)

ARC BEAM OPTICS TUNING

To preserve the emittance and bunch time structure during passage through the arc, the transport system was designed to be achromatic and isochronous. The arc is composed of six 30-degree bending magnets, seven quadrupoles and six sextupoles as shown in Fig.5. Strip-line type beam position monitors (BPMs) (resolution ~100 microns) [6] are set in most of the quadrupoles for orbit and dispersion measurement. A bunch monitor using optical transition radiation (OTR) viewed by a streak camera is placed just after the arc. It measures the bunch time structure and arrival time at 2-psec resolution [7].

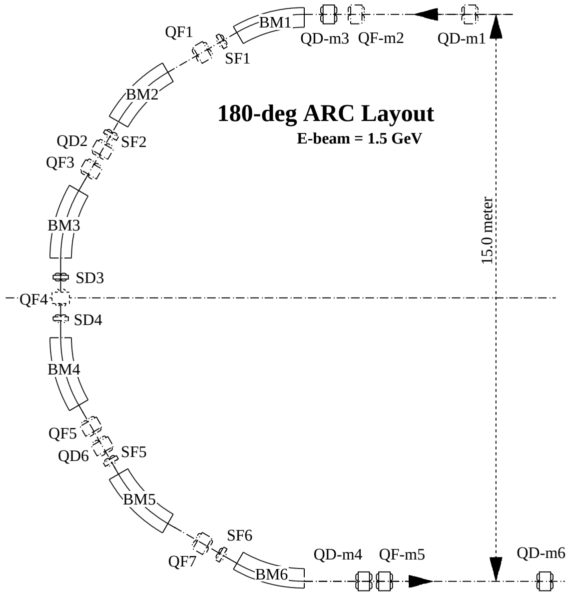

Figure: 5 Layout of the 180-deg arc.

At the start of optical parameter tuning of the arc, the designed values of quadrupole strengths to fulfill the first order achromatic and isochronous conditions were set as shown in Fig.6. The sextupoles were not used at that time.

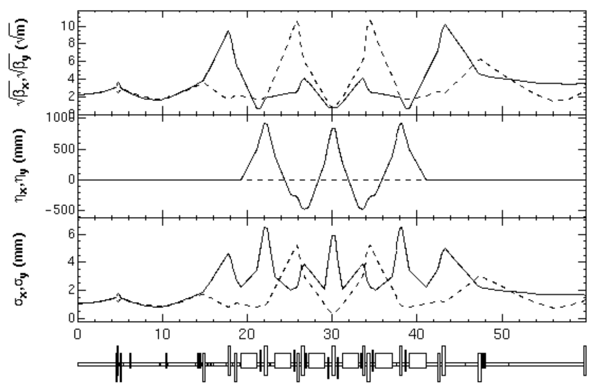

Figure: 6 First order achromatic and isochronous optics of the arc.

To evaluate the dispersion functions in the arc, we used the BPMs to measure the change of the beam position due to the deviation of the beam energy from the nominal value as shown in Fig. 7. The energy was changed by shifting the accelerating rf-phases of the last two accelerator units; the phases were changed in opposite directions from the crest to keep the energy spread small.

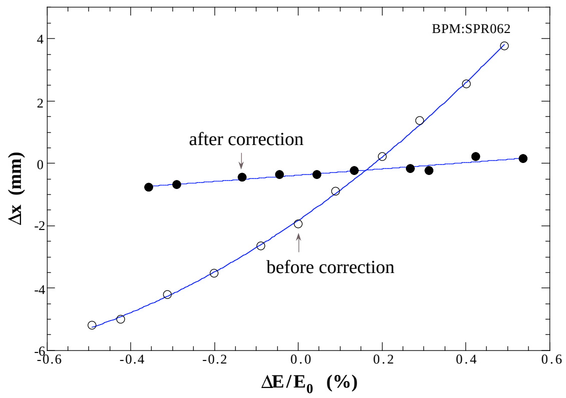

Figure: 7 Dependence of the horizontal orbit on the energy deviation. (White: before, Black: after optical parameter tuning)

By fitting a second-order polynomial to the data, the first- and second-order transverse components of the transfer matrix (R16=$\Delta x/(\Delta E/E_0)$ and R166=$\Delta x/(\Delta E/E_0)/(\Delta E/E_0)$) were obtained. Vertical components R36, R366 were also obtained. The measured dispersion functions are shown in Fig.8.

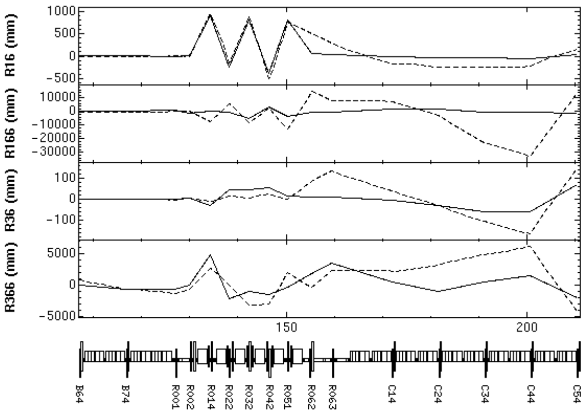

Figure: 8 Measured dispersion function around the arc. (Dashed: before, Solid: after optical parameter tuning)

Though the designed dispersions after the arc were zero, finite values were observed in the first measurement. The correction factors of the quadrupole strengths for fulfilling the achromatic condition were calculated from the observed R16 components. The quadrupoles were adjusted with these factors and the dispersions were measured again. First order dispersions were greatly reduced, however there were still large second order components. For suppressing them, the desired values of the sextupole strengths were calculated and set. The results of the correction of the sextupoles were satisfactory as shown in Figs .7 and 8.

With this dispersion-free beam condition, we proceeded to the measurement of the isochronicity. The changes of the beam arrival times were measured using the OTR monitors while deviating the beam energy as in the dispersion measurement. The arrival times were determined from the center-of-mass values of the gaussian-fitted bunch time structures. The correction factors of the quadrupole strengths for fulfilling both the achromatic and the isochronous conditions were calculated from the data and set. As seen in Fig. 9, the correction was successful.

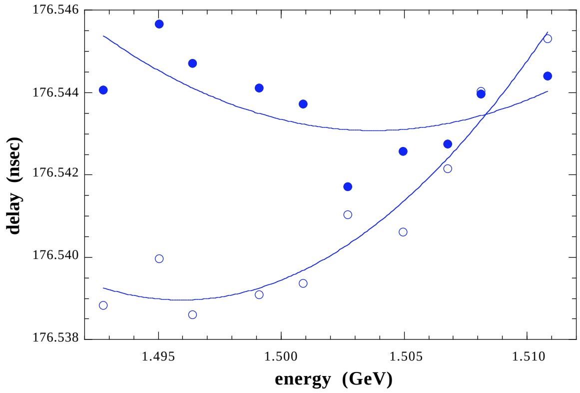

Figure: 9 Measured isochronicity just after the arc. (White: before, Black: after optical parameter tuning)

SUMMARY

In the beam optical matching in the 1.5-GeV linac, the measured Twiss parameters agreed well with the design, however large emittance growths were observed. The measured data and the preliminary results of simulation were shown. The results of the optical parameter tuning for the achromatic and isochronous conditions of the arc were also presented. The leakage dispersions and the non-isochronicity which observed in the first measurement were well suppressed by fine tuning of the quadrupole and sextupole strengths.

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