OPTICS CORRECTION FOR KLYSTRON SWITCHING AT THE KEKB INJECTOR LINAC

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Abstract

For the high luminosity operation of the KEKB-factory, the beam injection time from the linac to the storage rings is desired to be short. However, the injection is sometimes interrupted by a temporary rf-trip of the klystron. In case of a serious failure, the klystron is switched to a spare one to compensate for the acceleration energy. After the switching, the injection is often degraded because of the beam optical mis-matching due to the change in the beam energy at each quadrupole. We have developed software which can estimate the beam energy at each quadrupole, calculate the optics so as to achieve the desired matching and change the settings of the relevant quadrupoles in short time. The experimental result of the recovery of the optical matching is also shown.

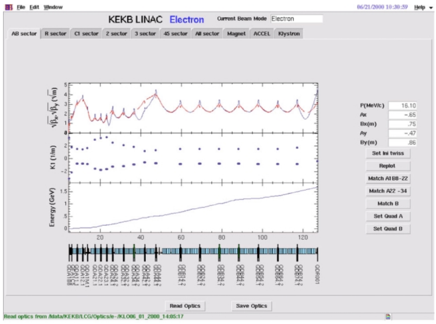
1 INTRODUCTION

The KEK B-factory (KEKB) is an asymmetric-energy electron-positron collider for the research of B-meson physics, especially CP violation. To obtain a sufficient number of useful collision events, not only achieving high luminosity during beam collision but also maintaining a good condition of the whole accelerator system, is important.

In KEKB operation, the linac injects beams to the storage rings approximately every 2 hours to compensate for any decrease of the stored beam currents. One of the frequent problems which prevent injection is a temporary rf-trip of the klystrons in the linac. In most cases, because a tripped klystron recovers as it is in several seconds, it is not a serious problem. However, in some cases, the klystron repeats discharging frequently, and requires a rf-conditioning time for recovery. In that case, the operator decides to switch the troubled klystron to a spare one to compensate for the acceleration energy.

In the beginning of a beam tuning, the field strengths of the quadrupole magnets are set to achieve the desired optical matching according to the beam energy in each position. However, when switching of the klystron has occurred, because of a change in the beam energy in the region between these switched klystrons, optical mismatching arises. This cause a degradation of the injection efficiency to the storage rings, in some cases, serious beam loss in the injector linac.

To maintain a good injection condition, even in the case of klystron switching, a correction of the optics according to the change in the acceleration energy is necessary. We have developed software which can evaluate the beam energy at each quadrupole, and calculate the optics so as to achieve the desired matching condition and change the settings of the relevant quadrupole magnets. (See the figure 1 as for the user interface.)



Current Beam Mode Electron

P(MeV/c) 16.10
Ax -.65
Bx(m) .75
Ay -.47
By(m) .86

Read optics from /data/KEKB/LCG/Optics/e-/KLO06_01_2000_14:05:17

Figure 1: User Interface of the software for the beam-energy estimation, the optics correction and the quadrupole setting

2 BEAM-ENERGY ESTIMATION

In this section we describe the various factors which are used in estimating the beam energy at each quadrupole magnet. Before mentioning each factor, the components of the KEKB injector linac are briefly reviewed. The most fundamental block forming the linac is an "acceleration unit", which is comprised of an S-band klystron and four 2m-long accelerating structures. These four structures have a common phase of the microwaves supplied from the klystron with respect to beam passage. This phase can be changed with the phase-shifter of each klystron and with that of the sub-booster, which supplies microwaves to a set of the eight klystrons, typically. The structures in same unit have almost equal field gradients, except for a slight difference in the shunt impedances. From the viewpoint of beam focusing, in most regions of the linac, a doublet or a triplet of the quadrupoles is placed in every unit. Thus a unit forms a cell of a periodic lattice.

The beam energy at each quadrupole magnets is estimated based on the following factors: (1) the acceleration field, (2) the acceleration phase, (3) the klystron status, (4) the longitudinal wake-field effect and (5) the normalization factor.

(1) The field gradient in each accelerating structure is estimated from the rf-power supplied from the klystron and the shunt impedance of the structure. The rf-power from the klystron is estimated based on the characteristic curve describing the relation between the supplied high voltage and the output power. The curve for each klystron is obtained from a measurement in the test stand. The shunt impedances are measured for each types of the accelerating structure. In the KEKB linac, at least five different types of the structure are used. They are all quasi-constant gradient type of structures, but have slightly different dimensions to spread out the resonant frequencies of the harmful wake-field component.

(2) The acceleration phase for each unit is given by the difference between the present rf-phase setting and the crest phase for maximum acceleration. The rf-phase is determined from the setting of the klystron phase-shifter and the sub-booster phase-shifter. The crest phase for each unit is determined by measuring the beam energy while changing the rf-phase at the 1.7-GeV 180-deg arc or at the end of the linac.

(3) The klystrons used for beam acceleration are triggered in synchronous to the beam arrival timing (the acceleration state). On the contrary, the spare klystrons are triggered out of the timing (the stand-by state) so as not to affect the beam. In switching the klystrons, the trigger timing of a failed klystron is changed to the stand-by state, and one of the spare klystron's to the acceleration state. In calculating the beam energy, the status of the klystron is checked so as to decide whether it contributes to acceleration or not.

(4) A single-bunch beam loading effect in the accelerating structure due to the longitudinal wake field is taken into account. The wake function of the accelerating structure has been measured for some typical structures. Since the effect is charge-dependent, the charge intensity at each position, which is measured with a strip-line type beam-position monitor, is used for the calculation.

(5) The estimated beam energy includes errors in the factors. Therefore, the estimated value, e.g. at the end of the linac, may be slightly inconsistent with the energy defined for the injection. To match the difference, the beam energy at each position is re-scaled so as to achieve the following conditions: the energy at the 180-deg arc is 1.7 GeV, the final energy of the positrons is 3.5 GeV and the final energy of the electrons is 8.0 GeV. For the case of injection to the Photon Factory ring and to the Accumulator Ring for SR applications, the beam energy is normalized to be 2.5 GeV.

3 OPTICS CORRECTION

Here, we describe the procedure for beam optical tuning of the focusing quadrupoles and their correction for klystron switching, taking the first 1.7-GeV linac before the 180-degree arc as an example. A typical result of the improvement of the optical parameters by the correction is shown.

The 1.7-GeV linac has two important matching sections. One is at the pre-injector, for matching the beam from the rf-bunching section focused by the solenoids to the quadrupole focusing system. The other is for the beam at the end of this linac to match to the special optics of the 180-degree arc, which was designed to be achromatic and isochronous. The details concerning the optical tuning of the arc itself, are described elsewhere [1].

At the pre-injector, the beam optical parameters, like the emittance and the Twiss parameters, are evaluated from the measured beam size on a screen monitor by changing the focusing strength of a quadrupole magnet. These measured parameters are used as the initial condition for the beam optics calculation performed with the SAD code [2] to achieve matching to the downstream focusing system. The 1.7-GeV linac can be divided into three parts which have different lattices. The quadrupole triplets are placed after every accelerating structure in the first two acceleration units, and every two or every four structures in successive two and eight units. The betatron phase advance is generally designed to be 90-degree per cell. Matching between the different lattices is performed only by a calculation. Matching at the end of the linac is performed using the measured optical parameters along with wire scanners [3] to accommodate any deviation from the design optics. This is because precise matching is required to avoid beam loss in the arc, which has a limited acceptance in the energy and in the transverse phase space.

For a beam-optics calculation with the SAD code and for translating the calculated k-values of the quadrupoles into the field strength of the magnet, information concerning the energy gain in each accelerating structure and the beam energy at each quadrupole is necessary. It is estimated as described in the previous section. The supply current of the magnet is determined from the field strength with an excitation curve which has been measured for each type of magnet.

During normal operation, the beam optical parameters are well matched to the designed optics, resulting in negligible beam loss. When one of the klystron fails because of frequent rf-trips, it is changed to the stand-by state. Instead, one of the spare klystrons is set to the acceleration state to compensate for the acceleration energy. In some cases, the energy is compensated just by changing the phase of the klystrons used for adjusting the beam energy to fit with that of the arc, instead of using a spare klystron. After switching the klystrons, the beam energy is considerably changed at each quadrupole and the focusing strength is deviated from the matched condition. To correct this optical mismatching, the beam energy for each quadrupole magnet is recalculated based on the new status of the klystrons. Based on this beam energy, the focusing strength of the quadrupoles is calculated so as to achieve the desired matching. The supply current settings of the quadrupoles are changed according to the result of the calculation.

4 EXPERIMENTAL RESULTS

In the beam operation for the commissioning of the KEKB, the software has been proved to be very useful. Most successful improvement was in the case of the serious failure of the klystron which supply rf-power into the second acceleration unit after the positron capture section. Since this unit resided in quite upstream in the positron accelerator, the change in the beam energy was very large (67% at maximum). Most of the beam charge was lost in this unit due to the enormous optical mismatching. In this occasion, the beam commissioning members have soon decided to correct the matching by using this software. Soon after finishing the calculation, the quadrupole settings were changed and resulted in almost full recovery of the beam intensity.

Recently, we have performed an experiment which demonstrate the improvement of the optical matching by measuring the beam optical parameters, like the emittance and the Twiss parameters. It is performed at the 1.7-GeV linac which included the pre-injector and the eleven acceleration units before the 180-degree arc. The optical parameters were measured just before the arc. In order to see the change in the optical parameters by a klystron switching and also by a correction of the optical matching, the klystron for the third acceleration unit after the pre-injector was set to the stand-by state on purpose. Instead, the rf-phases of the eighth and ninth units were adjusted so as to compensate for the acceleration energy. The estimated beam-energy in each accelerating structure is shown in Figure 2 and 3. There is no acceleration in the 11-th to 14-th accelerating structures which corresponds to the klystron turned off. The acceleration energy is compensated in the 31-st to 38-th structures, so as to obtain same energy at the arc. The ratio of a change in the beam-energy is around 28 %.

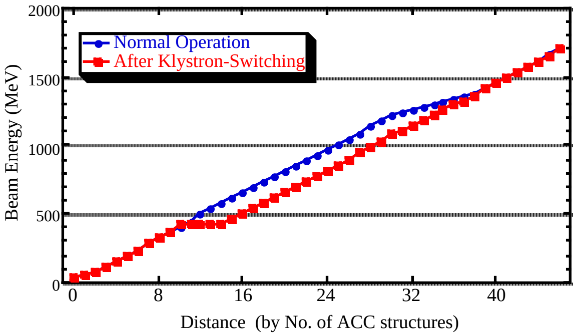


Figure 2: Change in beam-energy due to the klystron switching (absolute value)

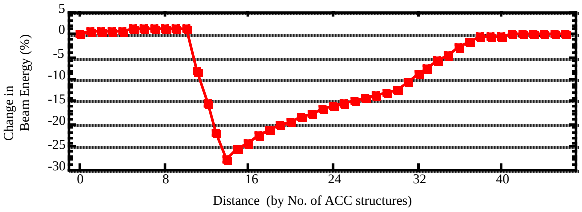


Figure 3: Change in beam-energy due to the klystron switching (ratio)

At first, the optical parameters with the normal operation states were measured. (data (1) in Table. 1 and Figure. 4) Then, the data (2) with the klystrons switched were taken. With this beam-energy condition, two kinds of the optics correction were applied. As a simple and quick correction, all the quadrupole settings were changed to have the same k-value as before the klystron switching. Finally, the full correction which re-calculated the optical matching all through the beam-line was applied.

Table 1: Measured Optical parameters

	Twiss parameter		**Emittance**
	α ,	β [m]	[10^-6 m]
(1) Normal state	3.4,	3.0	184
(2) KLY down	7.0,	9.0	96
(3) Simple Corr.	6.5,	5.9	107
(4) Full Corr.	3.2,	2.7	165

Figure 4: Measured emittance ellipses

Clear deviation of the optical parameters was observed by the klystron switching (data (2)). It was improved to some extent with the simple correction and improved much better with the full correction.

4 CONCLUSION

We have developed software which can evaluate the beam energy at each quadrupole and calculate its focusing strength so as to achieve the desired matching conditions. In the case of klystron switching due to rf-trips, it is used to correct for any mismatching of the optics. The experimental results show that it can well recover the optical matching.

REFERENCES

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