Distortion of the Booster Optics Due to Edge Effects of the Injection Bump Magnets

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Abstract

When an H^- injection bump system, which consist of four rectangular dipole magnets, is installed in a short straight section, edge effects of the bump magnets can be appreciably large. The Twiss parameters and the dispersion function may be considerably distorted by these effects. Results of calculation are described for a case of the KEK-PS booster synchrotron.

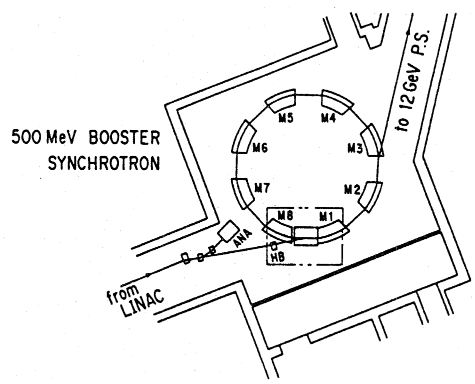
I. INTRODUCTION

At the KEK-PS booster synchrotron, a project for increasing the beam intensity has been undertaken since the injection scheme was changed to the H^- charge-exchange injection from the proton multiturn injection and the injection energy was upgraded from 20 to 40 MeV in 1985. The beam intensity gradually increased, and recorded the maximum instantaneous intensity 2.2×10^{12} ppp in 1989. Recently the beam intensity averaged in a cycle steadily maintains a level of about 1.7×10^{12} ppp that is three times as high as the value before the change of the injection scheme.

As the beam intensity increased, however, two serious problems came to the fore. One is that the harmful residual activity due to beam loss becomes as high as over 20 mSv/hr at some particular points around the booster ring. The other problem is that the vertical emittance of the beam accelerated in the booster is considerably large and this fact might be related with the bad condition of beam injection into the main ring. This emittance growth in the booster may also be the cause of beam loss. These two problems are now the main themes of accelerator studies at the KEK-PS booster.

Optical mismatch between the injected H^- beam and the booster optics has been repeatedly investigated since it is a possible cause of emittance growth of the beam accumulated in the booster. It turned out not straightforward to match the H^- beam from the linac with the synchrotron optics. Determination of the ion optical parameters of the H^- beam, such as the Twiss parameters and the dispersion function, is not so straightforward, because the phase-space distribution of the linac beam is considerably complicated. Moreover, the ion optical parameters of the booster are also ambiguous before confirmation by measurement because they can be modified by some other devices installed in the ring, such as the H^- injection bump system.

In such a small ring as the KEK-PS booster, the straight sections are short and the edge effects of the injection bump magnets become so strong that the ion optical parameters of the ring are considerably distorted. In the following, results of calculation are described on the distortion of optical parameters due to the edge effects of the H^- bump magnets, and also on a way for correcting the distortion with a correction quadrupole magnet.



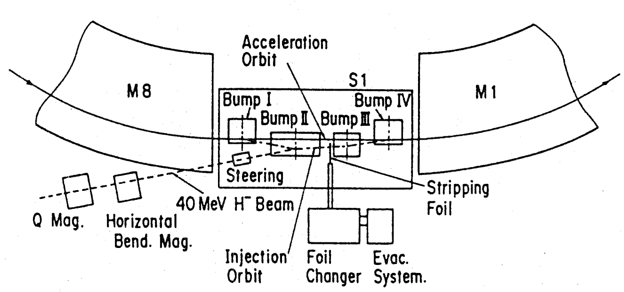


Fig. 1 The KEK-PS booster synchrotron and the H^- injection bumper system.

II. EDGE EFFECTS OF THE H^- INJECTION BUMP MAGNETS

A. The H^- Injection Bump magnets

The KEK-PS booster synchrotron consists of 8 combined type magnets which are conventionaly called as M1, M2, - - -, M8 as is shown in Fig. 1. The straight sections between magnets are also called as S1, S2, and so on in order. S1 is the straight section where the H^- injection bump system is installed. The H^- injection bump system [1] consists of four rectangular dipole magnets; Bump I through Bump IV. They form a bumped closed orbit during beam injection. The top part of the bump, which is overlapped with the injection orbit, is separateded 60 mm away from the acceleration orbit and passes through the stripping foil. The stripping foil is set 50 mm away from the acceleration orbit in order to secure the nesessary aperture for the beam circurating on the accelerating orbit. An injected H$^-$ beam comes on the injection orbit, goes through the stripping foil, changes to a proton beam and then starts to circulate on the bumped closed orbit. After the beam injection is completed and the bump magnets are turned off, the captured proton beam is brought back to the accelerating orbit and is ready for acceleration.

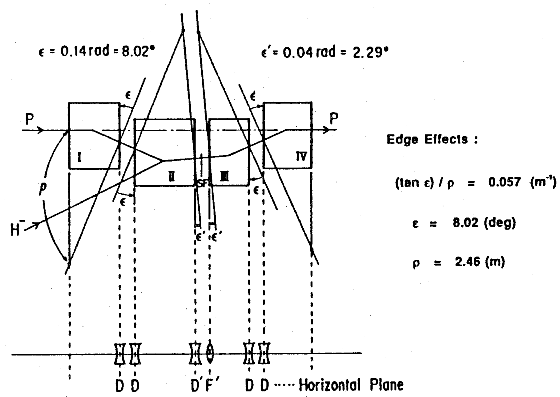


Fig. 2 The injection bump orbit and the edge effects.

B. Edge Effects of the Bump Magnets

Figure 2 schematically shows the injection bump magnets and the bump orbit. As the magnets are of rectangular type, the bump orbit crosses edges of magnets with angles shown in the figure except for the upstream edge of Bump I and the downstream edge of Bump IV. Because the magnet system is not symmetric, the part of bump orbit from Bump II to III is slightly inclined to edges of those magnets. The downstream edge of Bump II is defocusing in the horizontal plane, but the upstream edge of Bump III focusing. Therefore these edge effects cancel each other. As for four edges from Bump I to II and from III to IV, however, the inclination of the bump orbit to the magnet edge is the same and considerably large. Therefore these edge effects act on the beam additively. As a result, the H$^-$ bump magnets act to the beam circulating on the bumped closed orbit like a quadrupole magnet deforcusing in the horizontal plane. The focusing strength at each edge is 0.057 m^{-1} and the total effect can not be ignored as is shown in the following sections.

This problem is common to the compact synchrotron such as the KEK-PS booster. The booster ring is compact and the straight section is as short as 2.1 m. The H$^-$ injection bump system, which is installed in one straight section, has to make a 60 mm orbit separation to keep sufficient acceptance for the accelerated beam. Thus, the bending angle of the bump magnets becomes as large as 0.14 rad and the edge effects become noticeable. Of cource, there is no such problem, if the bump magnets are made of sector type.

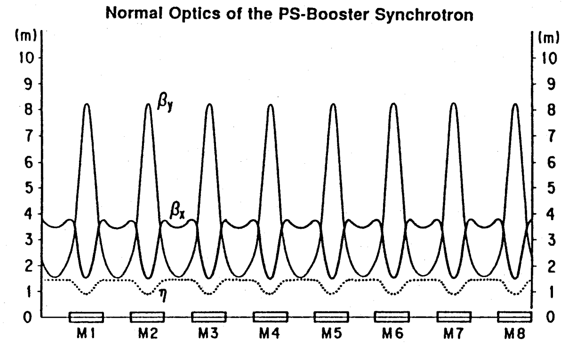


Fig. 3 The normal optics of the KEK-PS booster synchrotron.

III. RESULTS OF CALCULATION

The ion optical parameters of the KEK-PS booster synchrotron are calculated with a computer code SYNCH, using the lattice data reported in the reference [2].

A. Normal Optics

When the H$^-$ injection bump magnets are turned off, the optics of the booster synchrotron is that determined by the lattice magnets themselves. For convenience, we call this optics as the normal optics. The beta functions and the dispersion function of this optics are shown in Figure 3. The tune and the representative values of the beta functions and the dispersion function are as follow.

$\nu_x = 2.17$,	$\nu_y = 2.33$
$\beta_x(\max) = 3.77$ m,	$\beta_x(\min) = 1.50$ m
$\beta_y(\max) = 8.25$ m,	$\beta_y(\min) = 1.51$ m
$\eta_y(\max) = 1.43$ m,	$\eta_y(\min) = 0.88$ m

The optical parameters of the injected H$^-$ beam are usually adjusted to match this normal optics of the booster synchrotron.

B. Distorted Optics due to the Injection Bump Magnets

When the H$^-$ injection bump magnets are excited, the optics of the booster synchrotron is distorted by the edge effects. The calculation shows a considerable distortion of the optics as is shown in Figure 4. The tune and the representative values of beta functions and the dispersion function are as follow.

$\nu_x = 2.09$,	$\nu_y = 2.36$
$\beta_x(\max) = 7.58$ m,	$\beta_x(\min) = 1.01$ m
$\beta_y(\max) = 9.96$ m,	$\beta_y(\min) = 1.24$ m
$\eta_x(\max) = 5.31$ m,	$\eta_x(\min) = -2.56$ m

This optical distortion introduces two problems. One is that, because the maximum beta function and dispersion are enlarged, the maximum beam size becomes larger. In the vertical plane, $\beta_y(\max)$ is enlarged by a factor of 1.2 but this is not so serious. In the horizontal plane, $\beta_x(\max)$ becomes 2 times larger than the normal optics and $\eta_x(\max)$ 3.7 times. This enlargement, however, is neither so serious, because the horizontal aperture of the booster ring is sufficiently large and the optical distortion takes place only during the beam injection.

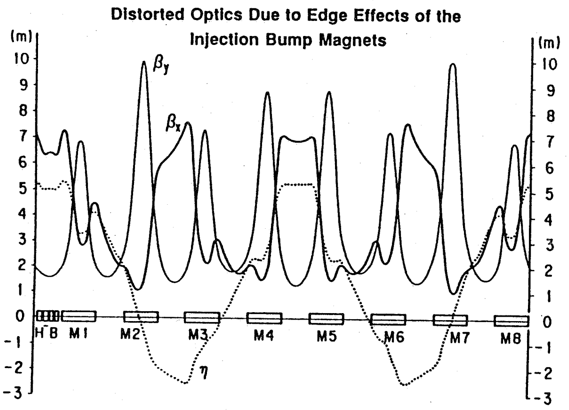


Fig. 4 The distorted optics due to edge effects of the injection bump magnets.

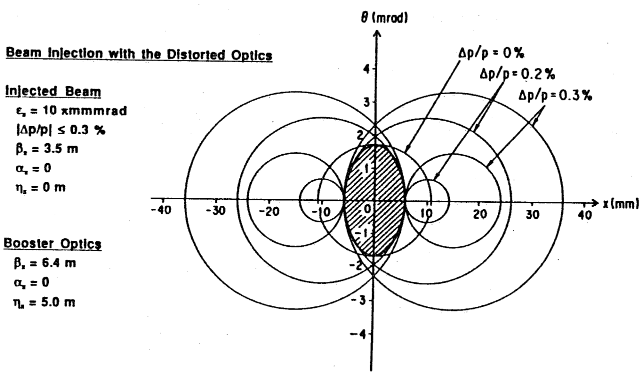


Fig. 5 Beam injection with the distorted optics.

The other problem is the optical mismatch between the injected H^- beam and the ring optics due to change of beta and dispersion functions at the injection point. In this case, dispersion mismatch is especially serious because the dispersion function becomes as large as 6.4 m at the injection point of the booster. Figure 5 shows how emittance of the injected beam is enlarged due to dispersion mismatch. So far the optical parameters of H^- beam at the end of the injection line, except for the dispersion function, have been adjusted to those of the injection point of the booster synchrotron in order to match the beam to the booster. The dispersion function of H^- beam is set zero, because the dispersion adjustment is not easy in the present injection beam transport. The momentum spread of the H^- beam is usually 0.3 %. Because the injection bump orbit, on which the beam is injected, is the central orbit for the beam without momentum error, the central orbit for the beam with momentum error is different from the injection bump orbit. Namely, an injection error is introduced for the part of the beam. Therefore, emittance of the part of the beam with momentum error becomes large after it begins to oscillate around its equilibrium orbit. The emittance of the beam with 0.1%, 0.2 % or 0.3% momentum error becomes 1.9, 4 or 6.9 times larger, respectively.

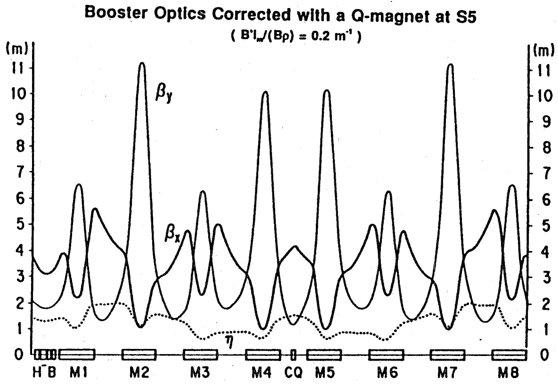


Fig. 6 An optics corrected with a quadrupole magnet at S5.

C. Corrected Optics with a Correction Q- Magnet at S5

As the distorted optics is twofold symmetric with respect to two axes at S1 and S5, it is expected that a quadrupole magnet installed in S5 may correct distortion of the optics. Correction is not perfect because the effect of the phase advance from S1 to S5 is not compensated by this way. Figure 6 shows the result of the correction. In this case, the beat of the beta function in the vertical plane is rather increased, but the amount of increase is acceptable. In the horizontal plane, the distortion of the dispersion function is remarkably decreased and beat of beta function becomes very small. Thus the optics matching at the injection is also remarkably improved. Figure 7 shows that emittance growth of the beam with 0.1%, 0.2% or 0.3% momentum error is suppressed at 1.2, 2.2 or 2.9 times, respectively.

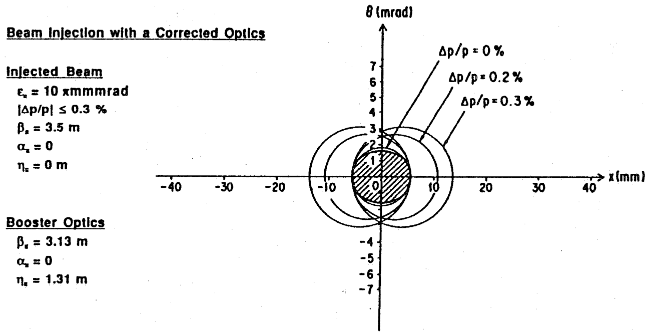


Fig. 7 Beam injection with a corrected optics.

IV. REFERENCES

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[2] M. Kumada, H. Sasaki, T. Takikawa, H. Someya, T. Kurosawa and Y. Miyahara, KEK-77-30, March 1978