ACCELERATOR STUDIES AT THE KEK-PS BOOSTER , PROBLEMS RELATED WITH HIGH INTENSITY BEAM

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Abstracts

The beam intesitry of the KEK-PS booster attained a level over 1.5 x 10^{12} ppp by a comprehensive and systematic tuning. Accompanying with beam intensity upgrade, residual activity around the booster ring and vertical beam blowup in the booster become two important problems to be solved before the booster beam intensity is increased higher.

1. Introduction

Increase of the booster beam intensity is a main theme of accelerator study that has been consistently undertaken since 1985, when the injection scheme was changed from the proton multiturn injection to the H^- charge exchange injection and the injection energy was upgraded from 20 to 40 MeV. Booster beam intensity gradually increased as the accelerator tuning was advanced. But beam intensity of the main ring did not increase as that of the booster. After a few years, it was made clear that beam intensity of the main ring had some limitations related with the injection porch and the transition energy. Then the aim to increase beam intensity of the main ring was changed to increase efficiency of data taking in physics experiments by expanding the length of the beam spill.

As for the booster, studies to increase beam intensity was continued as a project not only because BSF (the Booster Synchrotron Utilization Facility) eagerly required a beam as intense as possible, but also experience of those studies was considered to be very helpful for the future construction and operation of the high intensity proton accelerator that was planned in JHP (the Japan Hadron Project).

The target of the booster beam intensity was set as 2 x 10^{12} ppp, and this value was attained in 1989 as an instantaneous intensity. The standard intensity of routine operation, however, has been kept at a level a little over 1.5 x 10^{12} ppp, because residual radioactivity around the booster ring becomes harmful at some locations.

Two serious problems have come to the fore in this series of studies. One is the expected high level residual radioactivity around the booster ring and the other is abnormally large vertical emittance of the 500 MeV beam accelerated by the booster synchrotron. This latter problem was first indicated with respect to the bad condition of beam injection into the main ring. It also implied vertical beam blowup during acceleration in the booster, which would cause harmful beam loss in the ring.

Improvement of the RF system that played a very important role for increase of the booster beam intensity will not be mentioned in this report. But it will be reported in another paper of this proceedings [1].

2. History of the booster beam intensity

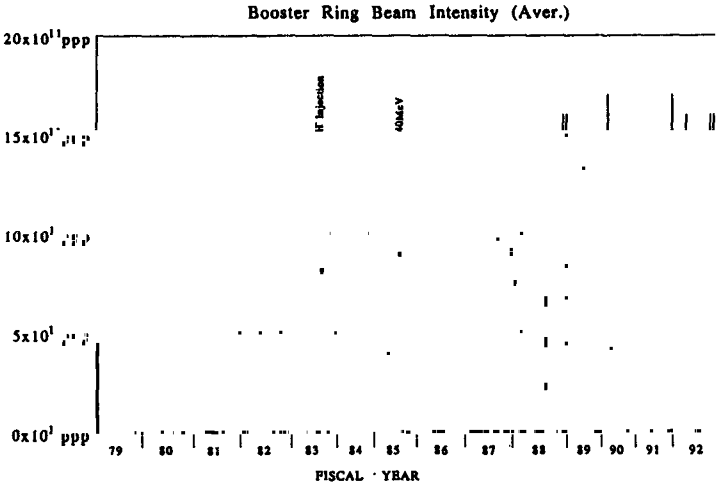


Fig. 1 Progress of the KEK-PS Booster beam intensity averaged in an operational cycle

Figure 1 shows the history of the booster beam intensity averaged in each operation cycle. A series of systematic tuning was undertaken in order to increase the booster beam intensity during '87 - '89. Main items of the tuning were

- correction of the booster injection error in both horizontal and vertical planes,
- adjustment of ionoptical parameters in the 40 MeV beam transport line,
- adjustment of RF power and phase of each linac tank,
- adjustment of ionoptical parameters in the linac injection beam line,
- adjustment of H^- beam intensity extracted from the ion source, and
- adjustment of the booster RF voltage program at the first stage of acceleration.

In these tuning following items were monitered as criteria for good tuning.

- Vertical and horizontal beam size observed by the profile monitor Pr5V or Pr6H respectively was sufficiently small.
- Injection efficiency of the booster was sufficiently high as.
- Beam loss during acceleration was sufficiently little as.

By this tuning booster beam intensity was gradually increased and in Feb. '89 the maximum beam intensity recorded 2.2 x 10^{12} ppp. Roughly speaking, this intensity is near to the space charge limit, 2.6 x 10^{12} ppp, that was calculated by T. Suzuki [2] .

Although intensity of proton beam showed temporary decrease, after the booster RF system was modified to cope with acceleration of a deuteron beam in '90, it recovered former value in '92 by efforts of the RF group. Recently the average intensity is cntrolled as a little over 1.5 x 10^{12} ppp in order to supress increase of residual radioactivity.

An important point to be mentioned with respect to beam intensity of the KEK-PS booster is the reliability of machine, (actual beam-on time) / (scheduled beam time). Reliability at BSF is usually no less than 95 % and this high reliability is considered to make for such a low average beam current as 5μA.

3. Distribution of residual radioactivity around the booster ring and monitoring beam losses

Figure 2 shows a recent distribution of residual radioactivity on surface around the booster ring. These data are usually measured three days after the end of an operation cycle 16 days long by persons of the radiation administration section. Distribution indicates three kinds of characteristic peak which should be harmful in the maintenance service.

peak A ----- peak at the beam extraction straight section (S3)
peak B ----- peak at the synchrotron magnet (M1) immediately downstream of the injection straight section
peak C ----- peaks at central part of the magnet M2 and M5

Beam loss distribution during acceleration along time axis is observed by loss monitors using ionization chamber [3] which are disposed around the booster ring as shown in Fig. 3. A typical variation of proton number during acceleration is shown in Fig.4 together with times when beam loss is observed. Beam losses are observed at following 6 times,

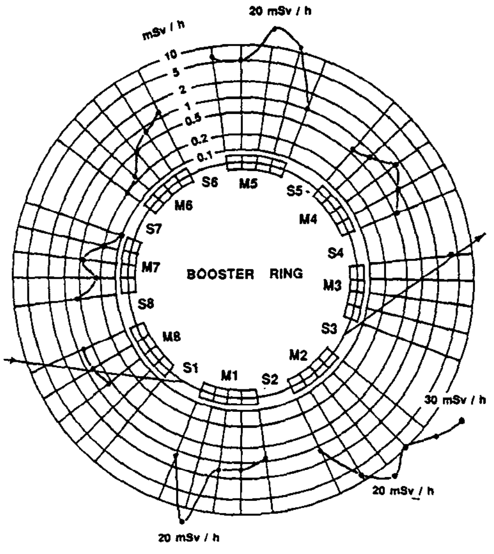
during injection,
at the instant when the injection bump magnet is turned off,
100 - 200 μsec after the start of injection,
about 1 msec after the start of injection,
some time later than fifteen msec after the start of injection, and
at the beam extraction instant.

These losses are called for the sake of convenience as " loss 1", " loss2 ", ---, " loss 6 " in order .

The peak A is obviously due to loss accompanying with the beam extraction , and corresponds to the loss 6. At the extraction, beam loss measured by current transformers is usually no more than a few per cent. Inspecting radioactivity distribution of the extraction septum, it was confirmed that a significant radioactivity was localized at the upstream end of the septum coil. At the extraction instant, the interval of two bunches is 167 nsec and the bunch length is typically 80 nsec. On the other hand, the rise time of the kicker magnetic field pulse is 80 nsec. Therefore the gap between two bunches does not have a sufficient margine and some fringe part of the beam bunch comes in the rising edge of the kicker magnetic field pulse. Such a part is insuficiently kicked and hits the septum coil.

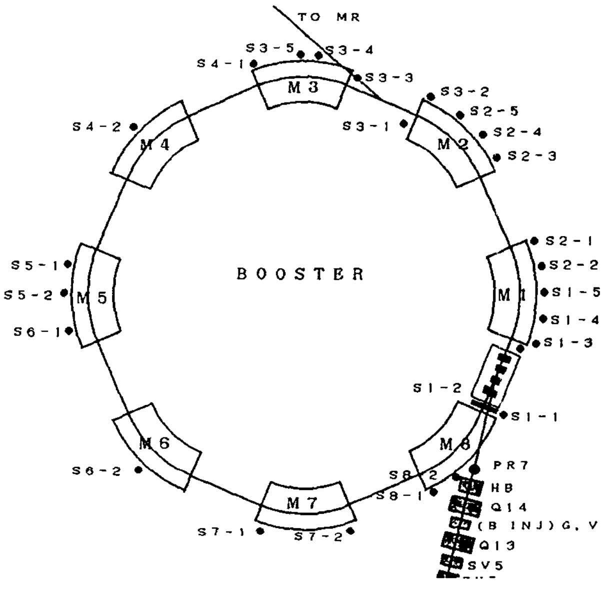
The cause of peak B has two conponents : the incompletely stripped H^0 atoms and the part of H^- ions which missed the stripping foil. It took place after the change of injection scheme and consisted of two constituent peaks. Using a loss distribution monitor [4], it was confirmed that the beam loss occured at the time of loss 1 and at two different but near locations as is shown in Fig. 5. The H^- ion part of the loss 1 can be controlled by adjustment of the foil position. The H^0 part also can be decreased to an allowable level by using a little thicker.foil

Observing loss monitors arranged near the peak C, it was found that beam loss causing it occurred at the time of loss 2. The beam loss increases as the beam intensity



Measurement ; 15 MAR 1993
Beam Stop ; 12 MAR 1993

Radioactivity Measured on Surface around the Booster Ring



Disposition of Loss Monitors around the Booster

Fig. 2 Recent distribution of residual radioactivity around the KEK-PS Booster

Fig. 3 Loss monitors around the KEK-PS Booster ring

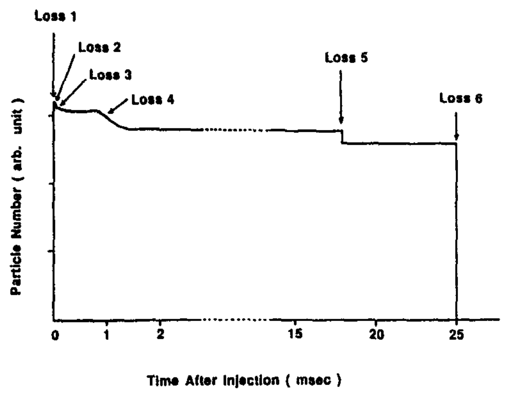
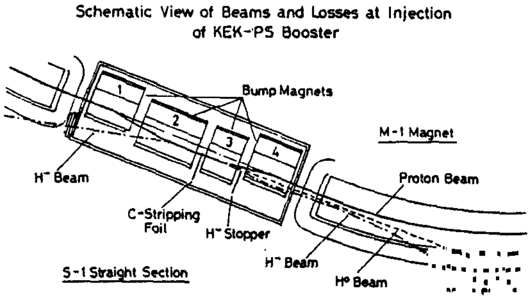


Fig. 4 Typical variation of the proton number during acceleration in the KEK-PS Booster and times when beam loss is observed



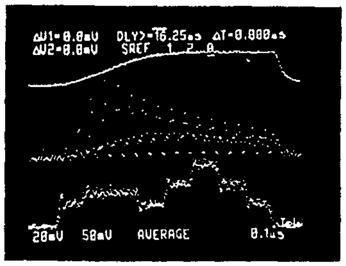


Fig. 5 (upper) relation among H⁻ ion loss, H^0 atom loss and the loss distribution monitor. (lower) a display of loss signals

causing it occurred at the time of loss 2. The beam loss increases as the beam intensity stacked in the booster. It starts to decrease when the H⁻ bump magnet is turned off and soon disappears. As the peak C takes place at the location where the vertical betafunction becomes large, it is cosidered that the vertical beam size becomes large while the beam circulates on the bumped orbit. Anyway, we dont know much about the cause of the peak C.

The time of loss 3 is that a beam bunch is first formed from the continuous beam after injection. It usually occurs when the beam intensity is as high as 1.5 x 10^{12} ppp. When the beam intensity is not so high, this loss can be avoided by adjusting the RF voltage.

The loss 4 is considered to come from the part of beam that is not captured by the RF bucket. Because the part is not accelerated, its orbit radius becomes amaller as the magnetic field rises and at last it hits the inside wall of the vacuum chamber. Loss signal corresponding to this beam loss is not observed, because the beam loss occurs very slowly and instantaneous loss is too little to make a signal in a loss monitor. Although the total amount of this loss is considerable, it does not make a peak of residual activity not only because the energy of lost particle is as low as 40 MeV but also because the loss is scattered all around the ring.

The loss 5 occurs when the RF system becomes unstable with a parasitic oscillation. When the RF system is in a bad condition, this phenomenon occurs as the beam intensity becomes high and limits the beam intensity. After this problem is overcome by improvement of the RF system, the booster beam intensity becomes stable at a level as high as over 1.5 x 10^{12} ppp.

4. Vertical beam size of the booster beam

Vertical beam size observed by the beam profile monitor Pr-5V in the 500 MeV beam line is typically about 40 mm in the full width including 99 per cent of beam, even after the injection and acceleration condition of the booster is carefully adjusted. As the beta function at the point is calculated to be 16 m, the vertical emittance is estimated to be about 25 πmmmrad. Although the value 16 m is only a calculated value, the emittance value is considered to be sufficiently resonable. This emittance is too large compared to the acceptance of the main ring, 20 πmmmrad.

On the other hand, the acceptance of the booster is about 50 πmmmrad. Theoretically, beam emittance is damped by a factor, βγ(40 MeV) / βγ(500 MeV) = 1/4, during acceleration from 40 to 500 MeV. Emittance of 500 MeV is expected to be 12.5 πmmmrad, even if the acceptance of the booster is fully occupied by the beam. Therefore, the observed emittance of 500 MeV beam is cosidered to be abnormally large. Moreover, the typical value of 40 MeV H^- beam is 20 πmmmrad and the injected beam is not scattered all over the acceptance artificially. So it is considered that some beam blowup occurs at the injection and/or during acceleration.

This problem had been indicated with respect to the main ring injection. It is now evident that the problem is also related with beam loss in the booster. It is necessary to make clear and remove, if possible, the cause of vertical beam blowup before the booster beam intensity of routine operation is increased higher than the present. Studies on this problem are being steadily continued and some results are already obtained as follows.

i) Matching of the injected beam to the booster optics

The taken procedure for beam matching is as follows.

step-1 Twiss parameters of the 40 MeV H^- beam are obtained from the phase space distribution measured with an emittance monitor in the 40 MeV beam line.

step-2 Twiss parameters of the beam at the exit of the linac are calculated using the inverse matrix of the transfer matrix from the exit of the linac to the emittance monitor.

step-3 Current set of the quadrupole magnets in the 40 MeV beam line are calculated so as to fit the beta functions of beam to those of the booster ring at the injection point.

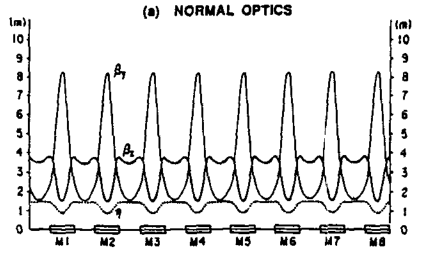
step-4 After currents of beam line quadrupole magnets are adjusted to the calculated values, the phase space distribution of the beam is measured again by the emittance monitor in order to check if the distribution is actually same as the expected by calculation. When the distribution satisfactorily coinside with the expected, the matching procedure is completed. If it does not, the procedure above mentioned are repeated again.

Although this procedure seemed to be adequit to fit Twiss parameters of the injected beam to those of the ring at the injection point, following two problems were also found.

problem-1 Since the phase space distribution of the beam accelerated by a linac has a very complicated shape, the beta function can not be determined straightforward and its determined value has some uncertainty.

problem-2 It was found that the beta function of the ring is deviated from the designed value during injection by edge effect of the injection bump magnets as is shown in Fig. 6. So measurment is necessary to get correct values of the ring beta function.

(a) NORMAL OPTICS



(b) ABNORMAL OPTICS DURING INJECTION

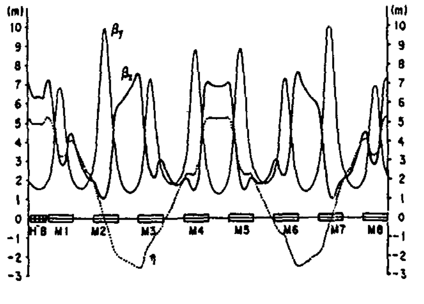


Fig. 6 Distortion of the booster optics due to edge focussing effects of the injection bump magnets

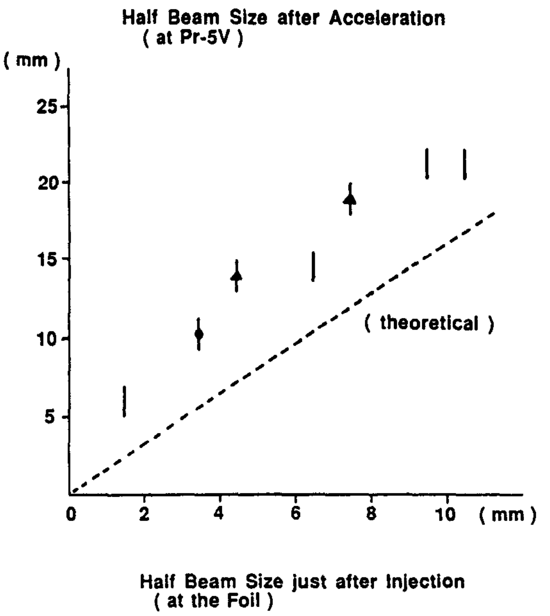


Fig. 7 Dependence of the beam size after acceleration upon that just after injection

Thus beam matching at the booster injection is very complicated process and a considerable beam blowup due to mismatch seems to remain at present.

ii) Correction of the vertical injection error

Two steering magnets in the 40 MeV beam line are used in order to correct the vertical injection error. Since locations of those steering magnets are not suitable, displacement and angle are not adjusted independently. Therefore a map of height of the beam profile observed by the Pr-5V is measured in a plane with currents of those steering magnets as two variables. Then currents are adjusted to the values at the peak of height distribution. This procedure turned out to work well.

iii) Size of 500 MeV beams accelerated from small beams formed at the booster injection

The initial beam size just after injection at the foil location can be defined with a scraper attached on a frame of stripping foil. Figure 7 shows dependence of the beam size at the Pr-5V profile monitor on the initial beam size. The beam size observed with the Pr-5V profile monitor is systematically larger than that theoretically calculated from the initial beam size (the dotted line). This fact is considered to indicate there is a vertical beam blowup halfway of acceleration.

iv) Emittance growth due to foil traverse

Variation of the beam size at the Pr-5V profile monitor was observed, changing the duration while the injected beam traverses the foil. The duration can be changed by changing the time of the H^- beam pulse with respect to the cut off-time of the injection bump pulse. The result is that there is appreciable emittance growth due to foil traverse but its amount is not significant.

v) Space charge effect

Beam blowup due to the space charge effect, if exists, is considered to occur most clearly when a beam bunch is first formed from the continuous beam just after injection by the RF voltage, namely at the time of loss 3. At first a vertical scraper at the straight section S3 is set at a position where the scraper edge is very near but does not scrape the beam with the RF voltage off. Beam intensity can be varied by changing size of the beam mesh or length of the H^- beam pulse. The beam mesh is installed in the 40 MeV beam line. It can only thin particle density of the beam but not change the beam shape. After a beam intensity is set, the RF voltage is turned on and the beam loss is searched for at the time of bunch formation. Of course, the RF voltage and frequency must be enough adjusted in advance not to excite a quadrupole oscillation in the longitudinal phase space. By this method, it was found that the beam blowup due to space charge effect certainly occured with a beam intensity about 1.5×10^{12} ppp or more.

5. Summary

At the KEK-PS booster, the beam intensity at the routine operation has recently attained a level over 1.5×10^{12} ppp by a series of comprehensive and systematic tuning for a few years. Although a higher beam intensity is available, it is controlled at the present level because the residual radioactivity around the ring becomes serious at some points.

Two problems has come to the fore in this process. One is the residual radioactivity around tha booster ring, and the other is vertical beam blowup at the beam injection and during acceleration in the booster. As for the residual radioactivity, there are three kinds of harmful peaks. Two of these turned out to relate with the beam extraction and injection. Peaks of the third kind are at the center of the synchrotron magnet M2 and M5 and are not well known about the cause of production.

The vertical beam blowup in the booster is considered to occur at the injection and at an early stage of acceleration. At present, there is considerable mismatch between the injected beam and the ring optics. Blowup due to space charge effects is appreciable when the beam intensity becomes as high as 1.5×10^{12} ppp or more.

These problems are now being actively studied and when they are solved the booster beam intensity will be increased to the level of 2.0×10^{12} ppp.

References

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