Injection Error Monitor for KEK 12 GeV PS

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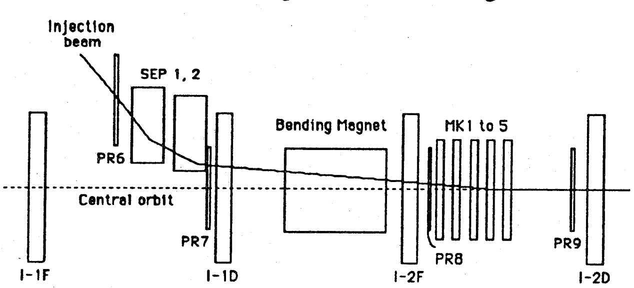
Abstract

The injection error monitor is now developing for an easy tuning of the main ring beam injection at the KEK 12 GeV proton synchrotron. The beam trajectory on the horizontal phase space plane is obtained by a test bench system. The injection error monitor proved to be available for the beam injection tuning.

I. Introduction

The proton synchrotron in KEK is a cascade type accelerator consisting of a pre-injector, a 40 MeV linac, a 500 MeV booster and a 12 GeV main ring[1]. In order to rise the efficiency of the main ring beam injection, some equipments and tools have been suggested and prepared. For example, beam profile monitors, beam position monitors and beam intensity monitors which provide bunch shapes, positions and intensities. The injection error monitor system is conducted for easy to use, easy to see and easy to tune the beam injection conditions by observing the beam status in the phase space.

Two septum magnets and five kicker magnets are prepared in the first and second long straight sections in the first superperiod of the main ring as shown in Fig.1. The beam profile can be seen by using the beam profile monitors. In this case, three profile monitors PR7, PR8 and PR9 are available. The profile monitor PR7 provides the bunch shapes and positions after the septum magnets where the beam might have a horizontal position and direction of about +60 mm and -15 mrad, respectively. The beam crosses the central orbit at the middle of the kicker magnets after traversing two quadrupole magnets and one dipole magnet in the main ring. The kicker magnets bend the beam and put it on the central orbit.



Steering Magnets are located upstream.
I-1F, 2F: Focusing Quadrupole Magnet.
I-1D, 2D: Defocusing Quadrupole Magnet.
SEP1,2: Septum Magnet.
MK1 to 5: Kicker Magnet.
PR6 to 9: Beam Profile Monitor.

Figure 1. Schematic view of the injection block.

The septum magnets are adjusted so that the beam intensity and the bunch shape become consistent between the booster extraction and the main ring injection by seeing the PR7. The beam, of course, must not hit the septum walls. The PR8 and PR9 are available to see whether the beam traverses the suitable positions in the main ring. The beam profiles should appear with the same distance from the central orbit on PR8 and PR9, oppositly. When kicker magnets begin to be fired the beam profile on the PR9 moves towards the center and the profile of the second turn beam may appear. The injection efficiency has been achieved to be over 90 % at the present day with much efforts because the trajectory of the injection beam and the abilities of injection equipments are not known well.

II. Injection Error Monitor

Principles

The beam orbit circulating in the main ring is described by using a matrix M as

$$\begin{pmatrix} x \\ x' \end{pmatrix} = M_{(s\,|\,s_0)} \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

ignoring the non-linearity effects. The two position signals are converted to the phase space variables at the arbitrary point. Assuming that the positions and betatron oscillation parameters of the positions s_1 and s_2 are indicated by (x_1, x'_1, β_1, α_1, ψ_1), (x_2, x'_2, β_2, α_2, ψ_2), the phase space at the objective point s ($x, x', \beta, \alpha, \psi$) is obtained as follows:

$$x = \sqrt{\frac{\beta}{\beta_1}}\left(\cos\Delta\psi - \frac{\sin\Delta\psi}{\tan\Delta\psi_{12}}\right)x_1 + \sqrt{\frac{\beta}{\beta_2}}\frac{\sin\Delta\psi}{\sin\Delta\psi_{12}}x_2$$

$$x' = \frac{1}{\sqrt{\beta_1\beta}}\left\{\left(\frac{\alpha}{\tan\Delta\psi_{12}} - 1\right)\sin\Delta\psi - \left(\alpha + \frac{1}{\tan\Delta\psi_{12}}\right)\cos\Delta\psi\right\}x_1 + \sqrt{\frac{1}{\beta_2\beta}}\frac{\cos\Delta\psi - \alpha\sin\Delta\psi}{\sin\Delta\psi_{12}}x_2$$

where $\Delta\psi = \psi - \psi_1$ and $\Delta\psi_{12} = \psi_2 - \psi_1$ and $\Delta\psi_{12}$ must not be zero obviously. The objective point was determined to just after MK5 and the measurement points for beam positions were determined to I-3F and I-4F, respectively. It is natural to use two position monitors since the beam position is required to be measured at two points. It is possible to go with only one beam position monitor because the circulated beam provides a new information in the same monitor unless the tune has an integer. In this case, the error due to the non-linearity of the lattice becomes 28 times greater and the value of $|\sin\Delta\psi_{12}|$ becomes small though the one position monitor system is simple.

The measurement errors of x_1 and x_2 transfer linearly to the results of the objective point. It is convenient for the accuracy that their coefficients are small, in other words, $|\sin\Delta\psi_{12}| = 1$. The actual value of $|\sin\Delta\psi_{12}|$ between the position monitors at the I-3F and I-4F becomes about one due to the typical tune value which is $\nu_H = 7.12$. The error due to the $\Delta\nu_H$ which is about 0.02 at the maximum is estimated to be less than 2%. The error of the bending magnet field at the injection period is 0.064 %[2] which is negligible. In addition, there is the pulse-to-pulse field fluctuation discussed later.

Fast beam position mesurements

The PS main ring has 56 wall-current type position monitors[3,4] along the beam line with the same intervals corresponding to the betatron phase of about $\pi/4$. It indicates to be able to choose the measurement points keeping the value of $|\sin\Delta\psi_{12}|$ to be one. The beam position monitor picks up the wall-current on the inner surface of the beam pipe with four splitted electrodes. The wall-current is extracted to the outside of the beam duct through the ceramic seal and then returns to the beam pipe through the signal transformer.

The operation to the position from the wall-current signals is expressed as:

$$\Delta R = K \frac{R_+ - R_-}{R_+ + R_-}$$

where ΔR is the beam position, R_+ and R_- are the pulse heights of the wall-current signals and K is the normalization factor. The accuracy of the beam position monitor system was estimated to be 0.5 mm.

A typical pulse width of the wall-current signals is about 100 ns which needs the fast sampling system over 100 MHz for accurate pulse shape measurement and requires much memories and calculation power. For example, several ten kilobytes of memories are required per channel for ten revolutions which correspond to about one cycle of the beam trajectory on the phase space plane. Since it is enough to get only pulse heights for the beam position, the data size can be extremely reduced by using the pulse height sampler which is preparing now. Since the wall-current monitor has a cut-off frequency of a few hundreds kilohertz, beam signal pulses shifts to cancel the DC component. The pulse height sampler consists of a baseline compensator and a fast sample/hold unit. The pulse height data are transfered to the computer through the CAMAC and VME bus system.

In one acceleration cycle, nine beam bunches are injected to the main ring with a time interval of 50 ms. The timing pulses K1 to K9 which are the trigger signals of the kicker magnets for each bunches are applied to the trigger of the monitor system for the target bunch selection.

C.O.D. measurement

The most important purpose is to put the beam on the central orbit which means the closed orbit but a design orbit. It is necessary to determine the C.O.D. as the central orbit at the objective point which is determined to just after MK5. The circulating beam changes its position on the phase space plane and the trajectory forms an ellipse. The center of that ellipse indicates the C.O.D. The betatron oscillation vanishes for a few tens millisecond after the injection. The injection error measurement after a proper time directly provides the C.O.D, too.

Test bench

Test bench consists of two digital oscilloscopes(LeCroy 9450, Hewlett Packered 5185) and a micro-computer(PC-9801VX). The oscilloscopes are used as the digitizing memory instead of the pulse height sampler. LeCroy 9450 is a 2 channel oscilloscope which has the spec of 400 MS/s, 300 MHz band-width and the memories of 50 kW/ch. HP 5185 is also a 2 channel oscilloscope which has a sampling rate of 4 ns and the memories of 64 kW/ch. The beam pulse data are transfered through the GP-IB bus. Since the computer takes whole data of the pulse shape and determine the pulse height by a calculation, the processing ability is limited by the CPU power and it typically takes about six seconds for one revolution event and over one minutes for ten revolution event, respectively.

The beam injection error has six dimensions: four dimensions for transverse section and two for longitudinal. Only two dimensions, horizontal phase space of the transverse section can be seen in this system.

III. Results and discussions

The trajectories on the horizontal phase space plane are shown in Fig.2 which shows the bunch positions of ten revolutions with the injection efficiency of 81% and 96%, respectively. The bunch rotates clockwisely about 2π radian along the ellipse within the periods of about 10 revolutions which well agrees with the measured horizontal tune: 7.10. The bunch ellipse size becomes smaller with respect to the injection error, i.e. the amplitude of the betatron oscillation

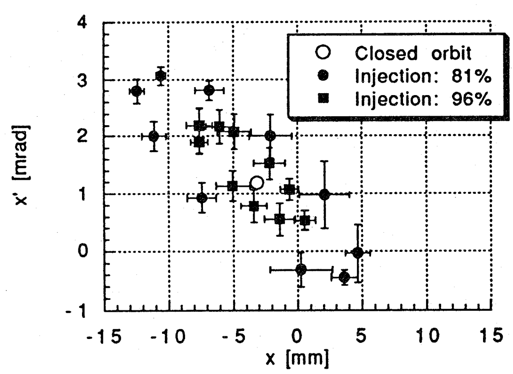


Figure 2. Injection beam trajectory in the horizontal phase space.

and the center point corresponds to the C.O.D. The injection efficiency strongly depends on where the first bunch is on this plane which is the most important plane.

The error bars are statistical which mainly come from the pulse-to-pulse field fluctuation of the bending magnets in the main ring. The position uncertainty at I-2F section is shown in Fig.3 with respect to the bending magnet field at P1+100 ms. The bending magnet field varies about 0.3 Gauss at the injection time cycle by cycle. Although this fluctuation corresponds to at most 0.02% of the magnetic field during the beam injection, it brings about the position deviation of about 1.5 mm.

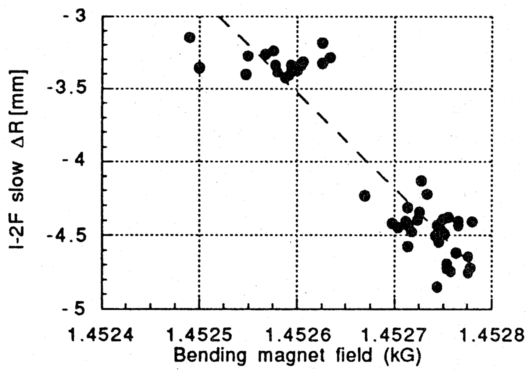


Figure 3. Orbit uncertainty during the beam injection.

The trajectories of the first revolution with respect to the set value of injection equipments are shown in Fig.4. It is apparant that this map is quite available to the injection parameter tuning because they make clear the problems during the beam injection tuning. The injection parameters are two septum magnets SEP1 and SEP2, three steering magnets ST6, ST8 and ST9 and five kicker magnets MK1 to MK5. The effects of them are displayed individually. The septum magnets and ST8 and ST9 seems to cause the almost same effect on this plane. The combination of these parameters are determined from the aperture of the septum magnets. The ST6 plays an important roll since the dynamic range of the kicker magnets is not so wide. If the proper point of ST6 exceeded the septum aperture, that difficulty can be avoided by making a bump orbit at the injection portion. For these problems, the orbit tracing is necessary.

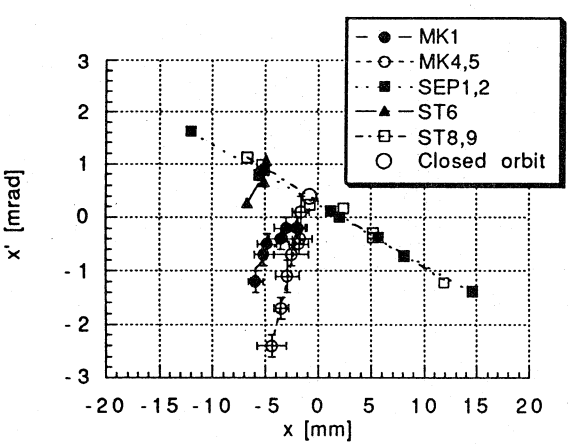


Figure 4. Beam trajectories at the first revolution.

IIII. Conclusion

The beam injection process seems to be simple and the tuning procedures are the position cerrection where the injection beam crosses the central orbit and the kick angle correction by kicker magnets. Although the actual beam injection process is more complex due to the longitudinal matching and so on, the good injection efficiency over 95 % is achieved by only using the injection error monitor. The beam trajectory at the injection point in the horizontal phase space have been clarified and the abilities of injection equipments are investigated. It is proved that the injection error monitor is quite available to tune the beam injection conditions. The final purpose of the injection error monitor system is to construct the automatic beam injection tuning system for the PS-main ring. The results in this study is meaningful and suggesting the concrete way of that.

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