INJECTION OPTIMISATION FOR INDUS-2

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Abstract

In this paper commissioning experience of injection into INDUS-2, a 2.5 GeV synchrotron radiation source is discussed. In initial stage commissioning, partial beam loss was observed. In this context effect of various injection errors such as mismatch between pulse widths, jitter and magnetic field stability of kickers on injected and stored beam are studied (1). A brief summary of the results is presented. After reducing jitter and fine adjustments of timings of kicker power supplies, partial beam loss reduced significantly.

INTRODUCTION

A multi turn injection scheme employing a compensated bump generated by four kickers has been chosen for beam injection into INDUS-2. The injector for this ring is a synchrotron with peak energy of 450-550 MeV. The synchrotron provides two bunches each one around 1ns long and separated from each other by nearly 30ns, at the required energy at a repetition rate of 1 Hz. After injecting several pulses at 450-550 MeV, the beam is accelerated to 2.5 GeV by slowly increasing the magnetic field of the bending magnets. The injection is carried out in the radial plane from the outer side of the ring by using a compensated bump generated by four kicker magnets. The Indus-2 storage ring has kicker magnets k1 to k4, placed symmetrically in a 4.5m-long straight section. The straight section part containing injection kickers is free from quadrupoles, so the deflection bump is independent of the machine optics

BEAM INJECTION

Since the synchrotron routinely delivers a beam to Indus-1 at 450 MeV, initial attempts were made to inject the beam in Indus-2 at this energy. To reduce the residual betatron oscillation of the injected beam as well as stored beam, it was decided to move septum chamber towards the beam orbit by 8 mm. By looking the beam position at BPM-1(just after up stream kicker magnet), BPM-3(located at achromat section) and just after one turn (at septum BPM) proper optimisation of position and angle was carried out by changing thick and thin septum currents. After this optimisation 2.ms Fig.1)beam rotation was observed. Further optimising RF frequency, kicker strength and time delays the beam survival time of more than 1 second was achieved. At 450 MeV beam energy the damping time in horizontal plane is 810 ms, this being comparable to the synchrotron repetition rate, the injected beam oscillations are not fully damped when the next pulse is injected into the ring. So it was decided to inject the beam at a higher energy. The energy in the synchrotron was then ramped to 550 MeV and the beam at this energy was extracted for injection into Indus-2. At this energy the damping time is 444 ms, therefore, the beam is fully damped when the next pulse arrives after one second. Once the beam was stored for full injection cycle the kickers were adjusted to allow the beam accumulation. At this stage, it was very important to adjust the timing of the kicker pulses. Much time and efforts were spent to ensure that the stored beam traversed kickers at the proper time. Further optimisation is carried out by optimising beta functions at the end of TL-3, in which beta function is reduced from 14m to 8m, with this exercise a small beam spot on the last BPM of TL-3 and BPM 1 of Indus 2 was observed.

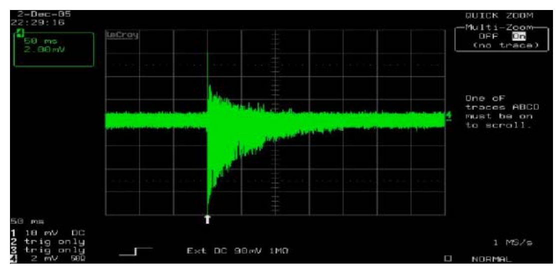

Figure 1: WCM signal indication of survival of the beam up to 200 ms.

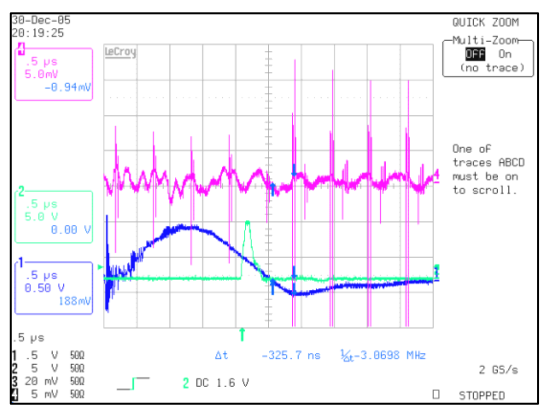

Figure 2: Beam storage to more than 1 second beam crosses injection kicker after 1 second.

In initial stage at time of injection, partial beam loss was observed. The loss was attributed to the following reasons associated with injection kickers namely 1) Magnetic field stability 2) Mismatch between pulse widths 3) Jitter. Initially effects of these errors were observed by looking at the synchrotron light monitor, which is located far away from the injection sections. Due to various injection errors, in the SLM beam spot variation was observed. A theoretical study of the effect of these errors is discussed in this paper.

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INJECTION ERRORS

The bump strength (B) and the location of the septum from the designed orbit (L_s) can be approximately calculated from the following relation[1]

$$B = 4\sigma_{xi} + S_{sc} + S_t$$

$$L_s = B + 4\sigma_{xs} + S_c + S_{res}$$

Where, σ_{xi}: Beam size of the injected beam, σ_{xs} : Beam size of the stored beam, septum clearance S_c =2.0mm; septum thickness S_t =3.0mm, $S_{Residuals}$: residual oscillation of stored beam which is arising due to nonclosure of the bump, injected beam emittance ε_{xi} = 2.35*10-07mrad and stored beam emittance ε_{xs} = 2.5*10-08mrad are respectively at 550MeV. The value of ε_{xs} has been arrived at by taking into consideration a blow-up of emittance due to intrabeam scattering and bunch lengthening due to single bunch instabilities[2], for the injected beam also a blow-up factor of two (2) has been assumed. If bump strength is reduced then it will increase the injected beam oscillation ($I_{Residual}$). In the case of Indus-2, above relations are only guidelines not exact due to sinusoidal nature of the kicker pulse having a slow fall time (1.6µS). In multi bunch-filling mode, injection kicker will be energized according to synchronize pulse. To simulate it, stored beam is tracked according to bunch filling pattern. Tracking studies have been carried out with the computer code RACETRACK[3]. To accommodate injection errors computer code RACETRACK has been modified. In studies, both bunches (coming from the synchrotron) are tracked. Here results are presented for design (9.3,5.2) & moderate optics[4] B(II) (9.3,6.2) for accepting 1.5 sigma of injected beam. In these calculations inner side of septum location is fixed at 15.0mm from design orbit.

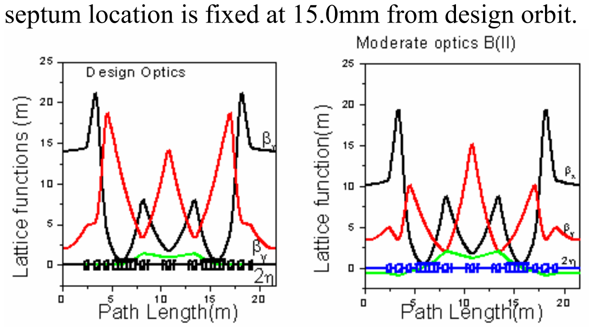

Figure 3: Lattice functions for design and moderate optics.

Effect of Magnetic Field Stability

To show its effect, injected and stored bunches are tracked with various combination of peak field stability according to measured data peak field stability is in the range of ($\Delta B/B = \pm 1*10^{-3}$). Its result shows that septum clearance is reduced by 0.5mm.

Mismatch between Pulse Widths

The four kicker pulse lengths are not identical; they differ from each other, as shown in the table-1. Mismatch between pulse widths leads to extra residual betatron oscillation.

Table 1: Measured Pulse Length of the Kickers

Kicker magnet	T_R(µs)	T_F(µs)
K1	1.3	1.53
K2	1.27	1.53
K3	1.29	1.60
K4	1.29	1.60

There are following four possibilities to minimize these effects, i.e. either starting point of all the four kickers are matched (Case A) or peak point of all the four kickers are matched (Case B) or downstream kickers are energised earlier then the upstream kickers (Case C), or the upstream kickers are energised earlier than the downstream kickers (Case D). From simulation of beam tracking for the four cases, maximum oscillation at septum location for both the injected and stored bunches at design & moderate optics B(II) are tabulated.

Table 2: For Design Optics

Case	$I_{Residual}$ (mm)	$S_{Residual}$ (mm)
Ideal	11.73	0.0
Case A	12.00	0.53
Case B	14.38	2.24
Case C	13.63	5.16
Case D	14.10	2.10

Table 3: For Moderate Optics

Case	$I_{Residual}$ (mm)	$S_{Residual}$ (mm)
Ideal	12.90	0.0
Case A	13.20	0.08
Case B	14.65	1.34
Case C	12.03	2.61
Case D	14.36	1.15

The above table clearly indicates effect of mismatch between pulse widths can be significantly reduced by matching the starting point of the kickers.

Jitter

Effect of jitter is very severe in comparison to any other errors. The effect of jitter will further detoriate injection efficiency. In table-2 effect of jitters for case (A) are tabulated.

Table 4: For Design Optics

Jitter (ns)	$I_{Residual}$ (mm)	$S_{Residual}$ (mm)
2	12.55	1.33
7	13.96	3.81
12	15.38	6.29

Table5: For Moderate Optics

Jitter (ns)	$I_{Residual}$ (mm)	$S_{Residual}$ (mm)
2	13.49	0.65
7	14.24	2.10
12	15.14	3.56

The tracking results indicate that for design optics, it is very difficult to inject the beam having jitter in the range of ±12nS. The deflection errors caused by jitters between k1 & k2 and between k3 & k4 are mainly responsible for it.

INJECTION OPTIMISATION

Initially effect of injection errors is minimized by reducing bump strength, and by optimising time delay between injection kickers at design optics. The results show that if kicker pulse widths have different pulse width then in this case it is better to match the starting point of kickers in comparison to peak matching. The bump strength reduction will lead additional oscillation in the stored beam as well as injected beam. To obtain a better solution it was decided to reduce kicker jitters from ±12ns to ±7ns.To increase the injection efficiency it is better to use moderate optics. In fig4, .5 & 6 for moderate optics B(II) tracking results are plotted for injected beam & stored beam having no jitter, jitter of 12ns and 7ns. These results indicate that for 7ns jitter, stored beam remain well separated from the septum magnet in comparison to 12 ns jitter. After reducing jitter and by using moderate optics partial beam loss was significantly reduced. In the longitudinal plane energy acceptance is small, the reason may be that the Indus-2 RF frequency is higher as the dipole current at injection is higher than the design current. Determination of correct RF frequency is expected to increase the energy acceptance in longitudinal plane as well as in the horizontal plane.

CONCLUSIONS

To increase injection efficiency into Indus-2, mismatch between kicker pulses and its jitter have to be further reduced. Further optimisation has to be carried out by optimising Indus-2 dipole current, RF frequency, RF voltage and by reducing closed orbit distortion. Injecting the beam at higher energy can also increase the injection efficiency, as in this case damping time of the injected beam is reduced

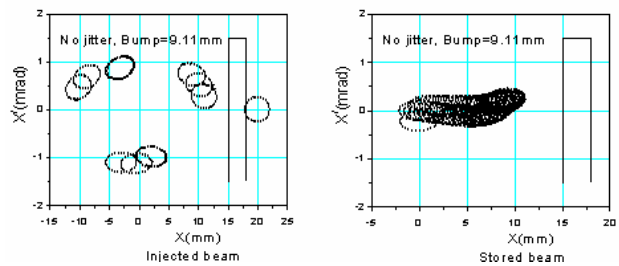

Figure 4: Injected and stored beam oscillations for an ideal case.

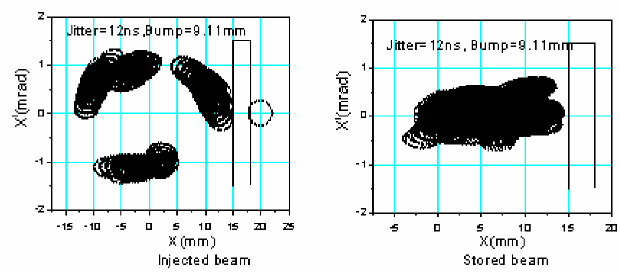

Figure 5: Effect of 12ns jitters in timing of kickers on injected beam and stored beam oscillations.

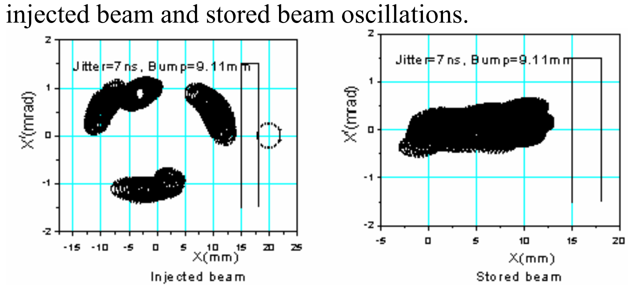

Figure 6: Effect of 7ns jitters in timing of kickers on injected beam and stored beam oscillations.

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