# BEAM DYNAMICS WITH NEW BOOSTER DIPOLES

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*Abstract*

New bending magnets are being designed for the booster synchrotron at RRCAT, Indore with the same effective length and field which will be installed in the existing ring with the same configuration of drifts and quadrupole magnets. Presently sector type dipoles are in use. It is easier to fabricate parallel edge (rectangular type) dipoles but the beam optics gets modified due to edges which provide additional focusing. The effect on tune point can be corrected using two quadrupole families. Studies indicate that the beam emittance is lower in the optics with rectangular type dipoles but the beam injection and extraction are more difficult. In this paper, the beam optics, beam emittance, injection and extraction with two configurations of the dipole magnets are compared.

## INTRODUCTION

The booster synchrotron [1] along with a 20MeV microtron as a pre-injector serves as a common injector for synchrotron radiation sources Indus-1 and Indus-2 at RRCAT and is being operated since 1995. The magnetic lattice of the booster synchrotron comprises 6 superperiods, each having one 60º sector type dipole magnet (bending magnet) and a pair of focusing and defocusing quadrupoles. Presently, the booster synchrotron is being operated at 450MeV for injection into Indus-1 and at lower energy of 550MeV for injection into Indus-2. It is planned to design new dipole magnets which will be operated at 1.32T at 700MeV to inject the beam into Indus-2. As these dipole magnets will have to be used in the existing dimensions of the booster synchrotron, it is required to design them with the same effective length and bending angle. Therefore only the edge angle is the degree of the freedom in the design of new dipole magnets. It is easier to fabricate rectangular type (parallel edge) dipoles therefore feasibility of using these magnets is studied.

The aim of the study is to keep the tune (working point) and the circumference fixed. In the rectangular dipoles, the edges work as thin focusing lenses in vertical plane. Therefore the replacement of sector type dipole with the rectangular type dipole will change entire beam optics with the change of the tune. Though the tune can be restored to the same by optimizing the quadrupole strengths but lattice functions around the ring may be different. The dynamic aperture and amplification factors will also be different. Therefore extensive studies required for these aspects will be done separately. Depending upon the lattice functions, the injection and extraction of the beam will also require the different strengths of the injection and extraction kickers. It is also necessary to see that the beam passes through the small aperture of the extraction septum. The effect on lattice functions, emittance, beam injection, extraction etc. in two configurations of the dipole magnets are compared in this paper.

## RESULTS AND DISCUSSIONS

### *Beam Optics*

Initially, the booster synchrotron was designed to operate at a tune (working point) of [2.25, 1.25]. But the tune of the present operating optics is [2.11, 1.44]. Therefore both of these working points are chosen for the studies. The Accelerator Toolbox [2] has been used for calculation of the lattice parameters. The lattice functions of the booster synchrotron for the present tune [2.11, 1.44] with present arrangement i.e. with sector type dipoles are shown in Fig 1a. After replacing the sector type dipole with rectangular type, the beta function in vertical plane increases by factor of three at beta max point and the tune changes to [1.40, 2.82]. The tune point [2.11, 1.44] is restored by optimizing the quadrupole strengths and the corresponding lattice functions are shown in Fig 1b.

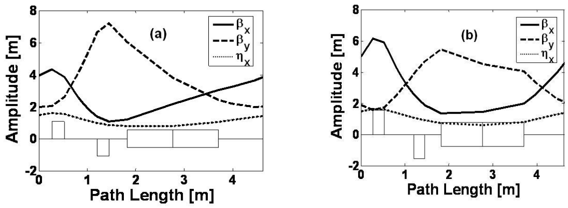


Fig 1: Lattice functions at tune [2.11, 1.44] (a) with sector type dipoles and (b) rectangular type dipoles.

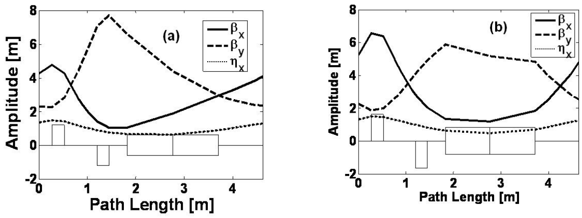


Fig 2: Lattice functions at tune [2.25, 1.25] (a) with sector type dipoles and (b) rectangular type dipoles.

The lattice functions of the booster synchrotron for the tune [2.25, 1.25] with sector type dipoles are shown in Fig 2a. After replacing the sector dipole with rectangular type, the beta functions in horizontal and vertical plane increase by ~20% at beta max point. Also the tune changes to [1.614, 2.557] and after correcting the tune the lattice functions are shown in Fig 2b. The horizontal beta function at injection is large in this case also.

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## *Beam Emittance*

The beam emittance is compared at energy of 450MeV. The beam emittance at tune [2.11, 1.44] with sector type dipoles is 131nm-rad which reduces to 83nm-rad with rectangular dipoles. Similarly at tune [2.25, 1.25], the beam emittance with sector type dipoles is 88.3nm-rad which reduces to 58.9 with rectangular dipoles. The reduction of the beam emittance is ~32% on replacing the sector type dipoles with rectangular type.

## *Beam Injection*

The booster synchrotron injection system consists of three kickers: K1, K2 & K3 and one injection septum magnet. At tune [2.11, 1.44], a closed orbit bump of 30mm, as shown in Fig. 3, is generated at the injection point using three kicker magnets for lattice with sector and rectangular type dipole magnets. The horizontal beta function at injection point is large with rectangular type dipole as compared to sector type dipole; it is possible to generate the same bump with reduced strengths of the injection kickers. But the large bump angle of 8mrad is generated at injection point as compared to 1.3mrad with sector type dipole which is not the favourable condition for beam injection. Similar behaviour is observed at tune [2.25, 1.25].

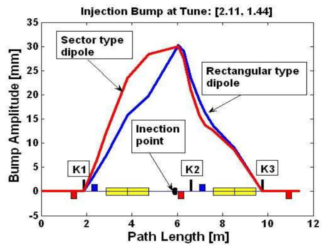


Fig. 3: Injection bumps amplitude of 30mm at tune [2.11, 1.44] for lattices with sector and rectangular type dipole.

## *Beam Extraction*

The booster synchrotron utilizes one fast switching kicker and one 16° extraction septum magnet with aperture of ±4mm. It is important to extract the beam such that the angle in the trajectory at the septum mouth is small so that a small change in the current of the septum magnet makes the trajectory parallel in TL-2 (Transfer Line-2). It is assumed that the central axis of the septum magnet is 35mm away from the design trajectory of booster. A bump of 35mm can be produced at the septum magnet using kicker strengths of 11.3mrad and 10.2mrad at the beam energy of 450MeV for tunes [2.11, 1.44] and [2.25, 1.25] respectively with the sector type dipoles. The extraction is possible for both the tunes. In the case of rectangular type dipoles, though it is possible to get the same amplitude at the extraction septum mouth with the less kicker strengths but it is difficult to pass the beam through the aperture of extraction septum.

To visualize the possibility of the extraction the amplitude of the trajectory at the septum mouth is reduced to 32mm from 35mm. This can be done on reducing the strength of the extraction kicker. In case of sector type dipoles, the extraction with parallel beam is possible for both the tunes. But in the case of rectangular type dipoles, a trajectory angle of 22.5mrad at the entrance of extraction septum is generated for the tune [2.11, 1.44] as compared to 9.5mrad in sector type. It has been tried to pass the beam through the aperture of septum by reducing the septum strength by ~7% w.r.t the case of sector type dipole. But the beam trajectory angle is 6.4mrad at the exit of extraction septum and with this angle it is difficult to make trajectory parallel in TL-2 as shown in Fig 4a. Similar behaviour is observed at the tune [2.25, 1.25]; here also trajectory angle at entrance mouth of the extraction septum is 21.6mrd and at exit of the septum mouth is ~4mrad. The extraction trajectories for optics at tune [2.25, 1.25] with rectangular and sector type diploes are shown in Fig 4b.

For the same extraction amplitude at entrance of the septum, a large excursion in the trajectory ~40mm is observed at the quadrupole location with rectangular type dipoles as compared to ~30mm in the sector type at the tune [2.11, 1.44]. Similar behaviour is observed in the case of the tune [2.25, 1.25].

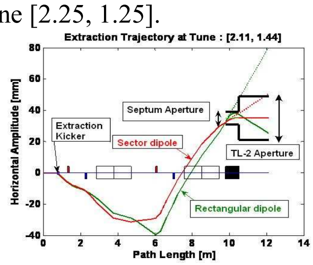


Fig 4a: Extraction trajectory at tune [2.11, 1.44] for two types of dipole magnets: sector and rectangular.

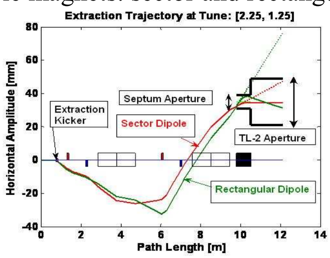


Fig 4b: Extraction trajectory at tune [2.25, 1.25] for two types of dipole magnets: sector and rectangular.

# CONCLUSION

The effects of rectangular dipoles on the beam optics were studied and compared with the optics for existing dipoles. These studies indicate that the beam injection and extraction are more difficult for the optics with rectangular type dipoles.

# REFERENCES


[1] D.Angal-Kalinan et al., 'Synchrotron radiation source Indus-1', Current Science, Vol. 82, No. 3, February (2002).

[2] A. Terebilo, Accelerator Toolbox in MATLAB, SLAC-PUB 8732 (2001).