FAST INJECTION INTO THE PS2

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Abstract

The conceptual considerations of a fast injection system for protons and ions in the proposed PS2 accelerator are presented. Initial design parameters of the injection septum and kicker systems are derived, taking into account rise and fall times, apertures and machine optics. The requirements for an injection dump used for failures are described. Possible limitations and technical issues are outlined.

INTRODUCTION

The 50 GeV PS2 synchrotron is foreseen as a replacement of the existing CERN 26 GeV Proton Synchrotron (PS). The aim is to replace the 50 years old PS synchrotron by a more modern, reliable, flexible and higher performance machine, which will allow future performance upgrades of the LHC and fixed target programs. The design studies are presently ongoing [1].

STRAIGHT SECTION LAYOUT

One of the two straight sections is dedicated to injection, extraction and an internal dump, see Fig. 1. The other straight section will be dedicated to RF and collimation. There is a 4.0 GeV H$^-$ injection foreseen, with a foil or laser stripping [2]. A fast injection system is required for 1.3 GeV proton equivalent heavy ions from the LEIR machine. Protons at 4 GeV may also be injected via this channel. In the same straight section are the extraction elements for slow extraction (third integer), fast extraction and low-loss island multi-turn extraction.

In this straight section all injection and extraction systems fit into a 6-cell FODO lattice, with the central two cells replaced by a symmetric doublet. The horizontal phase advance is fixed to 90° per cell.

FAST INJECTION

Definition of Parameters and Requirements

The required beam aperture $A_{x,y}$ is defined by:

$$A_{x,y} = nk_b\sigma_{x,y} + k_b|D_{x,y}|\frac{\Delta p}{p} + T_{mech} + \sqrt{\frac{\beta_{x,y}}{\beta_{x,y\,max}}}O_{x,y}$$

where $\sigma_{x,y} = \sqrt{\beta_{x,y}\varepsilon_{x,y}}$, n is taken to be 6 in both planes, the beta beat factor $k_b = 1.1$, the mechanical tolerance T_{mech} = 1 mm in both planes and the assumed tolerance on the orbit $O_{x,y}$ 5 mm in the horizontal plane and 3 mm in the vertical plane. The value for $\beta_{x,y\,max}$ is assumed to be 60 m.

The beam parameters used are summarised in Table 1. The least favourable parameters of the two beam types are taken into account (printed in bold characters) to define the injection elements. The required kicker rise and fall times are 100 ns.

Table 1: Beam Parameters Used for the Calculation of the Injection Elements

	Protons	Heavy Ions
Energy T [GeV]	4.0	1.3
Gamma	5.26	1.14
Bρ [Tm]	**16.2**	6.7
$\varepsilon_{n,x}$ [π mm mrad]	9.0	0.7
$\varepsilon_{n,y}$ [π mm mrad]	6.0	0.7
ε_x [π mm mrad]	**1.74**	1.26
ε_y [π mm mrad]	1.16	**1.26**
Δp/p	**±0.003**	-
Kicker rise/fall time [ns]	**100**	-

Optimisation of Injection Elements

The initial design for a fast injection system consists of two identical kicker tanks and two identical septum magnets, separated by a defocusing quadrupole. The injection takes place in the horizontal plane, see Fig. 2. The kicker magnets have been limited in field to 0.025 T to avoid saturation of the ferrites. They have been positioned as far away from the defocusing quad as possible, to maximise the lever arm to the septa. The resulting kick angle for a magnetic length of 2.05 m and the required full vertical aperture of 85 mm is 3.2 mrad per kicker tank.

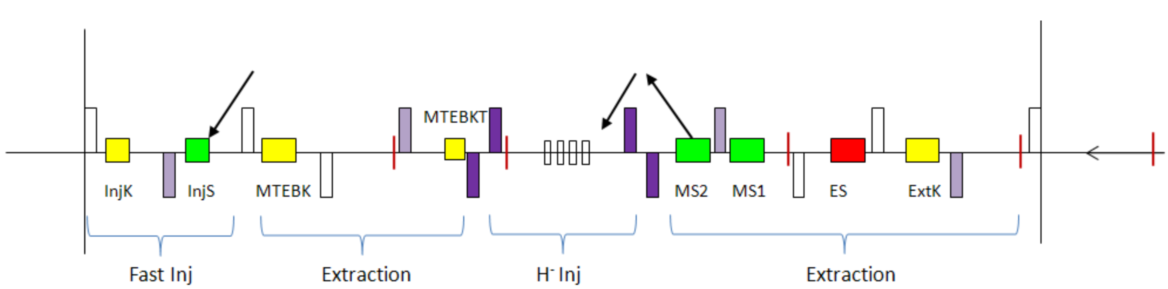

Figure 1: Layout of the PS2 injection and extraction straight.

The defocusing quadrupole between the kickers and the septa enhances the kick from the injection kickers. The quadrupoles are assumed to have a good field region of ± 100 mm in both planes and outside dimensions of 1100 mm.

The septa, with an assumed apparent septum thickness of 33 mm, are then placed as close as possible to the kickers, such that they do not restrict the aperture for circulating nor for the injected beam. This maximises the lever arm to escape the upstream quadrupole. The resulting required deflection angle is 55 mrad for each septum.

INJECTION KICKERS

Under Vacuum Kicker Magnets

The resulting injection kicker parameters are listed in Table 2. For a travelling wave system with a relatively high impedance of 16.6 Ω and a length of 2 m the expected rise and fall times of the system are 300 ns. Each kicker tank will have to be divided in four separate magnets to obtain the required rise time of 100 ns. With the aperture as listed in Table 2, no space for a ceramic chamber to reduce the beam impedance is accounted for. In this case the impedance can be reduced by the application of a metallic comb structure on the ferrites, similar to the CERN SPS extraction kickers [3]. This solution would minimise the required vertical magnet aperture, but it remains to be seen if the resulting beam impedance is acceptable.

Kickers Outside the Beam Vacuum

An alternative to obtain a much stronger reduction of beam impedance is to insert a ceramic chamber with metal stripes in the magnet aperture. This solution is already applied for the LHC injection kickers. The price to pay is that at least an additional 15 mm are required for the transverse kicker magnet apertures. The tank length is to be reduced to 1.3 m to facilitate the production of the ceramic chambers and each tank will consist of two magnets to obtain the required kicker rise time. A total of four kicker tanks are required, with different vertical apertures depending on their position, see lower half of Fig. 2. An overview of kicker parameters for this situation is listed in Table 3.

Table 2: Parameters of the in Beam Vacuum Injection Kickers

Number		2
Deflection angle per magnet tank	mrad	3.2
Magnetic length per tank	m	2.05
Number of magnets per tank		4
Magnetic field (max)	T	0.025
Gap height	mm	85
Gap width	mm	140
Current (max)	kA	17.1
System impedance	Ω	16.6
PFN voltage (max)	kV	56.7
Rise/fall time	ns	100
Pulse length	µs	4.5

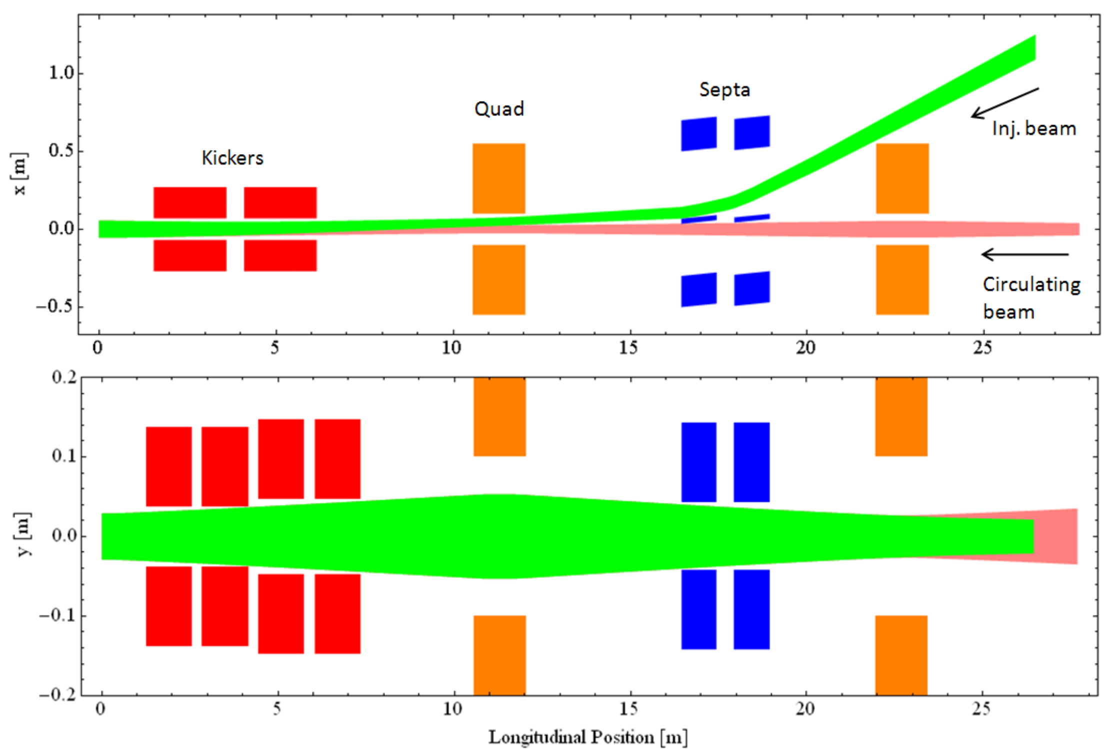

Figure 2: Layout of the fast injection. The top graph shows the view in the horizontal plane with two kicker tanks, the lower graph with four kicker tanks in the vertical plane, where the aperture available for the beams is drawn instead of the magnet aperture. The beam sizes plotted correspond to the required aperture $A_{x,y}$.

Table 3: Injection Kicker Parameters with Ceramic Chamber

		S-type	L-type
Number		2	2
Angle per magnet tank	mrad	1.8	1.5
Magnetic length per tank	m	1.3	1.3
Magnets per tank		2	2
Magnetic field (max)	T	0.021	0.017
Gap height for beam	mm	75	95
Gap width for beam	mm	140	140
Magnet gap height	mm	90	110
Magnet gap width	mm	155	155
PFN voltage (max)	kV	53	54

INJECTION SEPTA

In both cases (under vacuum or outside beam vacuum kickers) upstream of the kickers and the quadrupole, two injection septa are required which deflect the beam by 55 mrad each so the upstream quadrupole is avoided. The septa parameters are listed in Table 4. A multi-turn coil is used to limit the required current. To avoid compatibility issues with the beam vacuum and the coil insulation, the septa will be outside vacuum. The magnets will be pulsed at the injection frequency of 1 Hz to limit the power dissipation and the inherent thermal loads. To reduce the effect of induced eddy currents in the vacuum chamber on the magnetic field as seen by the beam, the vacuum chamber is made of corrugated Inconel™, which results in a required magnet gap 15 mm bigger than the beam acceptance. The rise and fall times of the magnet are chosen such as to limit the magnet voltage to 1 kV. To make optimum use of the space allocated, the vacuum chambers for the injected and orbiting beam will be designed to be part of the septum assembly. The orbiting vacuum chamber will be part of the septum coil retaining system, while at the same time it provides screening from the septum leak field.

INJECTION DUMP

In case of a missed kicker timing or erratic kicker firing the injected beam is lost downstream. The maximum injected proton beam intensity of $1{\cdot}10^{14}$ protons at 4.0 GeV presents an energy of 64 kJ. This is not expected to damage the downstream machine elements, but to minimise activation of these elements an injection dump is to be installed about 17 m downstream of the kicker centre, after the defocusing quadrupoles in the following FODO cell. A graphite injection dump less than 1 m long is expected to sufficiently absorb and dilute any mis-injected beam. The dump needs to be double sided and the aperture should be smaller than the downstream dipole aperture of ± 80 mm.

CONCLUSIONS

A conceptual study of a fast injection system for the future PS2 accelerator has been made. The kicker system promises to be challenging, taking into consideration the required short field rise and fall times and requirements on beam impedance. In case a ceramic chamber is required to reduce the beam impedance, the required number of kicker magnets is eight, distributed over four tanks. Two thick injection septa, pulsed at 1 Hz, give sufficient deflection to avoid the upstream quadrupole.

More detailed work is required to quantify the acceptable kicker impedance and the expected effect of kicker beam screening. For the septa the field deformation by the induced eddy currents in the vacuum chamber will have to be quantified, and the development of pulsed multi-turn coil insulation methods needs to be pursued. Material and aperture studies remain to be done for the injection dump.

Table 4: Injection Septum Parameters

Number installed		2
Deflection angle	mrad	55
Physical length	mm	1000
Equivalent magnetic length	mm	900
Magnetic peak field	mT	988
Integrated magnetic field	mT.m	889
Beam acceptance (vertical)	mm	90
Beam acceptance (horizontal)	mm	75
Magnet gap height	mm	105
Magnet gap width	mm	111
Apparent septum thickness	mm	33
Distance to orbiting beam centre	mm	35
Number of coil turns		10
Magnet peak current	A	8250
Magnet voltage	kV	<1.0
Magnet repetition rate	Hz	1

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