PS2 INJECTION, EXTRACTION AND BEAM TRANSFER CONCEPTS

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Abstract

The replacement of CERN's existing 26 GeV Proton Synchrotron (PS) machine with a separated-function synchrotron PS2 has been identified as an important part of the possible future upgrade programme of the CERN accelerator complex. The PS2 will require a number of new beam transfer systems associated with injection, extraction, beam dumping and transfer. The different requirements are briefly presented, together with an overview of the conceptual design of these systems, based on the initial PS2 parameter set. The required equipment sub-system performance is derived and discussed. Possible limitations are analysed and the impact on the overall design and parameter set is discussed.

INTRODUCTION

The proposed PS2 [1] has as main design goals high performance, flexibility for possible future applications and upgrades, low radiological impact, high reliability and availability and compatibility with a staged upgrade programme and with the ongoing LHC exploitation during the construction. Basic parameters of the PS2 are given in Table 1 for the Fixed-Target beam [2].

Table 1: Main PS2 design parameters

Injection energy (T)	GeV	3.5
Extraction energy (T)	GeV	50
Circumference	m	1346.4
Maximum beta function	m	43
Maximum beam intensity	p^+	1.5×10^{14}
Minimum cycle period	s	2.4
Normalised emittance (H-V)	π.mm.mrad	15.0-8.0

PS2 BEAM TRANSFER REQUIREMENTS

Injection

- Fast single-turn injection of ions at 1.3 GeV and of p^+ at 3.5 GeV (for staged construction);
- H^- charge-exchange injection of protons at 3.5 GeV.

Extraction

- Fast single-turn extraction of p^+ and ions at 50 GeV;
- Slow 3rd integer resonant extraction of p^+ at 50 GeV;
- Low-loss 5-turn transfer of p^+ and ions at 50 GeV.

Beam Dumps

- A fast single-turn 'emergency' beam dump;
- Beam dump blocks in transfer lines, for setting-up.

Beam Transfer Lines

- Line for 1.3 GeV ions and 3.5 GeV p^+ and H^- beams;
- Line to the SPS, for 50 GeV p^+ and ions;
- Lines to experimental areas, for 50 GeV p^+.

BASIC ASSUMPTIONS

The systems here have been evaluated on the basis of the following assumptions:

- Regular FODO cell structure in PS2 injection and extraction regions;
- Phase advance of ≈90º per cell;
- β-functions in the range 8-43 m;
- 25.9 m cell length;
- 10 m 'free' drift per half-cell available to accommodate beam transfer elements;
- Local dispersion function matched to $|D_x| < 0.5$ m;
- Kicker and septum apertures/elements kept outside a canonical half-aperture of 50 mm at a β of 43 m (~230 π.mm.mrad acceptance in H and V planes);
- Fast injection kicker rise time ~100 ns;
- Fast extraction kicker rise time ~150 ns.

INJECTION SYSTEMS

Fast Single-Turn p^+/ion Injection

The 1.3 to 3.5 GeV fast system needs a kicker pulse length of ≤2.5 μs. The maximum vertical beam size (3σ) at injection will be ±38 mm. A conventional injection concept is envisaged, with a pulsed septum and a fast kicker. The 1.3 GeV beam fills the acceptance and no injection bumper system is foreseen, although this might be an option to reduce the kick strength at higher energy. Main sub-system parameters are given in Table 2.

Table 2: Fast injection sub-system parameters

Kicker angle	mrad	7.0
Kicker pulse length	μs	2.5
Kicker rise time	ns	100
Kicker field	T	0.03
Septum angle	mrad	200
Septum thickness	mm	22
Septum field	T	0.96

Multi-Turn H^- Injection

The H^- charge exchange injection system will consist of an injection septum, chicane dipoles, stripping foil, and fast orbit bumpers for phase-space painting. The injection process is over ≤270 turns, i.e. ≤1.2 ms. Several serious challenges are presented by the 3.5 GeV injection energy. Field stripping of H^- limits fields in injection magnets to ~0.14 T to keep losses at about the 10^{-4} level, giving bend angles of ~9 mrad/m. The stripping efficiency of a foil of 500 μg/cm² density at 3.5 GeV is about 95 % giving ~5 kW of unstripped H^0/H^- to be extracted and dumped.

Fig. 1 shows a possible H^- injection system in 3 FODO half cells. The first half-cell contains the injection septum. The second contains the injection chicane dipoles to

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produce the 23 mm injection bump. The third contains the septum to extract the H^- and H^0 beams. Sub-system parameters are shown in Table 3. The beam must pass at an amplitude of about 60 mm through the aperture of the two quadrupoles either side of the injection chicane, which at injection energy presents no problem in regard to the H^- beam lifetime. The dispersion at the foil needs to be ≤10 cm to decouple the transverse and longitudinal painting processes. The small emittances result in high p^+ densities on the stripping foil and high temperature rise of over 1400 K, shown in Fig. 2 for anti-correlated painting. The average number of foil traversals per proton is ~20; this produces emittance growth from multiple Coulomb scattering of <0.1 π.mm.mrad, and a beam loss of <0.02% from inelastic nuclear interactions. The foil cools to ambient temperature in the 2.4 s between injections.

Other important issues which require study are the space charge effects during injection, longitudinal painting, H^-/H^0 dump and the stripped electron collection.

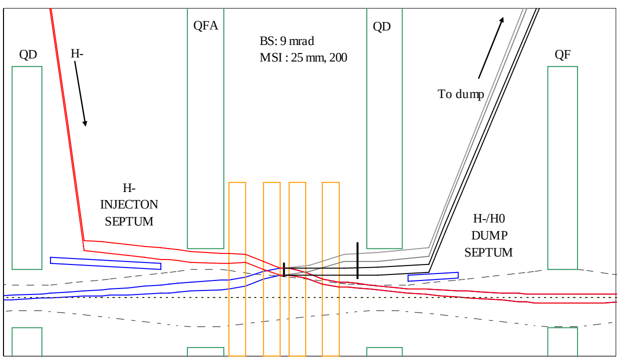

Figure 1. H^- injection system in FODO structure.

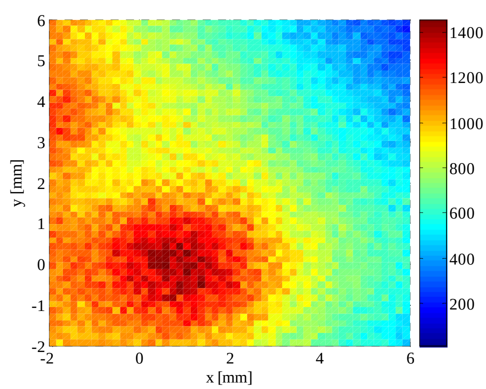

Figure 2. Carbon stripping foil temperature rise [K] for injection of 1.5×10^{14} p^+ over 270 turns.

Table 3: H- injection sub-system parameters

Injection septum angle	mrad	72
Injection septum field	T	0.14
Injection septum thickness	mm	5
H^-/H^0 dump septum angle	mrad	60
H^-/H^0 dump septum field	T	1.4
H^-/H^0 dump septum width	mm	5
Chicane dipole angle	mrad	9
Chicane dipole field	T	0.14
Carbon stripping foil thickness	μg/cm^2	500

EXTRACTION SYSTEMS

Fast Single Turn Extraction

A classical fast extraction system (orbit bump, septum, fast kicker) is needed as principal extraction system. The system has to be designed for variable extraction energies up to 50 GeV. The vertical beam size at 50 GeV is ±8 mm (±3 σ). Three different septum thicknesses are assumed, for compatibility with the slow extraction, Tab. 4.

Table 4: Fast extraction sub-system parameters

Kicker angle	mrad	1.6
Kicker pulse length	μs	4.2
Kicker rise time	ns	150
Kicker field	T	0.05
Orbit bumper angle (max)	mrad	1.6
Orbit bumper field	T	0.9
Septum angle (#1/2/3)	mrad	40
Septum thickness (#1/2/3)	mm	5/15/30
Septum field (#1/2/3)	T	0.14/0.7/1.4

3rd Integer Resonant (Slow) Extraction

The slow extraction is based on a classical 1/3 integer scheme, using an electrostatic (ES) and several DC magnetic septa. The system should allow spills of around one second. The jumps across the ES on the separatrix are assumed to be in the range 10-15 mm, allowing an ES gap of 17-20 mm. A series of 3 septa with increasing thickness and strength can give an extraction angle of about 40 mrad. The septa and bumpers are assumed to be common to the fast extraction, above: the parameters of the other elements are given in Table 5. Passive shielding will be needed downstream of the extraction.

Table 5: Slow extraction sub-system parameters

Electrostatic septum angle	mrad	1.2
Electrostatic septum field	kV/cm	100
Electrostatic septum thickness	mm	0.1
Sextupole gradient	T/m^2	~150

Low-Loss 5-Turn Continuous Transfer

The 5-turn continuous transfer extraction fills the SPS with a single extraction from the PS2. It will use non-linear fields to capture beam in stable islands to produce a physical separation at the entrance of the extraction septum, as proposed for the CERN PS [3]. Extraction takes place at a quarter-integer tune. Two kicker systems are needed; one produces a closed bump over the first 4 turns to extract the outer islands, with a second extraction kicker to extract the central island. The parameters of the kickers and septa are assumed to be similar to those described for the fast extraction system, with the addition of 2 kickers with similar deflection to produce the closed bump over 5 turns or 21 μs. Dedicated octupole magnets will also be required, in addition to sextupoles (which may be common to the slow extraction). Compensation of the slightly different 5th turn extraction trajectory may be required, with a smaller kicker unit in the transfer line.

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BEAM DUMP SYSTEMS

A beam dump system is needed to safely dispose of the 1.0 MJ beam energy. Either an internal or external dump can be envisaged. An external dump resembles the fast extraction channel, but the aperture must be large enough to accept the beam at injection energy. An internal dump is easier to implement and more compact, but potentially poses more problems in operation due to intense local activation. It is assumed that parameters and designs are similar to the extraction kickers and septa.

Dumps will also be required for the transfer lines, to enable setting up of the injection and extraction systems and of the lines themselves, and for personnel protection reasons when accessing downstream accelerator zones.

TRANSFER LINES

The PS2 optics with 25.9 m cell length and maximum beta-functions of 43 m needs matching into the SPS with 64 m cell length and maximum beta-functions of 110 m. The line design needs to respect the constraints on the location of the PS2 in the existing complex, and it should accommodate a stripping foil for Pb ions. Studies of possible solutions were made using two main achromat bends to provide the separation required between the PS2 machine and the existing transfer tunnels. The main problem in matching the line comes from the dispersion; this was addressed by evaluating during the matching the dispersion action $J_D = (D^2 + (\beta D' + \alpha D)^2)/2\beta$ and its modifier, at a bend with angle θ, of $\Delta J_D = \theta(\beta D + \alpha D')$, which enabled a solution to be found rapidly. A preliminary optics is shown in Figs. 3 and 4, with the PS2 to the right-hand side.

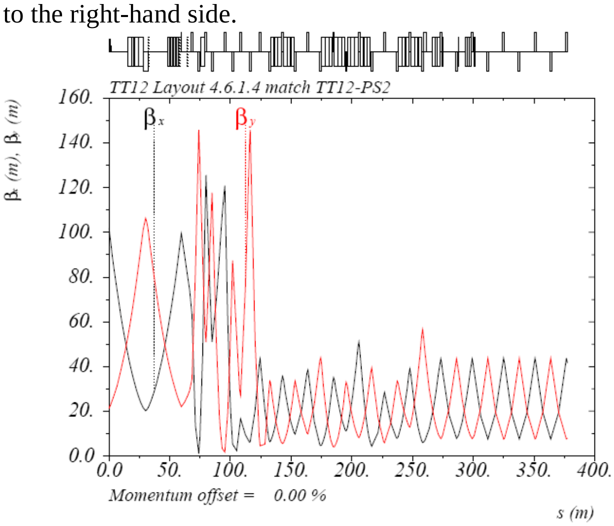

Figure 3. Beta functions for the PS2 to SPS line.

Quadrupole gradients were below 20 T/m and matching to dispersion errors of ±0.5 m and β errors of ±35 % was possible. A low-β location for a stripping foil was found.

The injection line to the PS2 for 3.5 (1.3) GeV beams requires enough acceptance for these low energy beams. The line must also be compatible with H^- ions, which means that the bending angles must be small (<9 mrad/m) to keep beam loss under control.

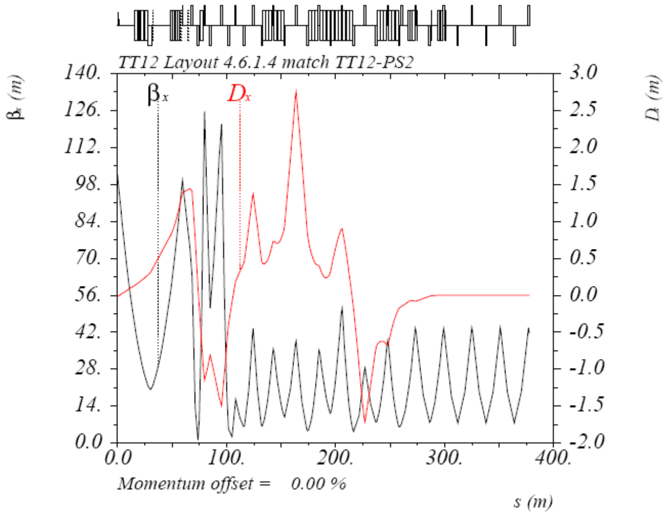

Figure 4: Horizontal beta and dispersion functions for the PS2 to SPS line.

CONCLUSION

Studies of the beam transfer concepts for the PS2 have produced basic equipment parameters, and highlighted possible problems and limitations. Some difficult aspects are the fast rise times requested for the extraction kickers, and the length of electrostatic septum for slow extraction. The H^- injection system poses a significant challenge and requires much more detailed study: a doublet insertion may be more suitable at these high energies, and the details of the injection region design need very careful attention, with full tracking using thick-lens models.

The total space required in the lattice for the beam transfer systems depends on the injection and extraction system layouts and juxtaposition [4]: the basic requirements detailed above require 7 FODO cells if all injection/extraction systems are combined into a single straight, of the order of 150 m of free straight section.

Topics of ongoing study are numerous and depend strongly on the evolution of the overall machine studies – areas being pursued in the short-term are the issues surrounding the H^- injection, the effect of different lattices, improvements in the extraction concepts to relax the kicker strengths, detailed requirements for the 5-turn transfer extraction and slow extractions, possible bipolar kicker system for an internal beam dump, and optimisation of the injection and extraction transfer lines. Many of these affect directly the machine layout, location and lattice, and are an integral part of the overall design effort even at this early stage.

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