INJECTION AND EXTRACTION CONSIDERATIONS FOR A 2 GEV RCS AT CERN

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Abstract

Conceptual studies have been made for a 2 GeV RCS at CERN as a possible replacement of the four-ring PS Booster. The lattice design has to accommodate suitable straight sections for a 160 MeV H- charge exchange injection system, and for a 2 GeV fast extraction system. The design constraints for the injection and extraction systems are described, together with the proposed concepts and potential equipment limitations.

INTRODUCTION

The RCS lattice is designed with a superperiodicity of 3 providing separate long straight sections (LSS) for injection and extraction. Each LSS consists of two FODO cells with four times 2.35 m drift space [1, 2]. Table 1 shows the main RCS parameters.

Table 1: Main RCS Parameters

Circumference	m	119.68
Injection energy	MeV	160
Extraction energies	MeV	1400 and 2000
Repetition rate	Hz	10
Max norm. emittance at extraction h/v	π·mm·mrad	15/9

160 MEV H- INJECTION

Design Constraints

Table 2 shows the beam characteristics from Linac4.

Table 2: Beam Characteristics from Linac4

Bunch frequency	MHz	352.2
Beam pulse length[a]	µs	400 - 600
# particles per pulse		$1.00{\cdot}10^{14}$
# particles per bunch		$1.14{\cdot}10^{9}$
Linac norm. transverse emittance	π·mm·mrad	0.4

[a] Depending on source current; the total pulse intensity remains constant

The maximum target rms emittance normalised to be painted is 15/9 π·mm·mrad for the high intensity fixed target beam. Considering an injected normalised rms emittance of 0.4 π·mm·mrad from Linac4 the maximum painting bump height amounts to 15.1 mm in the horizontal and 13.2 mm in the vertical plane compared to 30.8 mm horizontal and 19.5 mm vertical for the PS booster injection. The difference is due to a strong beam divergence at the foil position in the RCS.

Lorentz stripping limits the maximum field in the second chicane magnet (D2) to about 1 T which corresponds to a fractional loss of $5{\cdot}10^{-6}$ per m. This limit has also to be considered for the bending magnets in the Linac4 to RCS transfer line. A maximum loss level of $1{\cdot}10^{-4}$ due to Lorentz stripping shall not be exceeded.

Conceptual Design

The H^- charge exchange injection system comprises a horizontal 4 magnet chicane bump (D1-D4), one 4 magnet painting bump per plane (MKH1-MKH4 and MKV1-MKV4) and 3 stripping foils (F1-F3), see Fig. 1.

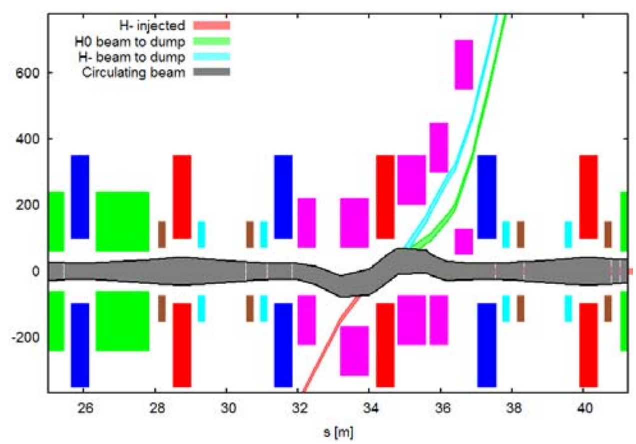

Figure 1: Layout of the H^- injection system with horizontal 3 σ beam envelopes in mm. Boxes indicate main bends (green, wide), focusing quadrupoles (red), defocusing quadrupoles (blue), horizontal and vertical painting bumpers (turquoise and brown, small) and chicane bumpers (magenta).

The injection system is a novel layout with a 2π chicane bump, housed in two empty FODO cells with a focusing quadrupole in the centre. The circulating proton beam (black) is bumped with an angle across the horizontal axis to be merged with the incoming H^- beam (red) in the D2 chicane dipole. The D1 chicane dipole deflects only the circulating beam and will therefore be a septum like magnet. The bump shape minimizes the excursion in the central QF quadrupole and hence the aperture required, and allows the system to be accommodated in the FODO straight section.

The stripping foil F1 is placed downstream of D2 to strip the H^- ions to protons. The foil thickness has to be optimised with respect to stripping efficiency, scattering losses, foil heating and emittance blowup of the

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circulating beam. The minimum in beam losses from stripping inefficiency and scattering is found for a foil thickness of 320 - 350 μg/cm^2, Fig. 2, details of the used model are described in [3].

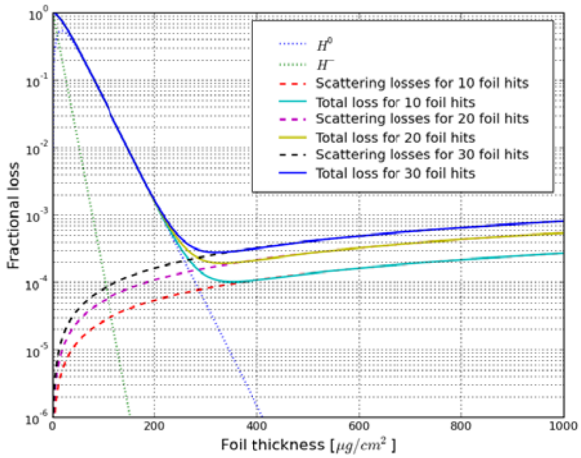

Figure 2: Optimisation of foil thickness with respect to beam losses from stripping efficiency and scattering. The optimum foil thickness is 350 μg/cm^2 for 10 foil hits per proton and 320 μg/cm^2 for 30 foil hits.

The emittance growth due to multiple coulomb scattering for this thickness amounts to 0.2 – 0.4 π·mm·mrad for an average of 10 foil hits per proton, Fig. 3. Thermal effects on the foil have to be studied in detail, in particular due to the high repetition rate of 10 Hz.

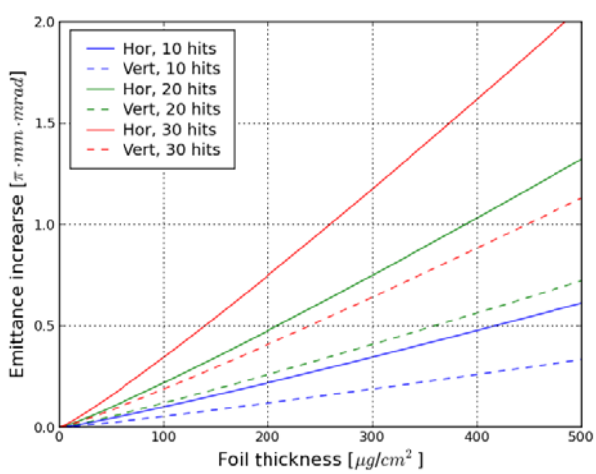

Figure 3: Emmitance increase due to multiple coulomb scattering in the foil.

The unstripped H$^-$ (turquoise) or partially stripped H^0 (green) need to be deflected into a dump line, Fig. 1. The D5 DC-dipole (septum) is required to deflect the H^0 waste beam only to clear the yoke of the downstream QD in the line to the dump. An open quadrupole design with a beam window at 350 mm is considered.

The painting bump amplitude reaches at the foil 30 mm in the horizontal and 25 mm in the vertical plane which gives a generous margin for changes in the optics. Twenty cm long magnets are needed for the painting bumpers with nominal fields of about 0.1 T (compared to 0.058 T in the 40 cm long KSW magnets of the present PSB). Figure 4 shows the shape of the chicane and painting bump in the horizontal plane.

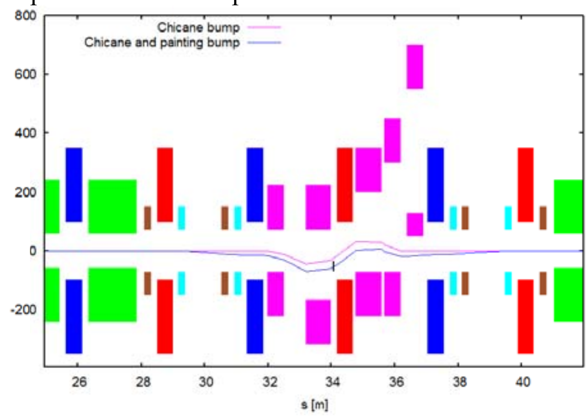

Figure 4: Horizontal bump shapes in mm.

Beta beating will result from the edge focusing of the strong chicane magnets. Its effect on the lattice focusing for full chicane strength is shown for SBEND and RBEND in Figures 5 and 6, respectively. This beating will change as the chicane is switched off, and a dynamic compensation will need to be considered as is being implemented in the PSB.

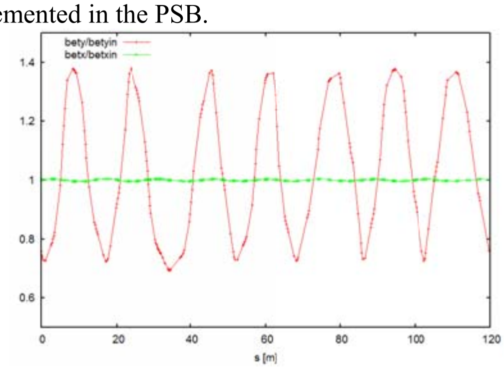

Figure 5: Beta beating for RBEND chicane and painting magnets.

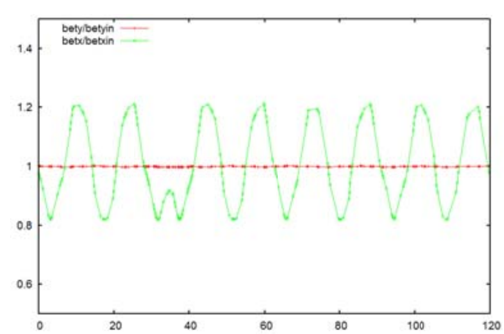

Figure 6: Beta beating for SBEND chicane and painting magnets.

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Table 3: Chicane Magnet Kicks and Integrated Fields at 160 MeV Kinetic Energy

Magnet	Angle [mrad]	Length [m]	B·l [T·m]	Field [T]
D1	-48	0.5	0.09	0.18
D2	128	0.8	0.24	0.30
D3	-162	0.8	0.31	0.38
D4	84	0.5	0.16	0.32
D5	300	0.5	0.57	1.14

2 GEV FAST EXTRACTION

The extraction system is designed to extract beams with energies at 1.4 GeV and 2 GeV. The extraction is a fast bunch-to-bucket transfer with a kicker and septum system placed around a defocusing quadrupole, Fig. 7. The width of the downstream quadrupole in Fig. 7 indicates the use of open quadrupoles with a beam window at 350 mm.

A 4 magnet extraction bump (magenta envelopes in Fig. 7) alleviates the kick requirements of the kicker and septa magnets by providing a horizontal displacement of 11 mm and an angle of 13 mrad at the septum entrance.

The septum system consists of two thick (19/25 mm) magnetic septa with a vertical gap height/width in the extraction channel of 40/60 mm and 80/120 in the circulating chamber. The kicker system consists of 2 tanks of 1.6 m length in two adjacent half cells.

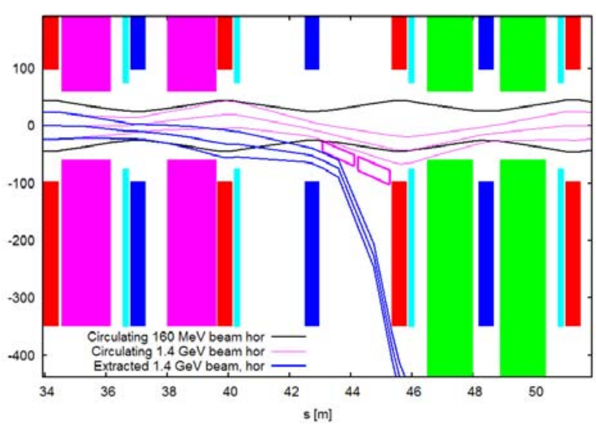

Figure 7: Extraction at 2 GeV kinetic energy from the RCS. The filled boxes in magenta and turquoise show the extraction kickers and bumpers and the magenta lines the septum blades. Beam envelopes (blue for injection energy, black for lowest extraction energy) are shown for a 3 sigma beam size including a closed orbit distortion of 1 mm.

The required rise time is 220 ns (5-95%) assuming harmonic 1 at extraction. The gap height and width are 74 and 120 mm, respectively. The total required kick strength amounts to 14 mrad. The RCS extraction kicker estimate is based on the assumption that conventional RG220 cables with a voltage not more than 40 kV can be used. The system requires 16 magnets divided in two tanks with 2 magnets per generator. The kick strengths and fields for the extraction elements are shown in Table 4. The possibility of harmonic 4 and significantly shorter rise times for the kicker system has strong impact on the extraction system and was therefore ruled out.

Table 4: Kicker and septum strengths and fields at 2 GeV kinetic energy

Magnet	Angle [mrad]	Length [m]	B·l [T·m]	Field [T]
MKE (x2)	7	1.6	0.065	0.041
MSE (19mm)	105	1	0.974	0.974
MSE (25mm)	130	1	1.206	1.206
MKH1	5.5	0.2	0.051	0.255
MKH2	-8.7	0.2	0.081	0.404
MKH3	6.7	0.2	0.062	0.311
MKH4	-5.9	0.2	0.055	0.274

CONCLUSIONS

The feasibility of injection and extraction systems for a 2 GeV RCS has been shown. An open quadrupole design is considered for both beam transfer straight sections to reduce the required kick strengths. A further iteration of the lattice design aiming at longer drift spaces should be investigated to improve the design of injection and extraction.

Different injection chicane types were studied; an asymmetric 2π-bump with three stripping foils and deflection of the waste beams to the outside was chosen to minimise quadrupole apertures and magnet strengths. Further studies should address the waste beam handling and the foil heating due to the high repetition rate.

For extraction the use of eddy current septum technology requires further studies to alleviate the needed kick strength of the fast pulsed magnets.

REFERENCES

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