EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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CERN-AB-2007-043

160 MeV H^- Injection into the CERN PSB

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Presented at
PAC07, 22nd PAC Conference, June 25-29, 2007, Albuquerque, USA

Geneva, Switzerland
August 2007

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The H^- beam from the proposed LINAC4 will be injected into the four existing rings of the PS Booster at 160 MeV. A substantial upgrade of the injection region is required, including the modification of the beam distribution system and the construction of a new H^- injection system. This paper discusses beam dynamics and hardware requirements and presents the results of optimisation studies of the injection process for different beam characteristics and scenarios. The resulting conceptual design of the injection region is presented, together with the main hardware modifications and performance specifications.

INTRODUCTION

LINAC4 is an H^- linear accelerator, intended to replace LINAC2 as injector to the PS Booster (PSB) [1]. The PSB consists of 4 superimposed synchrotron rings. The 160 MeV beam from the LINAC4 transfer line (BI) will be distributed to the four rings by a vertical bending magnet (DVT30), a system of five kicker magnets (DIS), another vertical bend (DVT40) and 3 septum magnets (SMV). The beam will be subsequently injected horizontally into the PSB by means of an H^- charge-exchange injection system. The proposed beam injection line can be built by modification of existing equipment to work at a $\int B \cdot dl$ of a factor 1.9 higher, with some new equipment also required.

BEAM DISTRIBUTION SYSTEM

The DIS vertical distribution system [2] in the injection line, as schematically represented in Fig. 1, will kick time resolved slices of the beam sequentially into the aperture of the appropriate vertical electromagnetic septa (SMV), which provide the main vertical deflection for beam separation, Table 1. The LINAC4 beam enters the DIS, a system of five pulsed ferrite core magnets, with a ~5.2 mm vertical offset and is deflected by a fixed field iron magnet (DVT40) into an absorber block (head dump). The DIS system, in combination with the DVT40, then deflects the beam sequentially into the different apertures of the SMV with a ~3.5 mrad deflection producing a vertical beam separation of 35 mm. The DIS rise- and fall-time need to be less than 1 µs and the pulse lengths will be fixed but different for each magnet. The SMV then further deflects the beam vertically into the 4 separate BVT vertical dipole magnet apertures to achieve the required PSB beam level separation of 360 mm between each ring. The falling edge of the LINAC4 pulse is deflected to a second absorber block (tail dump).

Three separate SMV magnets will be required to provide the ~131 mrad deflection necessary for ring 2 and ring 4, and the ~166 mrad deflection necessary for ring 1. Beam designated for ring 3 will see no magnetic field and passes between SMV2 and SMV3. The head and tail dumps will be positioned just upstream of the SMV yokes, allowing for maximum beam separation and optimum protection of the septa.

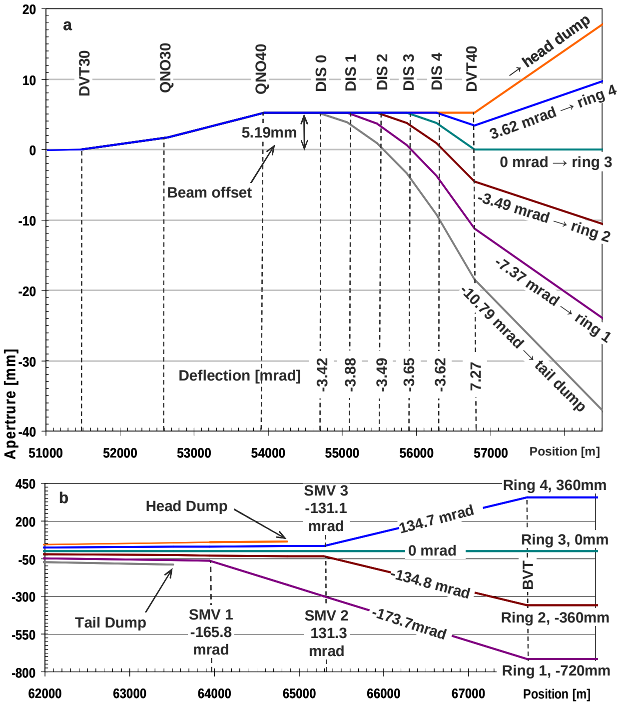

Figure 1: Schematic of the PSB injection line with the DIS (a) and SMV (b) vertical separation schemes.

LINAC4 PULSE STRUCTURE

The rise and fall time of the DIS system is ≤ 1 µs and therefore the pulse structure from LINAC4 will consist of 4 individual pulses, as schematically represented in Fig.2, typically 65-100 µs long, depending on the required number of injected turns per ring. These pulses will be separated by a 1 µs particle free gap allowing for the DIS rise time.

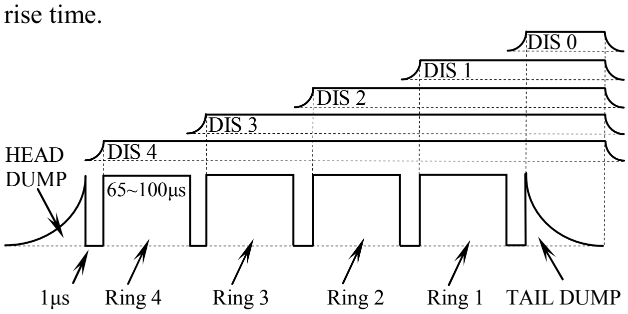

Figure 2: Proposed LINAC4 pulse structure (below) and DIS timing (above) showing nominal operation with 65~100 injected turns per ring.

In order to keep flexibility the LINAC4 pulses and DIS timing can be adjusted, to fit the required number of injection turns from pulse to pulse, or to not fill a ring if needed. Therefore the DIS timing must be linked to the LINAC4 pulse structure. The DIS pulse lengths will be fixed, but different for each magnet.

H^- INJECTION SYSTEM

The injection system is based on the H^- charge-exchange injection already conceived [3] where the 160 MeV H^- beam from LINAC4 is injected into the ring through a graphite stripping foil to convert ~98% of the beam to protons, including beam missing the foil. It is assumed [1] that the local orbit of the circulating beam is displaced, using two independent closed orbit bump systems, by 87 mm, to meet the incoming beam, see Fig. 3.

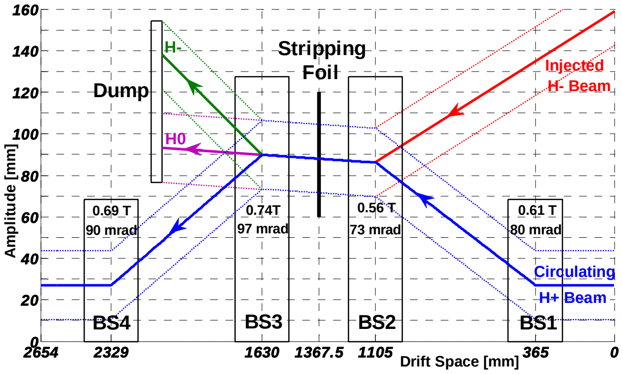

Figure 3: PSB injection region, showing injected and circulating (first t urn) beam envelopes of ±4σ for ±0.4% δp/p variation.

The first bump, called the injection bump, is made by a set of four pulsed dipole magnets (BS1 - BS4) located in the injection straight section, and displaces the beam by a constant 60 mm during the injection process. In each of the four PSB rings the injection region of 2.654 m is being redesigned to accommodate the injection elements: four new BS magnets, foil holder and handler, a beam dump for unstripped H^0/H^-, and suitable instrumentation for setting up and optimising the injection process.

Table 1: Main DIS, SMV and BS magnet parameters

(Design values)		DIS	SMV	BS1,4	BS2,3
Deflection angle	mrad	4.3	170	92	100
Integrated field	mTm	8.2	324	175	190
Gap field	mT	23.1	337	700	760
Gap height	mm	98	32	46	46
Gap width	mm	50	70	110	170
Magnetic length	mm	354	960	250	250
Peak current	kA	950	18.3	2.56	2.78
Magnet inductance	µH	0.9	1.3	75	116
Magnet resistance	mΩ	0.03	0.1		
Number of turns		1	1	10	10
Repetition rate	Hz	2	2	2	2
Rise / Fall time	µs	1		40	40
Flat Top duration	µs	420	100	100	100

The geometry of the injection region is defined by the space available and the angle of 66 mrad of the incoming H^- beam which intersects the PSB 2.41 m after the start of the injection region. The stripping foil edge will be located at about 65-70 mm from the central orbit, with the exact position being a compromise between intercepting the maximum amount of the incoming H^- beam and minimising the number of foil traversals of the circulating proton beam. The first BS magnet (BS1) must act as a septum, with a thin element dividing the high-field region of the circulating beam from the field-free region through which the injected H^- beam must pass.

All BS magnets, of which the magnet parameters are given in Table 1, are assumed to have a magnetic length of 0.25 m and need to provide a field of up to 0.76 T, which will keep the losses due to Lorentz stripping of the incoming H^- beam below the 10^{-7} level.

The layout leaves space for instruments between the BS1,2 and the BS3,4 magnets, as shown in Fig. 4.

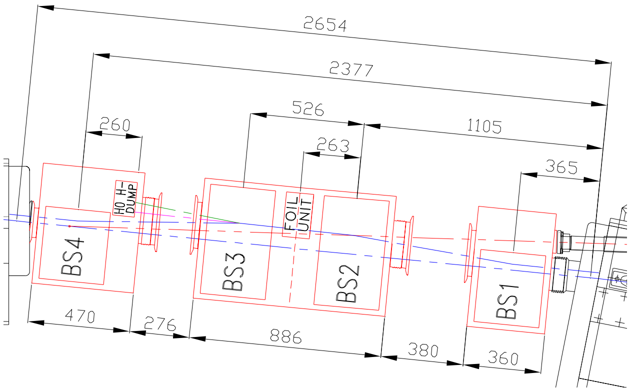

Figure 4: Proposed new layout of the injection straight section, showing available space [mm] of main elements.

INJECTION PAINTING AND MATCHING

To minimise the space-charge tune shift at injection transverse phase space painting is planned using the H-injection system [4]. A series of four horizontal kickers outside the injection region produce a 27 mm closed orbit bump with falling amplitude, which will paint the beam into the required emittance. Linear tracking simulations have been carried out to optimise the injection process. The vertical distribution will be obtained by injecting with a fixed beam offset. The horizontal phase space painting may be significantly complicated by the need to perform longitudinal painting of the injected beam, since the dispersion of ~1.5 m at the injection point strongly couples the longitudinal and transverse dynamics. The matching of the injection line optics to the PSB must also be chosen with care. The effect can be seen in Fig. 5, where the injection line dispersion is matched to the PSB injection point. A longitudinal painting of ±0.4% in δp/p has been applied, and the strong correlation between particle amplitude and horizontal position (and hence particle energy) is evident. The repercussions of this for the beam dynamics still require study, but for the injection line and foil the need to match the dispersion of the transfer line and the large energy swing mean that apertures have to be enlarged and the foil size increased by about 12 mm. In addition the number of foil hits will increase by a factor of about 2, to about 35 per p+ for the CNGS beam.

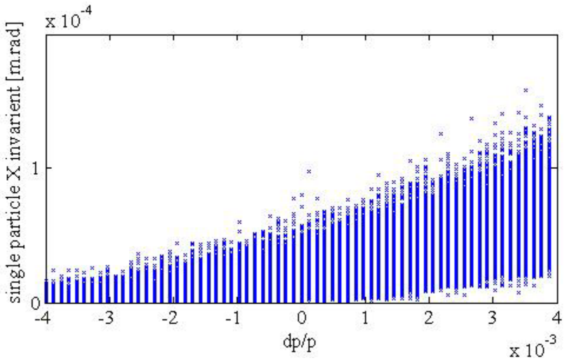

Figure 5: Horizontal single particle invariant (maximum amplitude) as a function of δp/p for CNGS beam.

STRIPPING FOIL

The foil is assumed to be a 2 µm thick (400 µg.cm^{-2}) graphite foil. A relatively thick foil is assumed, to minimise the amount of unstripped H^0 or H^-. The benefits of a thicker foil may outweigh the disadvantages of extra foil heating, losses and emittance blow-up. The estimated beam loss due to inelastic nuclear scattering is ~3×10^{-4} and the normalised emittance increase due to multiple-Coulomb scattering is 0.34 and 0.18 π.mm·mrad for the CNGS and LHC beams, respectively. Fig. 6 shows the foil temperature distribution after 7 CNGS injections of 70 turns per ring with each turn consisting of 1.14×10^9 particles. Peak temperatures are ~680 K at the end of an injection pulse, with cooldown primarily due to radiation to ~320 K during the 0.5 s between injections, Fig.7.

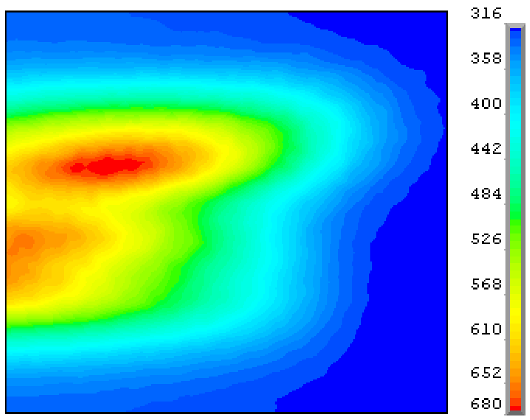

Figure 6: Temperature [K] of a 2 µm thick, 400 µg.cm^{-2} graphite foil at the end of the injection of 7 CNGS pulses.

The foil should strip ~99 % of the H^- to H^+, leaving about 1% of H^0 and less than 0.1 % of H^- [5]. For operational efficiency, it must be possible to exchange foils remotely. The space available for the foil holder/handler module is only 126 mm long: this will be difficult to design mechanically, especially given the need for four such superimposed mechanisms.

The unstripped ions must be intercepted by a beam dump, which for space reasons will have to be located in the PSB ring. The injection geometry and the very limited space available in the region appear to preclude extraction of the unstripped or partially stripped ions, as used for high-power charge-exchange injection systems such as JPARC [6]. The only possibility for such an extraction-based external dump system would be to increase the angle of the incoming BI line to at least 100 mrad, requiring a completely new geometry, stronger, ~1.2 T, BS magnets, an additional foil holder/handler unit and an extraction septum. This alternative is presently not under consideration instead an internal dump is proposed, housed in a separate unit directly up-stream of BS4.

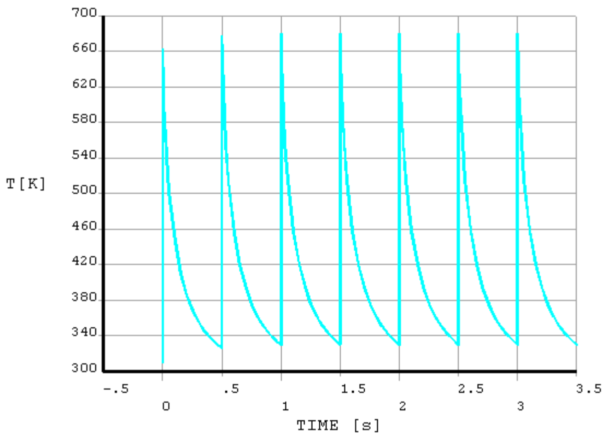

Figure 7: Peak foil temperature over 7 CNGS cycles.

In the proposed layout, the physical aperture requirements are important to minimise beam loss in this already difficult region. The vertical aperture of the BS magnets has been chosen to remain in the shadow of the main PSB dipoles. Assuming a BS1 septum width of <25 mm, the aperture available for the injected and the circulating beam is about 30 mm from the beam axis.

CONCLUSION

In order to distribute and inject the 160 MeV beam from LINAC4 into the four rings of the PSB, new distributor magnets and magnetic septa with a performance increase of 1.9 in ∫B·dl need to be built. The pulse structure from LINAC4 will consist of 4 individual pulses, typically 65-100 µs long. A completely new H^- charge-exchange injection needs to be built comprising four injection dipole magnets, a stripping foil unit, an internal beam dump, and suitable instrumentation.

REFERENCES

[1] L.Arnaudon et al., CERN-AB-2006-084 ABP/RF.
[2] P. Bossard, F. Völker, Proc. MT-5, Frascati, April 1975.
[3] E. Troyanov and K. Schindl, PS/HI Note 91-1, 1991.
[4] M.Martini, C.Prior, EPAC'04, Lucerne, July 2004.
[5] R.C. Webber and C. Hojvat, IEEE Trans. Nucl. Sci. NS-26 (1979) 4012.
[6] I. Sakai et al., PAC'03, Portland, May 2003.