EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ATS-2012-212

Status of the 160 MeV H- Injection into the CERN PSB

W. Weterings, B. Balhan, E. Benedetto, J. Borburgh, C. Bracco, C. Carli, B. Goddard, K. Hanke, B. Mikulec, A. Newborough, R. Noulibos, J. Tan, CERN, Geneva, Switzerland

Abstract

The 160 MeV H^- beam from the LINAC4 will be injected into the 4 superimposed rings of the PS Booster (PSB) with a new H^- charge-exchange injection system. This entails a massive upgrade of the injection region. The hardware requirements and constraints, the performance specifications and the design of the H^- injection region are described.

Presented at the 3rd International Particle Accelerator Conference (IPAC 2012),
20-25 May 2012, New Orleans, Louisiana, USA

Geneva, Switzerland,
July, 2012

STATUS OF THE 160 MEV H- INJECTION INTO THE CERN PSB

W. Weterings, B. Balhan, E. Benedetto, J. Borburgh, C. Bracco, C. Carli, B. Goddard, K. Hanke, B. Mikulec, A. Newborough, R. Noulibos, J. Tan, CERN, Geneva, Switzerland

Abstract

The 160 MeV H^- beam from the LINAC4 will be injected into the 4 superimposed rings of the PS Booster (PSB) with a new H^- charge-exchange injection system. This entails a massive upgrade of the injection region. The hardware requirements and constraints, the performance specifications and the design of the H^- injection region are described.

INTRODUCTION

LINAC4 (L4) 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 L4 transfer line will be distributed to the four rings by a vertical bending magnet (DVT30), a system of 5 kicker magnets (DIS), a vertical bend (DVT40) and 3 septum magnets (SMV) [2].

The beam will be subsequently injected horizontally into the PSB by means of a H^- charge exchange injection system, one for each ring, through a graphite foil converting ~98 % of the beam to protons. Partially stripped H^0 and ~1% H^- missing the foil will be directed to an internal H^0/H^- [3].

The local orbit of the PSB beam is displaced, using two independent closed orbit bump systems, by ~81 mm, to meet the incoming beam. The first, called the injection bump, is made by a set of 4 pulsed dipole magnets (BSW) located in the injection straight section, and displaces the beam by a constant 46 mm during the injection process. A series of 4 horizontal kickers (KSW), outside the injection region, will produce a 35 mm closed orbit bump, with falling amplitude during the injection, to accomplish transverse phase space painting to the required emittance. The energy of the injected beam will be varied to fill the bucket with an equal density distribution to achieve longitudinal painting [4].

KSW PAINTING MAGNETS

The KSW magnets will be used for transverse painting and to move the circulating beam away from the stripping foil. This allows reduction of the emittance (ε_x) blow-up induced by space charge effects and scattering processes.

The PSB has to provide beams with different intensity and emittance to several users. The number of turns needed to fill the PSB rings and the current modulation of the KSW magnets depends on the user requirements. Moreover, 40 turns (~40 μs) are needed to accomplish the longitudinal painting which is performed by the L4 RF system to fill the bucket with an equal density distribution.

Simulations with the particle tracking code ORBIT were used to define the optimum KSW pulse shape for all PSB users. A 6D particle distribution was tracked over several turns. H^- charge exchange, space charge, foil scattering, acceleration and apertures were included in the simulations.

A multiple-linear waveform was defined for the KSW generators, Fig. 1; the initial current I_0 corresponds to a maximum bump of 35 mm (see Table 1 for KSW values).

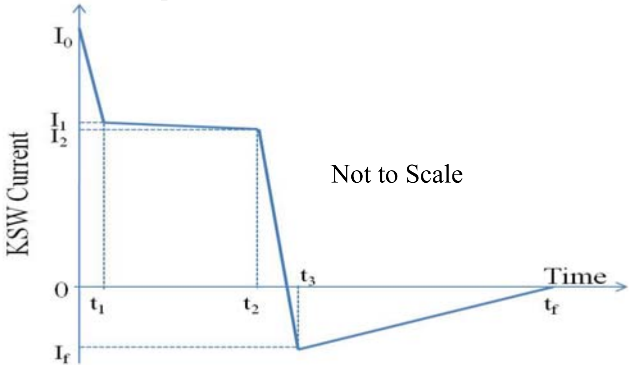

Figure 1: Decay of KSW current as a function of time.

Table 1: KSW longitudinal position with respect to stripping foil, kicks and magnetic fields to generate a painting bump of 35 mm.

	s from foil [m]	Kick [mrad]	B [T]
KSW16L1	-9.67	5.85	0.030
KSW16L4	-3.85	0.83	0.004
KSW1L4	5.97	1.15	0.006
KSW2L1	10.52	5.41	0.028

A fast current decay (t_1: 10-25 μs, depending on the user) is followed by an almost flat part until the end of the injection (t_2: 40-124 μs). This allows populating both the core and the outer part of the beam in a more uniform way. Once the injection process is finished the KSW current decays rapidly to a negative value I_f (t_3-$t_2 \leq 20$ μs for all users). This permits to shift the beam completely off the stripping foil which would otherwise fall in the acceptance of the high emittance beams (i.e. ISOLDE $\varepsilon_x = 15\ \pi\cdot\mu m$), when the BSW bump is at its maximum amplitude. The BSW current decay starts at the end of injection (t_3) and lasts 5 ms. I_f corresponds to 1/5 of the BSW maximum amplitude and the KSW current goes back to 0 in 1/5 of the BSW decay time (t_3-t_f). A high flexibility in the KSW current decay is required; current change requirements are 10% I_0 and 35% I_0 over 10-25 μs and 1% I_0 over 15-85 μs.

Two new sets of 4 KSW magnets with RF screens will be built. The outer (KSW16L1, KSW2L1) and inner (KSW16L4, KSW1L4) magnets will be mechanically and electrically identical. One generator per magnet, 16 in total, will be implemented in order to make the system more flexible.

BSW CHICANE MAGNETS

The injection bump is made with 3 different magnets. The circulating beam is first deflected using a 2-turn septum magnet (BSW1) which leaves the adjacent injected beam untouched. The required current for this magnet imposes that a transformer will be installed close to the magnets in the accelerator tunnel. Subsequently the injected H^- and circulating proton beams merge in the second magnet (BSW2), an 8-turn window frame magnet. After the stripping foil, the proton beam is deflected by an identical window frame magnet (BSW3) towards the circulating beam path. Finally the bump is closed, using an enlarged version of the 8-turn window frame magnet, to provide sufficient aperture for the circulating beam as well as the internal H^0/H^- dump [3], absorbing the partially and un-stripped H^-.

Initially, to allow powering all 4 magnets in series, they were designed to have the same magnetic length. Using 8-turn magnets avoids the need for large current transformers close to the magnets. Unfortunately the space available for the septum does not allow the BSW1 to be built as an 8-turn magnet; it was therefore decided to abandon the series powering of the injection chicane. At the same time this provides more flexibility for operation. For the BSW1 also a 4-turn variant is studied. Although the leak field of such a coil configuration is worse than for a 2-turn variant, the reduced current may avoid the need for a transformer close to the magnets, facilitating integration into the tunnel significantly. A definitive decision is still to be taken.

To validate the individual design of the magnets, a full model of all 4 BSWs was made using Opera [5]. Using the particle tracking feature in the program, the bump closure was verified; it remains within the accuracy of the model (mesh size 2 mm). The main BSW parameters are shown in Table 2.

Table 2: BSW magnet main parameters

		BSW1	**BSW2/3**	**BSW4**
Aperture H x V	[mm]	162 x 85	218 x 85	242 x 85
Magnetic Length	[mm]	316	316	316
Physical Length	[mm]	373	380	380
$\int B_y dl$	[Tm]	0.126	0.126	0.126
Relative field homogeneity	[%]	±1	±1	±1
Deflection angle	[mrad]	66	66	66
Number of turns		2	8	8
Current I	[kA]	13.5	3.4	3.4
Resistance R	[mΩ]	0.8	3	3
Inductance L	[μH]	3.2	66	77

The BSW1 and 4 are in the fringe field of the adjacent main dipoles (BHZ). The BHZ was modelled together with the BSW1; a reduction of ~3 ‰ of the BSW1 integral field was observed with the BHZ field at injection energy. The effect on the field homogeneity was within the precision of the simulation. Inversely, the BSW has a noticeable impact on the BHZ field; further studies are required to evaluate this effect.

Preliminary studies of the magnetic field between the BSW2 and 3 magnets show that a leak field of ~0.08 T can be expected. The stripped electrons have a beam rigidity (B·ρ) of about 1 m·Tm. The impact of electrons removed from the H^- hitting the injection foil several times, thus increase the foil temperature, will be studied.

At present, the vacuum chambers inside the BSW's are foreseen to be made of ceramic, resulting in minimal disturbance to the magnetic field. However, since the series powering option is abandoned, the delay induced by metallic vacuum chambers, of different shapes, could easily be managed by the power supplies. Nevertheless, the impact of the deformed field due to thin walled undulated metallic vacuum chambers on the beam should be investigated. Such metallic vacuum chambers would be both mechanically more robust as well as financially more attractive.

STRIPPING FOIL & HANDLING SYSTEM

The material choice and thickness of the foil is driven by the stripping efficiency, beam loss through nuclear scattering, emittance blow-up of the circulating beam and temperature rise of the foil [6]. For thermal stability, high sublimation temperature, radiation resistance and mechanical reasons the stripping foil material will be carbon, either in amorphous or diamond form.

The foil thickness is specified by the areal density in $\mu g/cm^2$; the equivalent thickness is assumed with a bulk density of 2 g/cm^3. To keep the emittance increase below 0.1 π·μm, for the ε_x ~2 π·μm for the LHC beam at injection, the foil should be < 250 $\mu g/cm^2$ in thickness. Nevertheless, to ensure a theoretical stripping efficiency > 99 % the thickness should be > 150 $\mu g/cm^2$. To keep the uncontrolled beam loss below the 10^{-4} level a foil thickness < 200 $\mu g/cm^2$ is required [7]. Since the benefits of a thicker foil outweigh the disadvantages of extra foil heating, losses and emittance blow-up a foil thickness of 200 $\mu g/cm^2$ (~1 μm) was specified.

Simulations [2] have shown that the highest foil temperatures are obtained for the high intensity CNGS type beam, where ε_x around 8 and 6 π·μm are assumed in the horizontal and vertical planes, respectively. The temperature rise for a single injection of 1.3×10^{13} p^+ is about 280 K. The effect of multiple injections at 1.2 Hz was investigated, assuming only black-body radiation cooling. An equilibrium peak temperature of 650 K is reached after a few cycles. Thermal foil damage is therefore unlikely a foil lifetime or performance issue.

The foil lifetime is expected to be dominated by purely mechanical effects or by accidents, such as shocks or being moved into the circulating beam. A minimum of 4 foils per ring should be available in the exchange unit. A foil movement in the horizontal plane of ±8 mm will be needed to adjust the injection and cover the movement for setting up from a retracted position to the nominal position. The foil will cover the total vertical acceptance of the PSB, thus no vertical adjustment is necessary.

To minimize the losses occurring from beam missing the foil, the foil size needs to be large enough to fully cover the incoming H^- beam. Nevertheless, a too large foil will result in larger numbers of foil hits per proton during injection, resulting in increases in beam loss, emittance and foil temperature. The optimum [7] width of the foil is 21 mm for injection with zero dispersion at the end of the transfer line and 32 mm for matched dispersion (-1.4 m). The support edges of the foil holder are kept outside the acceptance of the PSB and the lateral edge far enough, in order not to intercept the circulating beam.

Foil and target changers are commercially available and a conceptual design and prototype has been made based on a NEC FS6 foil changer [8], Fig. 2. Due to the limited space between BSW2 and 3 the stripping foil cannot be at the exact theoretical stripping point location, but will be positioned with an offset of ~30 mm longitudinal, upstream of the straight section centre.

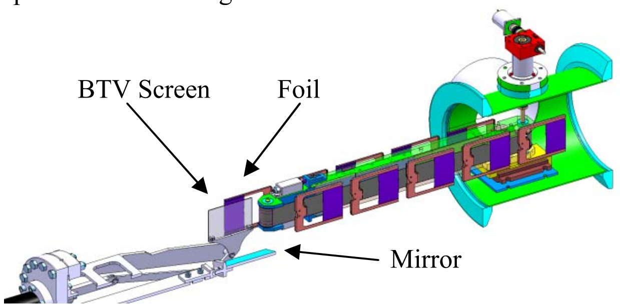

Figure 2: Conceptual design of stripping foil change unit.

In order to avoid foil damage due to differential pressure, it will be possible to isolate the foil exchange system from the overall PSB vacuum system; an interlock system shall be in place to avoid venting of the PSB vacuum system before isolating the foil exchange unit.

BEAM INSTRUMENTATION

Beam instrumentation is essential for the commissioning phase of the PSB injection with L4 beam and for routine operation later on. Furthermore, some signals are integrated into the machine protection system.

A removable scintillating screen, with a position accuracy of ±0.2 mm, is foreseen in front of the foil to measure the injected beam position and size for steering the beam onto the foil, Fig. 2. A Vidicon-tube-based camera is chosen for lifetime reasons, but at the price of beam size accuracy of 10%. Setting the screen at rest position will also allow visual inspection of the foil.

The stripping efficiency is monitored via a pair of 1 mm-thick plates in front of the H^0/H^- dump, measuring the waste beam current. Aluminum is preferred for its good thermal conductivity and low Z (lower yield of neutrons and γ rays). Secondary electrons will be repelled onto the plates with a pair of polarizing rings.

A set of three ionization chambers per ring is required for monitoring beam losses due to foil degradation, and for the fast machine protection system. Furthermore, fast losses, foil degradation and stripping efficiency optimization will be achieved with a diamond-type monitor placed in close vicinity of the dump.

A profile monitor for injection matching and emittance measurement will be implemented. The principle consists in injecting half a turn to separate turn-by-turn profiles for up to 20 consecutive turns. With a factor two betatron mismatch of the incoming beam, the rms beam size is expected to be between 1.1 and 2.2 mm. For these measurements a compact SEM grid (20 mm wide, 48 carbon wires) per plane in one ring will be sufficient.

In addition to closed-orbit and mean radial position measurements, the new ring pick-up (PU) acquisition system will feature turn by turn position monitoring for injection steering, bump closure and trajectories. A new system will be tested this year, having three ring PUs in parallel with the present ones, followed by a test phase with multiplexed signals before full deployment and commissioning.

OUTLOOK

During a recent external review it became clear that integration of all required equipment in the ~2.4 m injection region is a great challenge. The possibility of installing ~25 cm shorter main dipoles is now being investigated. This would open the possibility for an external dump, less influence between BSW and BHZ fringe field and reduced aperture limitations. The mechanically robust and financially attractive possibility of thin walled undulated metallic vacuum chambers, instead of ceramic ones, also needs further study.

Baseline installation date is end 2015 only ~6 months will be available for installation and commissioning. To avoid surprises it is planned to do a full mechanical pre-assembly of the injection region. The possibility of installing part of the injection chicane, including stripping foil, instrumentation and H^0/H^- dump, in the L4 beam line during L4 commissioning is also being investigated.

REFERENCES

[1] F. Gerigk et al., CERN-AB-2006-084, CERN (2006).
[2] W. Weterings et al., PAC’07, Albuquerque, June 2007, TUPAN109, p. 1628 ; http://www.JACoW.org
[3] M. Delonca et al., TUPPR054, these proceedings.
[4] C. Bracco et al., IPAC”11, San Sebastián, September 2011, THPS052, p. 3544; http://www.JACoW.org
[5] Opera by Cobham finite element software.
[6] M. Martini, C.R. Prior, EPAC’04, Lucerne, 2004, WEPLT028, p. 1891; http://www.JACoW.org
[7] B. Goddard et al., IPAC’10, Kyoto, May 2010, THPEB030, p. 3951; http://www.JACoW.org
[8] NEC, 7540 Graber Road, P.O. Box 620310, Middleton, Wisconsin 53562.