DUMP AND CURRENT MEASUREMENT OF UNSTRIPPED H^- IONS AT THE INJECTION FROM THE CERN LINAC4 INTO THE PS BOOSTER

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Abstract

Linac4 is the new H^- linear accelerator under construction at CERN aiming to double the brightness of the beam injected to the CERN PS Booster (PSB) for delivering proton beams to experiments or further CERN accelerators, down to the LHC. The injection system in the PSB is based on the H^- charge exchange where the 160 MeV H^- beam is converted into an H^+ beam by stripping the electrons with a carbon foil. A beam dump located inside a pulsed magnet for the injection bump will intercept the unstripped ions (H^0 and H^-) and measure the collected charge to detect the relative efficiency and degradation of the stripping foil. The challenge of the dump design is to meet the requirements of a beam dump providing a current measurement and at the same time minimizing the perturbation of the magnetic field of the surrounding pulsed magnet. This paper describes all phases of the dump design and the main issues related to its integration in the line.

INTRODUCTION

The 160MeV H^- beam from the Linac4 [1] will be injected horizontally into the four superimposed rings of the PSB through a graphite stripping foil used to convert about 98% of the beam to protons. The local orbit of the circulating beam is displaced by four pulsed dipole magnets (BS) creating the required injection bump. Four internal dumps, one per ring, will be installed downstream the stripping foil to intercept the unstripped particles (H^0, H^-) and any injected H^- that might miss the foil (Fig. 1).

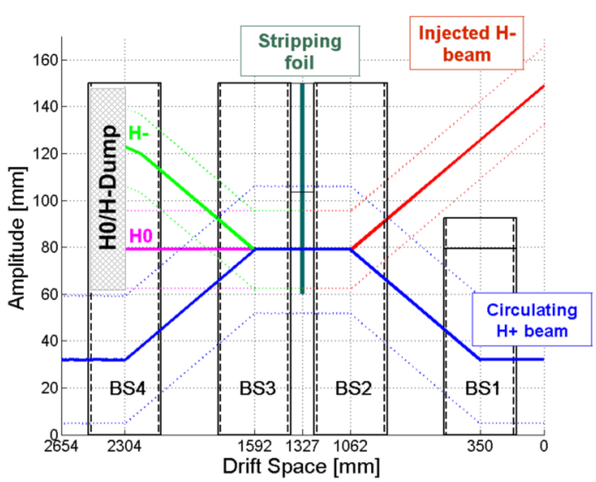

Figure 1: Top view of the PSB injection region, showing injected and circulating beam envelopes

In order to monitor the injection efficiency and detect any degradation of the foil, it is required to measure the current induced in the dump by the H^0 and H^- beam. An H^0/H^- monitor will be installed with this purpose just upstream of the H^0/H^- dump.

OPERATING CONDITIONS

The beam parameters relevant for the design of the dump are summarized in Table 1

Table 1: Linac4 beam parameters for PSB injection

Beam energy	MeV	160
Beam size	mm	σh= 2, σv= 3
Pulse length	µs	100
Beam current	mA	40
Repetition rate	Hz	1.11

Dump Performance Requirements

During nominal operation, the stripping foil will convert the H^- beam into a proton beam with about 98% efficiency for each of the four PSB rings [2]. In the case of a degrading foil, a decrease up to 90% in the efficiency of stripping is assumed. The accident scenario considers the full failure of the stripping foil or an accidental injection without it. Table 2 summarizes the power deposition in the dump for all operation scenarios.

Table 2: Power deposited in the dump for all operation scenarios

	H^0,H^-/pulse	Power
98% stripping efficiency	$5.55\cdot10^{11}$	14W
90% stripping efficiency	$2.5\cdot10^{12}$	71W
No stripping	$2.5\cdot10^{13}$	710W

DESIGN CONSIDERATIONS

The geometry of the dump must provide the passage for the circulating beam while absorbing the unstripped beam during regular operation and the full 100µs H^- beam in the event of a foil failure. In addition, the dump must allow a dynamic vacuum of 10^{-8}mbar to be achieved.

The most significant design constraints come from the close interaction between the dump, the surrounding BS4 dipole magnet and the monitor required for the beam current measurement. The perturbation on the magnetic field of the BS4 dipole magnet (0.34T) due to the presence of the dump should remain under 1%. Therefore, the material of the dump core should be non-magnetic. In addition, to minimize the eddy currents induced in the core, an electrically highly resistive material would be desirable. Nevertheless, in order to avoid the electrical charging of the dump and, to allow a correct beam current measurement, an electrically conducting material would be required. One of the main challenges of the dump design is to fulfil these opposite requirements.

In addition, the choice of materials for the dump should minimize as much as possible the residual dose in the area.

CONCEPTUAL DESIGN

Graphite is a diamagnetic material and has a relatively high electrical resistivity, $\rho=13\mu\Omega\cdot m$, but it is still slightly conductive, what makes it a convenient material for the dump core. Table 3 summarizes the main properties of the graphite used for the design of the core.

Table 3: Thermo-mechanical properties of the graphite used for the design

Density	g/cm^3	1.83
Young's Modulus	GPa	11.5
Thermal conductivity	W/mK	100
Flexural Strength	MPa	60
Compressive Strength	MPa	125

In the proposed design, the dump is fixed to the end of the vacuum chamber surrounded by the BS4 dipole magnet, in such a way that it provides a free passage for the circulating and injected beams while absorbing the H^0 and H^- beams, as shown in Fig. 2.

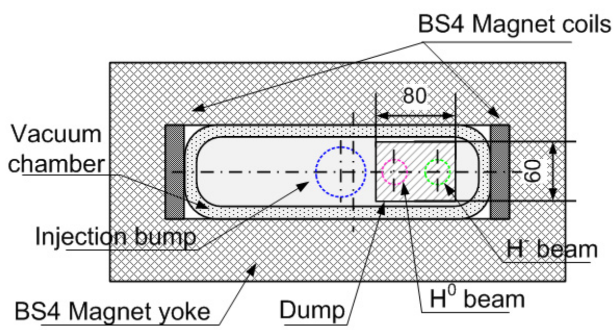

Figure 2: Representation of the proposed design of the H^0/H^- dump inside the vacuum chamber

The dump core is constituted by a graphite rectangular block fixed to a plate made of Al_2O_3 that allows the transition between the vacuum chamber and the outside. This transition plate guarantees the electrical isolation of the graphite block needed for the monitoring of the beam current while permitting a correct heat exchange with the outside-vacuum water cooling system, composed by a set of CuOFE pipes. Fig. 3 represents the described dump geometry.

Depending on the requirements from the beam current measurement, it might be envisaged to segment the block in order to monitor separately the H^0 and H^- beam currents. Therefore, the mechanism of joining the graphite to the transition plate is still to be defined. A thermal resistance of 0.3C/W has been added to the interface graphite/Al_2O_3, simulating a bad mechanical contact (which is conservative with respect to the characteristics of a good brazing). In the same way, a thermal resistance of 0.11C/W has been included in the interface Al_2O_3/CuOFE.

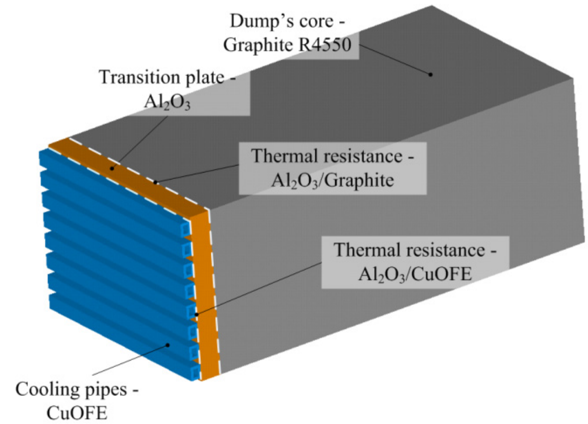

Figure 3: Proposed geometry of the dump

Thermo-Mechanical Calculations

The MonteCarlo code FLUKA [3] was used to assess the amount of energy deposited in the dump. The simulation was set assuming that all particles are of the same type (i.e. H^-), which is the most pessimistic case for the thermo-mechanical calculations while this simplification has a negligible impact for the later studies on activation and residual dose.

The thermal loads obtained in FLUKA were given as input to an ANSYS® [4] finite element (FE) model. Fig. 4 shows the energy deposited in the dump in the case of a 90% efficient stripping of the H^- beam. The maximum value of energy density and the integral of the energy deposited over the volume were checked. In both cases, less of 2% error was found between the FLUKA results and the loads deposited in the FE ANSYS model.

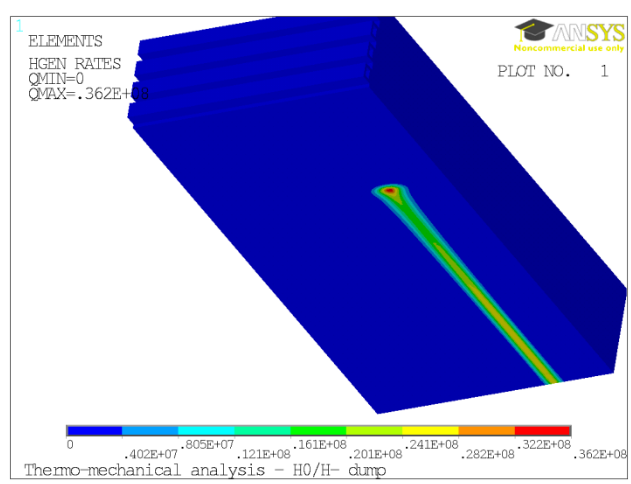

Figure 4: Energy deposited in the dump (W/m^3) by the 100μs H^- beam (accident scenario), with a symmetry on the mid plane

The results obtained from the ANSYS FE simulation of the different operational scenarios are summarized in

Table 4. Even with a non-efficient thermal contact between the different materials, the temperatures reached during standard operation are relatively low. Although the accident scenario corresponds to the most demanding case in terms of thermo-mechanical stress, the maximum equivalent tensile stress (used to assess the structural risk for the dump) is much lower than the tensile strength of the graphite, assumed to be 40MPa (about 2/3 of its flexural strength). In the case of a foil failure, the only effect to be considered is a probable degradation of the vacuum quality due to the outgassing of the graphite, which would not be a real issue since this configuration corresponds to an abnormal operation and the interlock system should anyhow stop the beam.

Table 4: Results of the ANSYS FE simulation for the different operation scenarios

	98% stripp. effic.	90% stripp. effic.	Foil failure
ΔT (1 pulse)	4	18	153
T (equilib.) (ºC)	20.8	24	*NA*
Max. Equivalent. Tensile Stress (foil failure)			
		Von Mises (MPa)	7
		Stassi-d'Allia (MPa)	2.5

Although both criteria of elastic failure (Von Mises and Stassi d'Alia) have been studied, the most realistic taking into consideration the non-symmetric elastic behaviour in tension and compression of the graphite, is the Stassi-d'Alia criterion for which, the situation is even more favourable.

Effect of the Dump on the BS4 Dipole Magnetic Field

The proposed material and geometry of the dump were modelled in a time varying field simulation using Vector Fields Opera 2D. The Fourier analysis of the field over the passage area of the beam during a ramp down of 5ms showed that the harmonics induced by the eddy currents in the dump are expected to be in the 10^{-4}-10^{-5}T range. Therefore, the perturbation of the magnetic field by eddy currents induced in the dump remains below 1%, which is acceptable.

Study of Induced Radioactivity

FLUKA was also used for the study of the induced radioactivity [5] after one year operation (200 days).

The dose absorbed by the BS4 magnet coils was calculated. The predicted peak dose was about 280kGy/year, lower than the threshold of 3MGy from which a degradation of the mechanical properties of a standard coil can be expected by experimental results [6]. Nevertheless, once the layout of the line will be fixed and the geometry of the surrounding equipments will be defined, this simulation should be redone in order to assess the impact of the secondary showers on the upstream and downstream equipment.

The ambient dose equivalent rates *H*(10)* were estimated for different cooling times after one year operation of the dump. Fig. 5 represents the spatial distribution of *H*(10)* over a top view of the PSB tunnel. The z-axis corresponds to the beam longitudinal axis (beam coming from negative z values) and x corresponds to the horizontal axis directed toward the centre of the PSB rings. The ambient dose equivalent in the immediate surroundings of the dump is, as expected, quite high (around 8mSv/h), but the ambient dose equivalent outside the BS4 magnet is considerably reduced due to the shielding effect of the BS4 magnet itself.

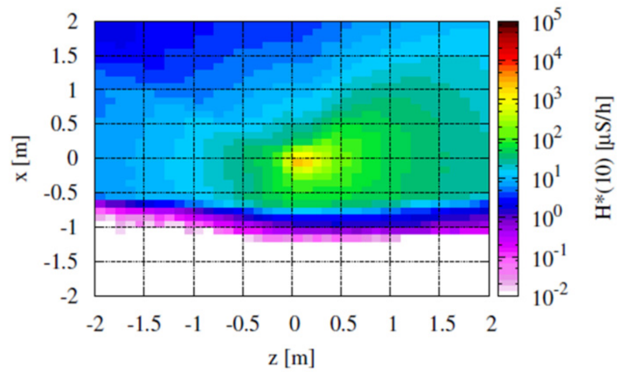

Figure 5: Top view of the spatial distribution of *H*(10)* in the PSB tunnel.

These results give a preliminary idea of the personal doses received while working in the surroundings of the dump.

CONCLUSIONS

The proposed design of the H^0/H^- dump for the PSB injection meets the requirements of a beam dump without major impact on the vacuum quality and in the magnetic field of the surrounding BS4 dipole magnet. The choice of materials and configuration of the dump respond to the basic requisites for implementing a monitoring of the beam current. Nevertheless, the design of the dump cannot be fixed until the beam current monitor will be fully defined and the validity of the ensemble will be checked.

From the analysis of the radioactivity induced by the dump it can be concluded that the mechanical integrity of the BS4 magnet is assured. The ambient dose equivalent rates *H*(10)* around the dump should not be an issue either. However, these last set of results can only be taken as preliminary since the contribution of the adjacent equipment (upstream and downstream) cannot be taken into account until the layout of the line will be fixed.

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