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THE INSERTABLE BEAM STOP IN THE ESS SPK SECTION

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Abstract

This paper deals with the Insertable Beam Stop (IBS) to be installed at the transition between the normal conducting and superconducting sections of the ESS linac. The IBS will be used to avoid beam losses in the cryogenic cavities during tuning and commissioning of the ESS linac. The IBS will stop protons in the energy range from 73 MeV to 92 MeV. The proton beam has a current up to 62.5 mA, and 5 and 50 µs long pulses at a rate of 14 or 1 Hz, respectively. Firstly, the IBS was designed in MCNPX/ANSYS to withstand thermal and structural stresses, while minimizing neutron production and limiting the deposited power in the cryogenic cavities below 0.2 W/m. Secondly, the prompt background and residual dose in the vicinity of the IBS were computed, as well as the activation of the IBS components themselves. Finally, a feasibility study was performed to determine if the IBS can be profitably used as a beam-profile monitor. The results will serve as input for calculations of the expected signal in beam loss monitors. Moreover, they will enable the design of the nearby shielding limiting the activation of surrounding structures and allowing maintenance works.

INTRODUCTION

The European Spallation Source (ESS) in Lund (Sweden) is currently one of the largest science and technology infrastructure projects being built today. The facility will rely on the most powerful linear proton accelerator ever built, a rotating spallation target, 22 state-of-the-art neutron instruments, a suite of laboratories, and a supercomputing data management and software development centre [1].

The ESS accelerator high-level requirements are to provide a 2.86 ms long proton pulse at 2 GeV at repetition rate of 14 Hz. This represents 5 MW of average beam power with a 4% duty cycle on the spallation target [2].

A comprehensive suite of beam instrumentation and diagnostics [3] has started to support the commissioning and operation of the normal-conducting linac (NCL) section of the ESS linac. Additional devices are going to be deployed in the superconducting linac (SCL) section, and in the transport lines to the tuning dump and to the spallation target.

At the transition between the NCL and the SCL sections, an Insertable Beam Stops (IBS) will be installed in order to avoid beam losses in the cold cavities during tuning up and commissioning of the ESS linac.

In the following three paragraphs, the main studies that are ongoing and devoted to the design of the IBS will be summarized:

1. MCNPX/ANSYS studies to perform thermo-mechanical simulations,
2. MCNPX/CINDER’90 studies for activation calculation and shielding design,
3. Feasibility studies of utilizing the IBS as a beam-profile monitor.

THERMO-MECHANICAL ANALYSIS

The IBS must guarantee that the proton beam is fully stopped and the beam power is safely dissipated as waste heat. The maximum proton beam current is 62.5 mA and the maximum beam energy is 92 MeV, leading to a peak power of 5.75 MW.

In order to withstand the high power, to minimize the heat transfer to the cold linac section and also the residual radioactivity, the only possible choice for the IBS core is graphite (with a density of 1.8 g/cm^3). Further challenges are posed by the limited space available in the Linac Warm Unit (LWU, see Fig. 1), and its particle-free environment. Therefore, the graphite core is embedded in a tungsten shielding, surrounded in turn by a 3 mm thick layer of titanium, allowing vacuum cleaning and avoiding particle generation.

The outer IBS radius is 5.5 cm and the total IBS length is 8 cm. The IBS is water cooled and the pipes of the circuit system are made of SSL. Energy deposition calculations

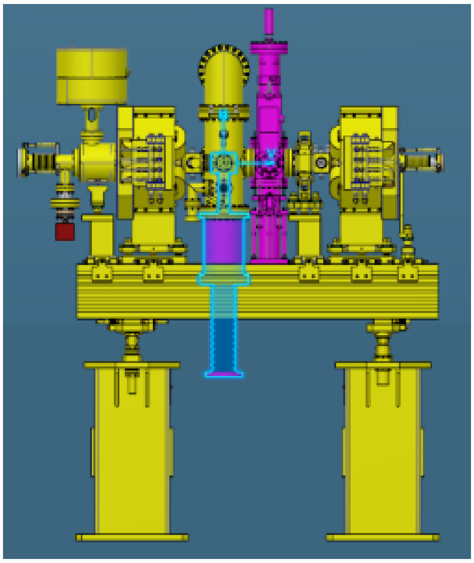

Figure 1: The Linac Warm Unit (LWU) in the ESS spoke (SPK) section, holding the IBS (highlighted in blue). The beam goes from right to left. (Courtesy of STFC and the ESS Vacuum section).

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were performed in MCNPX [4], assuming two possible commissioning modes:

- Fast tuning (5 µs, 14Hz, 62.5 mA),
- Slow tuning (50 µs, 1Hz, 62.5 mA).

An asymmetric gaussian beam was simulated with dimensions of (1.8 mm × 2.4 mm). The beam energy was varied in the [73, 92] MeV range. The position of the Bragg peaks within the IBS are reported in Fig. 2 for reference just in the minimum and maximum energy cases. The peak maximum is reduced by 20% when comparing the 92 MeV case to the 73 MeV one. The maximum value of the energy deposition in the graphite bulk is 350 MeV/cm^3/p at the lowest proton energy.

The corresponding temperature rise was obtained via ANSYS [5], using the temperature-dependent heat capacity of each material. The most demanding case is posed by the slow tuning mode, leading to a maximum temperature of 450°C after one single pulse with 73 MeV protons. At the highest energy of 92 MeV, the graphite temperature is below 350°C. In all the considered cases, the maximum temperature of the Ti surface remains below 200°C.

Further ANSYS calculations are ongoing in order to compute the von Mises stress and to optimize the water cooling system.

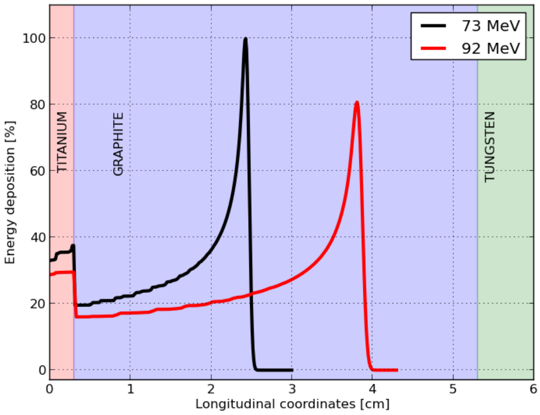

Figure 2: Energy deposition due to 73 MeV and 92 MeV protons, as a function of the longitudinal coordinate of the IBS. The three sections indicate the different structural materials intercepted by the beam. Values are scaled to the maximum value of the Bragg curve for 73 MeV protons.

ACTIVATION AND SHIELDING

Another set of simulations were performed in CINDER'90 [6] to determine the IBS activation after relevant irradiation and cooling periods for the ESS linac commissioning. In general, soon after irradiation, the outer layer of titanium is found to be the most activated component. The total IBS activity saturates at nearly 10^{11} Bq after 12 h of continuous irradiation, for both the two proton energy that were analyzed (73 MeV and 92 MeV).

After irradiation times longer than 8 h and cooling times longer than 100 h, it was noticed that the most activated component is the tungsten bulk instead. A Python script was developed to automatically run CINDER'90 calculations and process the output files; this will be helpful in case information at specific irradiation and/or cooling times will be needed during the ESS linac commissioning.

The activation calculations serve also as input for the design of the IBS shielding. In fact, the dose rate at 30 cm from a surface of the shielding shall not exceed 100 µSv/h after 120 h of irradiation at the maximum average power and 4 h of cooling. Therefore, the IBS and a simplified geometry of the LWU was implemented in MCNPX. As previsouly shown in Fig. 1, two quadrupoles and one corrector magnet, two Beam Position Monitors, a Beam Shape Monitor, a vacuum pump were included in the simulations. Downstream of the LWU, a simplified spoke cryomodule is simulated, too. As a reference value, the map of residual dose in the vicinity of the IBS is reported in the left plot of Fig. 3, after an hypothetical irradiation for 120 h and 4 cooling hours at with 93 MeV protons. Further analysis will provide an estimation of the dose received by each LWU components and the power dissipated in the cryogenic components. These information will enable the selection of the shielding material(s) in the tight LWU space. The first investigated material is lead; its impact is notable in the right plot of Fig. 3. Further improvements will enable the reduction of the dose not only sideways but also downstream with respect to the IBS. To further reduce the dose to staff, the installation of a concrete or temporary shielding wall parallel to the beam propagation axis is being considered. A separate set of calculations is

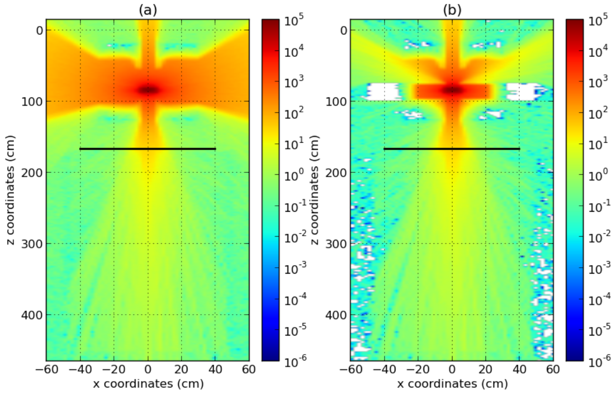

Figure 3: Residual dose distribution in the IBS surroundings (in µSv/h) after irradiation for 120 h with 93 MeV protons and cooling for 4 h. The black horizontal lines indicates for reference the end of the LWU and the start of the SPK crymodoule. The IBS is located in the hot spot. (a) Without shielding and (b) with a compact lead shielding around the IBS.

planned in order to compute airborne radioactivity and the cooling water activation.

A BEAM PROFILE MONITOR?

To avoid melting any of the IBS components due to a too high power density, the feasibility of embedding a beam-profile monitor is being investigated. The inclusion of such feature is at an early design phase and highly constrained by several requirements. Firstly, the system must be ISO-5 qualified, i.e. particle free. Secondly, the system must fit within the allocated space, as no modification of the vacuum vessel is permitted. With these constraints, several possible diagnostics have been considered: an imaging system, a multi-wire grid or a silicon sensor. In the following paragraphs these three options are outlined.

An imaging system would be composed of two elements: the light source (chromium-doped alumina), which would be flame coated on the Ti layer of the IBS. The material is luminescent and radiation tolerant. This coating materials was already selected for the imaging system of the ESS target [7]. The luminescence is high, in excess of 1000 to 10000 photons per MeV deposited in the material. Samples have been produced and are being tested for ISO-5 cleanness qualification. The image from the beam would be produced by a standard industrial camera and lens, designed to get a field of view of about 100 mm. The camera and lens would be positioned outside of vacuum, looking through a viewport on an upstream vessel that supports also the Bunch Shape Monitor. The optical path contains a single flat mirror, reflecting the light from the IBS to the lens. The system performance is expected to image a probe beam pulse in single shot, and with resolution in the 0.1 mm range.

As a second option, a multi-wire grid could be composed of a grid of tungsten wires, assembled on a ceramic frame, and connected on both sides to a triax connector, so that the shielded ground and signal can be read by an AMC pico4 current ADC. The wire diameter should be thick enough to enhance the signal as well as thin enough to withstand beam-induced heat loads. Based on previous studies [8], a 40 µm tungsten wire would satisfy the requirements. One may note that this system is not a full 2D diagnostics, but it may be sufficient for reporting beam sizes smaller than 1 mm. Assuming a wire spacing of 2 mm, the system would be composed of 100 wires, positioned both in the vertical and horizontal axes of the proton beam.

As a third option, a multi-strip silicon detector on top of the entrance IBS face could serve as beam position, profile and also halo monitor. Moreover, it could potentially monitor the beam intensity if absolutely calibrated e.g. with an upstream Faraday cup or Beam Current Monitor. On one hand this latter solution would be the most compact and radiation-hard one, but on the other hand it is expected to be the most expensive one.

CONCLUSIONS AND OUTLOOK

The first steps for the design of the SPK IBS were presented. Firstly, MCNPX/ANSYS calculations were performed to investigate the thermo-mechanical properties. Further calculations will determine the von-Mises stress and optimize the water cooling system.

Another set of simulations in MCNPX/CINDER'90 were performed to assess the activation of the IBS components and the residual doses after relevant irradiation and cooling times during the ESS linac commissioning. These results will be the starting point for designing the shielding needed to limit the dose to surrounding linac components and to minimize the power deposition in the cryomodules. Moreover, they will serve as input for dedicated calculations of the expected signal in beam loss monitors closed to the IBS.

A self-protection capability would make possible to avoid melting any of the IBS components; therefore the possibility of embedding an imaging system, a multi-wire grid or a silicon sensor on the IBS entrance face is being considered. Exploiting the IBS as a beam-profile monitor would certainly provide a useful diagnostics tool during the commissioning of the ESS linac.

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