

# THE BEAM STOPS FOR THE ESS SUPERCONDUCTING LINAC

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## Abstract

For the ESS superconducting linac in Sweden, two types of insertable beam stops were manufactured instead of bulky beam dumps. The beam stops dump protons either up to 100 MeV or 250 MeV; the most demanding beam modes have an average beam power of 700 or 1140 W, respectively. The beam stops are water-cooled and moved by pneumatic actuators. The beam stops were designed at the ESS in Sweden and manufactured by Proactive R&D in Spain, supported by the ESS workshop and many companies from all around Europe. The assembly, acceptance tests and metrology measurements were performed in ISO5 cleanrooms, before the installations in the particle-free environment next to the superconducting cavities of the ESS linac.

This contribution summarizes the assembly, test and commissioning experience.

## INTRODUCTION

The commissioning of the proton accelerator for the European Spallation Source (ESS) started in Lund (Sweden) during 2018, with the ultimate goal of delivering 2.86 ms long pulses at 14 Hz and the nominal current of 62.5 mA on the ESS spallation target [1]. The compact ESS beam stops were designed in place of bulky beam dumps to safely dump the proton beam within two superconducting linac sections: the SPoKe (SPK) and Medium Beta Line (MBL) sections (see Tab. 1 with the key beam parameters and impact). The most demanding beam modes have an average beam power of 700 W and 1140 W for the SPK and MBL IBS, respectively. In the most demanding beam modes, the beam-interceptive cores reach a temperature of 685 °C in the SPK beam stop and 280 °C in the MBL beam stop.

Table 1: Key Beam Parameters and Impact on the Insertable Beam Stops (IBS) for the ESS Superconducting Proton Linac

	SPK IBS	MBL IBS
Nominal Energy	92 MeV	216 MeV
Energy Range	[21, 100] MeV	[21, 250] MeV
Peak Power	700 W	1140 W
Peak Power Density	4 GW/cm <sup>3</sup>	30 MW/cm <sup>3</sup>
Peak Temperature	685 °C	280 °C

The design of the ESS beam stops required a careful selection of the materials, geometry and cooling system, informed by neutronics and thermo-mechanical calculations [2]. The Insertable Beam Stops (IBS) were designed to fit in the limited space inside as well outside the vacuum vessel (see for instance the fully packed SPK1 section in Fig. 1). Moreover, they must fulfill the ISO5 requirements. In particular,

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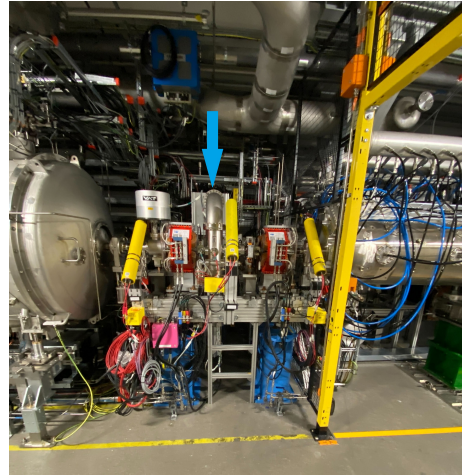


Figure 1: Installation location of the SPK IBS [3] between the first cryomodule of the ESS superconducting linac (on the left), and the end of the DTL5 section in the ESS normal conducting linac (on the right).

during the operation with beam the outgassing must remain below  $10^{-7}$  mbar·L/s. In this paper, the assembly and tests are summarized, with emphasis on the rigorous control of particulate contamination which is mandatory to sustain the high accelerating gradients in the ESS superconducting linac [4]. The very first commissioning results are presented.

## ASSEMBLY IN ISO5 CLEANROOMS

The beam stops were designed at the ESS; the detailed design and assembly was performed in collaboration with the company Proactive R&D (in Spain). The manufacturing of all the components was supported by the ESS workshop and many companies from all around Europe. All the ESS beam stops have a graphite core to fully stop the proton beam; the core is enclosed in a TZM shell. The graphite cores required thermal treatment in order to minimize the outgassing prior to installation in the ESS superconducting linac. This is evident from the results of the RGA measurements in Fig. 2, which compares the RGA scans before and after after vacuum firing at 950 °C and pumping for 24 h of the MBL IBS graphite core. The final RGA confirmed the absence of heavy hydrocarbons.

The beam stops are water-cooled and movable in/out of the beam axis by means of a pneumatic actuator operated at 6 bar. The welding of the cooling pipes was performed by Allectra Ltd (in UK). The brazing of the cooling pipes on the TZM bulk was performed by the company Reuter Technologie GmbH (in Germany) for the SPK beam stops, and by TWI (in the UK) for the MBL beam stops, requiring in both cases multiple furnace runs above 950 °C.

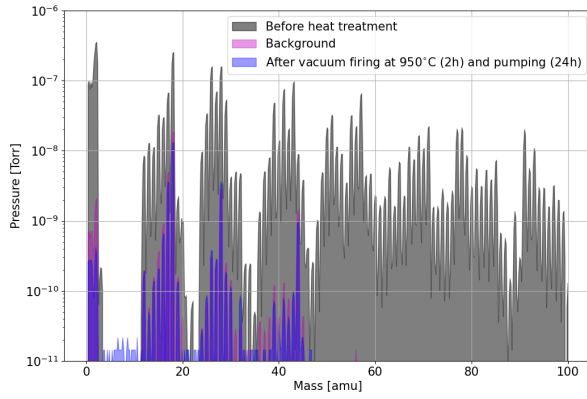


Figure 2: RGA results before and after the thermal treatment of the MBL IBS graphite core.

Special attention was posed for pressing the graphite core into the TZM shell in order to maximize the contact heat transfer (see Fig. 3 for the second MBL beam stop). All the components were degreased, rinsed, dried, cleaned and controlled in particles. The leak tightness of each vacuum component was checked and quantified below  $10^{-10}$  mbar·L/s.

Once all the parts were manufactured and prepared, the assembly started in an ISO5 cleanroom. The structural support and pneumatic actuators were mounted on a dedicated platform to ease the assembly and subsequent transportation. The beam-interceptive components were then added to the supporting structure. Due to the heaviness of the TZM body (approx. 40 kg) and the small dimensions of the cooling pipes, an additional compact bellows was welded on top of the shaft of the MBL IBS. In fact, such bellows minimizes the stress on the cooling pipes during the assembly processes and the actuation of the device.



Figure 3: The pressing of the MBL IBS graphite core into the TZM enclosure. The core is a cylinder with  $h = 30$  cm and  $r = 3.6$  cm. Image courtesy of the ESS workshop.

## FACTORY ACCEPTANCE TESTS

Following the assembly, metrology measurements and adjustments were performed in the ISO5 clean room to center the device on the beam axis and avoid collisions with the surfaces of the vacuum vessel. At the end of the motion repeatability tests, the beam stop was cleaned for particles with ionized nitrogen once again. Leak checks using helium were performed on bellows, flanges, feedthroughs, pipes and the vacuum vessel itself. The total leakage rate was below the acceptable limit of  $2 \cdot 10^{-10}$  mbar·L/s. Once all the vacuum-related tests were completed, the shipment vessel was closed and the whole system taken out of the clean room. Outside the cleanroom, the hydrostatic tests on the cooling pipes were carried out.

In parallel, the EPICS [5] control systems and the operators' interfaces were developed and tested for their use in the ESS main control room.

## COMMISSIONING HIGHLIGHTS

The beam stops were installed to support the commissioning of the ESS superconducting linac. The beam is interlocked by beam current monitors located just upstream the beam stops.

The SPK IBS was permanently installed in the ESS linac, to support the beam commissioning from March 2025 onwards. Figure 4 includes the vacuum pressure in the SPK IBS vacuum tank as a function of the time, while dumping the so-called probe-beam on the SPK IBS (i.e.  $\leq 6$  mA, 1 Hz, 5  $\mu$ s). During the beam tests, the vacuum level in the SPK vacuum tank remains below  $2 \cdot 10^{-8}$  mbar. The temperature in the peripheral area of the entrance beam window is monitored by four thermocouples and remained below 30 °C.

The MBL IBS was permanently installed in the ESS linac during August 2025, to support the beam commissioning from January 2026 onwards. The vacuum level as a function of the time during the initial four commissioning months in 2026 is shown in Fig. 5. In both cases, the vacuum level remained below  $2 \cdot 10^{-8}$  mbar. No thermocouples were installed on the MBL IBS due to the need of minimizing vacuum feedthroughs as well as the maintenance in the radiation environment of the linac.

## CONCLUSIONS AND OUTLOOK

For the commissioning of the ESS superconducting linac, four beam stops were manufactured. Two were permanently installed in the first SPK and sixth MBL sections, whereas two were kept as spares, if need be.

The beam stops are compact devices to stop the proton beam: up to 100 MeV in the SPK section and up to 250 MeV in the MBL section. The assembly, motion tests and metrology measurements were all performed in ISO5 cleanrooms. The main challenges were posed by the ISO5 requirements, the unconventional steel/TZM brazing of the cooling pipes, and the limited space inside as well as outside the beamline. The initial results of the commissioning with beam in 2025

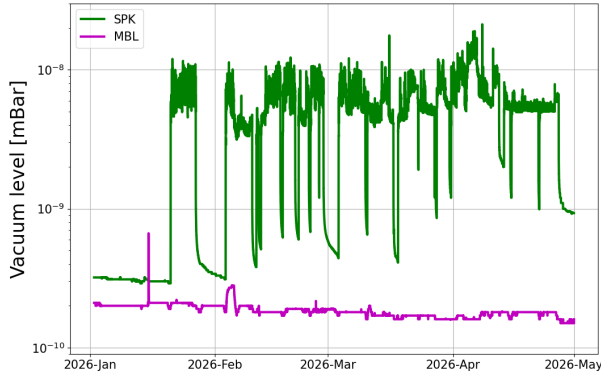


Figure 4: Vacuum level and temperature increase in the beam entrance window of the SPK IBS, while dumping the probe beam i.e.  $\leq 6$  mA, 1 Hz,  $5\mu\text{s}$ .

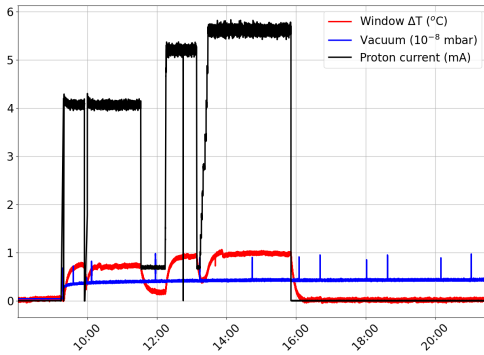


Figure 5: Pressure during the linac commissioning months from January 2026 to May 2026, within the vacuum tanks for the SPK and MBL beam stops.

and 2026 were summarized for the SPK and MBL beam stops, respectively.

Both beam stops are ready for the future tests at the nominal proton current (i.e. 62.5 mA) and pulses longer than  $5\mu\text{s}$ , when the cavities and control systems of the ESS superconducting linac will be ready.

In the future, the developed workflows and established network of European companies are going to be useful for developing new beam-interceptive devices in the ESS superconducting linac.

## ACKNOWLEDGMENTS

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