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Mechanical design of the gamma blockers for the high-energy beam transport region of the European Spallation Source

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Abstract. The European Spallation Source (ESS) is a collaboration of 13 European countries to build the world's most powerful neutron source for research. The project, situated in the south of Sweden, is approaching the end of the construction phase, and the first scientific results are planned for 2023. This paper gives an overview of mechanical design of the gamma blockers (GBs) in the accelerator to target (A2T) and dump line (DmpL) sections. The presence of GBs in the beam line should limit the gamma radiation emitted from the activated tungsten target and beam dump to allow the safe access of the staff to the machine. The presented design allows for efficient operation and the same shutting time independently of the vacuum status.

Keywords: European Spallation Source (ESS) • Gamma blocker • Gamma radiation

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Introduction

The European Spallation Source (ESS) at Lund, Sweden, is under construction and is intended to function as a multi-disciplinary research facility [1]. The ESS will start the scientific user programme in 2023, and the construction phase will be completed by 2025.

The ESS consists of a linear accelerator that nominally delivers a 2 GeV, 5 MW proton beam to a rotating tungsten target. In the high-energy beam transport (HEBT; shown in Fig. 1) section, the dipole magnet in the so-called dog-leg (DgLg) part bends the beam upward with an inclination of 4° toward the accelerator to target (A2T) area. An additional straight tuning dump line (DmpL) will be also used during initial commissioning and linac tune-up, to study the beam without its reaching the target [2].

The beam dump in both the DmpL and target will be strongly activated during the ESS linac operation and have the potential to produce significant gamma radiation in HEBT, with consequences for the ESS accelerator and access to the A2T area. Therefore, two gamma blockers (GBs) have been designed, one for A2T and one for the DmpL sections, respectively, to minimize the gamma radiation from the activated target and beam dump.

The GBs' main function in both cases is to allow the safe access and maintenance in A2T and DmpL – the GBs will be used only during the beam

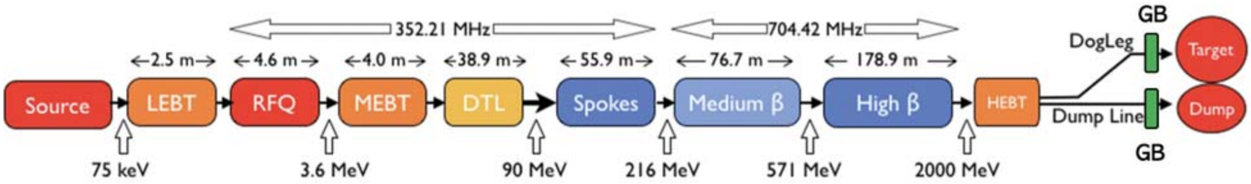

Fig. 1. The ESS linac schema with DmpL and A2T GB locations (based on Fig. 1 from Ref. [2]).

off mode. Operation of the GBs will be controlled by the Personal Protection System (PPS), which also switches off the ESS accelerator during access to the controlled area.

The design of GBs was based on detailed radiation studies [3], after perusal of which its needed specification was determined as a dose rate limited to 100 μSv/h on contact with 200 mm thick, 200 mm diameter steel GB installed in the beamline, immediately after 5 years of continuous irradiation of the target by 2 GeV, 5 MW proton beam.

Technical challenges

Taking into account the safety requirements, the GBs should meet the following requirements:

1. The movable shield shall be inserted coaxially with beamline (GB in "closed" state) or retracted from the beam area (GB in "open" state) remotely, by an electrically powered actuator.
2. The shield shall be installed inside a vacuum chamber connected to the beamline.
3. The position of the movable shield shall be indicated in "closed" or "open" position.
4. Due to the personnel safety reasons, in case of GB system failure, the shield should remain in "closed" position or should close automatically.
5. Due to the machine protection reasons, any movement of the shield that can result in shield interaction with proton beam shall be indicated with a certain advance, to allow a safe beam shutdown.
6. GBs shall work in the described way not only when the beamline is under vacuum but also when the beamline is ventilated.
7. Due to the high radiation level, radiation resistant solutions for all engines, lubricants, and mechanical parts are needed to assure the expected 40 years of operation.
8. To avoid the activation, stainless steel is preferred as a material for GBs. The required GB dimensions, according to radiation studies, would be given by a 200 mm thickness and 200 mm diameter for A2T GB, and a 50 mm thickness and 375 mm diameter for DmpL GB. In both cases, the expected weight is around 50 kg.

Due to the space limitations in the ESS tunnel, the GBs cannot exceed their reserved volumes: for the GB in the A2T section, 500 mm is reserved along the beamline between adjacent flanges, the beam axis is placed 1500 mm above the tunnel floor, and 1000 mm free space over and on the sides of the beam axis is required. The beampipe diameter at this point is 150 mm. In the DmpL area, the beamline diameter is 250 mm and the beam axis is placed 500 mm above the floor. The space provided along the beamline is also 500 mm, 1500 mm in transverse direction, and 1500 mm above the beam axis.

State of the art

Personnel radiation protection is a concern in all accelerator facilities. Many of them have already introduced dedicated devices to minimize the radiation level during the machine hands-on maintenance. The following can be mentioned as examples:

– GB of the Spallation Neutron Source (SNS) [4, 5]: backstream gamma radiation shielding by a horizontally actuated absorbing block, enclosed in a vacuum chamber, driven with a pneumatic cylinder;
– Fail-safe radiation shutter in Los Alamos Neutron Science Center (LANSCE) [6]: backstream gamma ray protection for the isotope production facility, consisting of a tungsten block vertically actuated with a pneumatic cylinder;
– Lead shutter for the Linear IFMIF (International Fusion Material Irradiation Facility) Prototype Accelerator (LIPAc) [7]: a truncated conical block of lead with a pneumatic actuator, separating the accelerator area from the activated beam dump target.

Other known radiation shutter installations are significantly bigger and more focused on neutron radiation protection, like the several-meters-high maintenance shutters in the SNS Second Target Station [8] or the 2-m long, pendular shutter for the Kolkata superconducting cyclotron [9].

Design

The layouts of a vacuum chamber placed in the beamline and external actuator were adopted from the SNS GBs [4, 5]. Due to differences in personnel safety rules, in contrast to the SNS, the ESS GBs shall move to the closed position in case of any failure.

With the given restrictions and requirements, an arrangement with a vacuum chamber in the beamline area and a vertical actuating mechanism installed on top of the chamber was chosen. Each chamber was also equipped with a support post and mechanical position adjustment device below. The actuating mechanism consisted of a chassis installed on the vacuum chamber, which is a base for an actuator and for position indicators (limit switches for device controls and laser reflective fiducials for metrology reference). The GB core shield block is placed inside the vacuum chamber and coupled to the actuator through a vacuum bellow. A detailed view of the GB model is presented in Fig. 2.

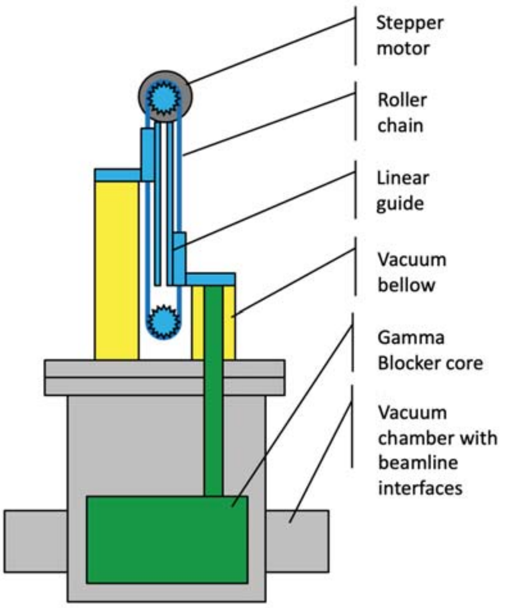

Fig. 2. Block model of GB system including the most important elements.

Fig. 3. Detailed 3D models of both GBs (DmpL – left, A2T – right).

During the motion dynamics calculations, a difference in loads depending on the pressure in a vacuum chamber was discovered. When the beamline is under the atmospheric pressure, there is no additional load, while with the beamline pumped out, the vacuum induces a significant amount of force. This force difference leads to the changes in drive load, and thus to the free-falling acceleration. Consequently, the self-closing time cannot be predicted in an unknown vacuum state. Therefore, to reduce the load fluctuations on the actuator and diminish the beamline pressure forces, a second vacuum bellow linked with the first was added. With two bellows, connected with opposite vacuum force direction, the beamline pressure is compensated, and the only variable force is position-related bellow spring force. This force is pulling both bellows to its central position, and so with the GB core in "open" position, the spring force is tending to close the GB together with core gravity force (ca. 550 N), while when the core is approaching the "closed" position, the spring force is acting opposite to the gravity.

Finally, the GBs were built using a roller chain to link those two bellows (Fig. 2) and a stepper motor with reduction gear as an actuator.

The "free falling" motion was declared to maintain a speed in the range of a couple of centimeters per second. It guarantees the machine protection system reaction when GB motion is detected, to avoid the risk of possible collision of high-power proton beam and GB core. To reduce the movement speed, a hydraulic rotation damper was foreseen as a motion speed limiter. During GB design and machine controls development, it emerged that a delay of 0.25 s should be enough to stop the proton beam, and thus the usage of a typically radiation sensitive damper is not necessary. The friction of the reduction gear, device inertia, and detent torque of the motor reduce a falling speed of the GB core. At the end of the falling motion, a hydraulic impact damper is installed to recover excessive kinetic energy of the core.

Beside the kinematics demands, the requirement of the radiation resistance and a long service life of the devices is very important. Therefore, none of the selected components contain radiation sensitive materials. The chassis, the vacuum chambers, and the GB cores are made out of stainless steel (304L grade), with the copper seals on CF ports and the aluminum wire seal on rectangular flange.

In addition, a convenient way for fast replacement of worn/damaged parts has been provided. The GBs design allows for repairs and replacement of all parts of the actuating mechanism without a need for removal of the GB core from the beamline. Further modifications of the GBs are possible thanks to an open structure of the actuating mechanism. The final design of both GBs is presented in Fig. 3.

Factory tests

During the Factory Acceptance Tests (Fig. 4), the devices were pumped down with the leak rate below 1×10^{-10} mbar·l/s. The measured free fall times were 0.90 ± 0.04 s for A2T GB and 1.05 ± 0.04 s for DmpL GB, whereas the time intervals between the beginning of the movement, signalized by limit switch contact, and possible interaction of the GB core with the proton beam were 0.4 s for A2T and 0.5 s for DmpL. Such intervals are long enough to allow the Machine Protection System to switch off the beam before any interaction. The times were identical (within measuring error), both with the chambers pumped down and ventilated.

The performed test confirmed the fulfillment of the requirements. The GBs close the core in reaction to the intentional power cut-off by the control system and to the simulated unintentional damage to the power cables. The position sensors provide

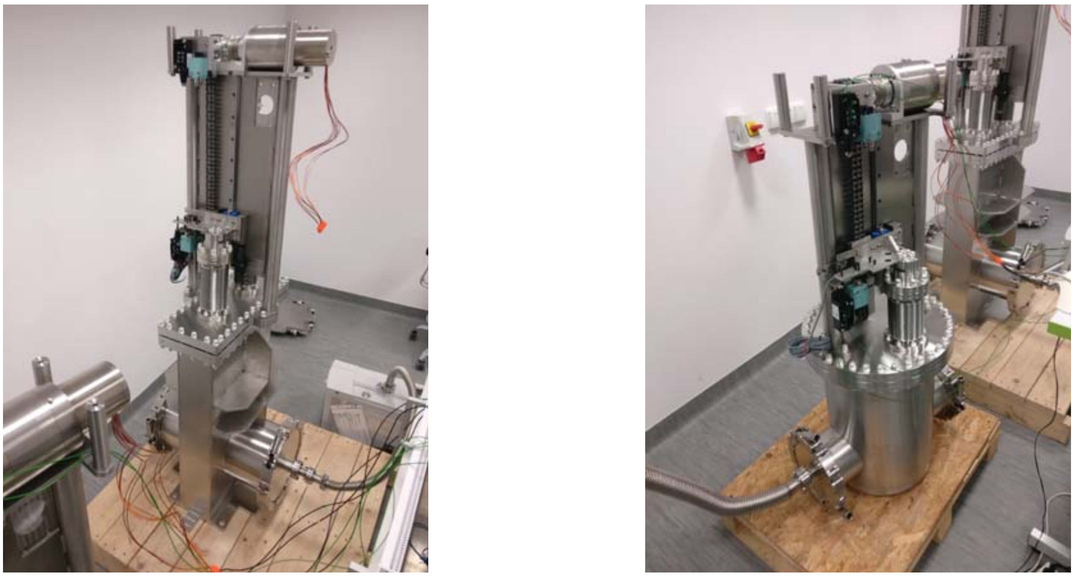

Fig. 4. GBs during factory test (DmpL – left, A2T – right).

the information about the core position even if one of the sensors is damaged.

Conclusions

Two GBs dedicated to ensuring the safety of personnel activities in the ESS accelerator tunnel have been designed, manufactured, tested, and successfully installed at ESS. The parameters, as well as other features such as the dimensions, position indication, fail-safe operation, reduction of heavy mass impacts, and serviceability, are similar to the installations in other facilities; however, the main difference is the actuating medium, as the ESS GBs do not use compressed air for proper work.

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