OVERVIEW OF ESS BEAM LOSS MONITORING SYSTEM

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Abstract

The European Spallation Source (ESS) proton accelerator will be a multi-MW proton linear accelerator and will require a very carefully designed beam loss monitoring (BLM) system. Slow, continuous losses will have to be monitored and kept low enough to allow hands-on maintenance of the machine. Fast and large losses will have to be prevented by sending a beam-abort signal to the control system. This paper gives a conceptual design of the ESS BLM system; it describes the detectors planned at ESS and discusses their quantity and positioning. An ionization chamber (IC) was chosen as a primary detector for measuring the losses. The design parameters of the detector are given based on the response time considerations. The results for the response functions of the new detector as a function of the incident particle type, angle and energy are presented.

INTRODUCTION

The European Spallation Source will be an accelerator complex consisting of a 5 MW proton accelerator, target and a number of neutron instruments. ESS will be built in Lund, Sweden. The facility will be the world's most intense spallation neutron source for neutron scattering research. In Fig. 1 the schematic view of the accelerator is given. The accelerator is divided into the normal conducting and superconducting parts. Protons are generated in the ion source and after passing through the low energy beam transport (LEBT) they are accelerated to 3 MeV in the radio frequency quadrupole (RFQ). Later, the proton beam is injected in a medium energy beam transport (MEBT) and a drift tube linac (DTL) further accelerates the beam up to 50 MeV. The beam continues to travel through the superconducting part of the machine, where the acceleration is done by the superconducting radio-frequency (SRF) technology, and at the end of the journey the protons achieve 2.5 GeV kinetic energy. After passing through the high energy beam transport (HEBT), the beam hits the target [1].

The ESS accelerator will be around 500 m long and will generate 2.86 ms long macro pulses, with an average pulse current of 50 mA and 14 Hz repetition rate, resulting in a maximum beam power of 5 MW [1].

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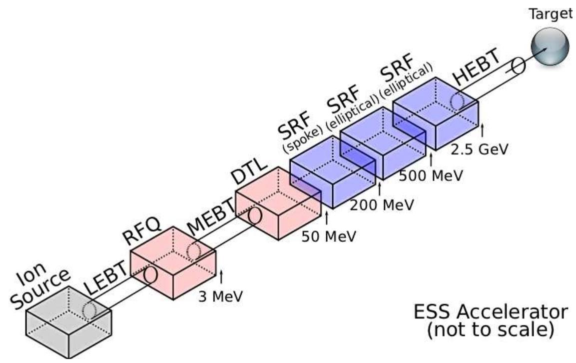

Figure 1: Schematic view of the ESS accelerator.

SYSTEM REQUIREMENTS

General requirements

According to the baseline parameters, ESS will generate 8.94×10^{14} protons in a single macro-bunch. However, the BLM system will be designed for an intensity of 1.34×10^{15} (1.5 times greater than the baseline value) to allow the possible future power upgrades.

The BLM system has the following requirements. It should provide real time data to tune the beam and minimize losses. It should measure the losses continuously and also should be able to quickly send the beam abort signal to the machine protection system in case the losses exceed the limits. There will be several thresholds set to inhibit the beam. One threshold will be set for average long time losses according to the allowed activation levels in the machine and the tunnel. Another limit will be set for an uncontrolled, high losses based on the calculations given in the next section.

Detector sensitivity requirements

The BLM system detectors should be sensitive enough to observe low and slow signals as well as fast and high signals. Sensitivity of 70 nC/Rad was obtained with an Argon filled, sealed glass ionization chamber designed and developed by Shafer at Fermi National Accelerator Lab (FNAL) [2]. The same sensitivity was kept for the spallation neutron source (SNS) main BLM detector [3]. SNS has an accelerator similar to ESS and produces a pulsed H^- beam of up to 1.4 MW [3]. Although higher sensitivity is desired, the 70 nC/Rad is considered to be good enough for the ESS as well. Further tests will determine if there is a need for a sensitivity increase.

Detector time response requirements

In terms of the response time, the main requirement for the beam loss detector is the following: even in the case of full power loss, it should generate a beam abort signal fast enough to prevent any damage. At SNS the BLM system was designed so that it can produce stop-the -beam signal in less than 10 μs [4]. Since ESS has roughly 3-5 times higher power the required response time has to be rescaled by the same factor. This means that a new, faster detector has to be designed which will respond to critical losses in less than 2-3 μs. The new prototype design is given in the next section. The future simulations and tests will verify the goodness of the prototype.

Dynamic range requirements

Like at SNS we require the BLM system to be able to measure at most 1 % of local beam loss and achieve at least 1 % resolution of 1 W/m loss limit [3]. This implies dynamic range of 10^6-10^7, which is achievable with the current ionization chamber detectors and subsequent electronics circuits [4].

CHOICE OF DETECTOR

At the ESS the main beam loss detector is chosen to be an ionization chamber. Two possible detectors were discussed. One is the LHC type ionization chamber. This is more than ten times faster than the SNS detector [5] but is not readily available. Another detector is the modified SNS type ionization chamber with lower ion collection time. The last consideration was developed and the results are shown below.

The positive ion transit time in an ionization chamber is given by [6]

$$t = \frac{d^2}{\mu_0 V (P_0/P)}, \tag{1}$$

where μ_0 is the ion mobility at standard temperature and pressure, V is applied voltage, P_0 is an atmospheric pressure, P is a working pressure and d is an effective electrode separation. For cylindrical geometry the effective gap between the electrodes

$$d = \left((R^2 - r^2) \, \frac{\ln R/r}{2} \right)^{1/2}, \tag{2}$$

where R and r are the outer and inner radii of the electrodes respectively.

At SNS the FNAL IC was considered to be used initially [6]. However, the charge collection time had to be improved. This was achieved by moving the detector electrodes closer to each other, which decreased the collection time from 560 μs to 72 μs (at 3 kV applied voltage) [6]. The length of the detector had to be adjusted to leave the detector sensitivity constant.

The same strategy was used to design the new, ESS prototype ionization chamber to further decrease the charge transit time. The outer electrode radius was fixed to $R = 4$ cm and the charge collection time was plotted as a function of the inner electrode radius (see Fig. 2). From the graph we can see that making the inner electrode radius $r = 3.8$ cm decreases the charge collection time to less than 8 μs. This is almost an order of magnitude better than the SNS detector. The new prototype detector should be 23 cm long to maintain the same sensitivity as the SNS detector. The schematic design of the detector is shown in Fig. 3. The effective volume of the detector was fixed to 110 cm^3 as in the original FNAL ionization chamber [2]. The calculations are done for 3 kV bias voltage and $P = P_0$ =1 atm Argon gas pressure. Argon gas was chosen because of faster ion transit time [7].

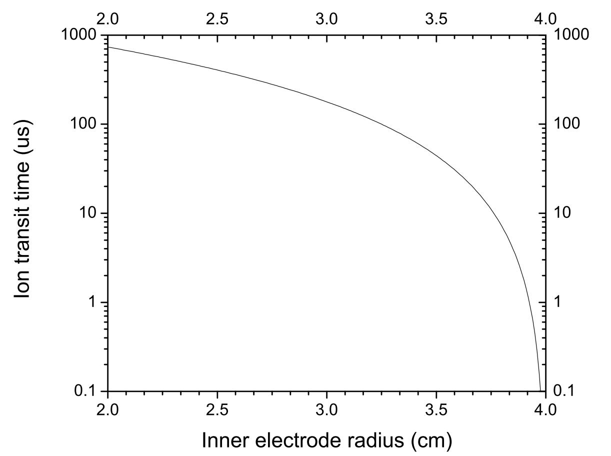

Figure 2: Cylindrical ionization chamber ion collection time as a function of the inner cylinder radius. The detector is filled with Argon gas at 1 atm pressure. Outer electrode radius is 4 cm, bias voltage - 3 kV and effective volume - 110 cm^3.

The short, 2 mm gap between the electrodes limits the maximum possible applied voltage. At 1 atm the limit is 3.5 - 4 kV according to the Paschen law for the breakdown voltage in gasses [11], which is higher than the desired operating voltage.

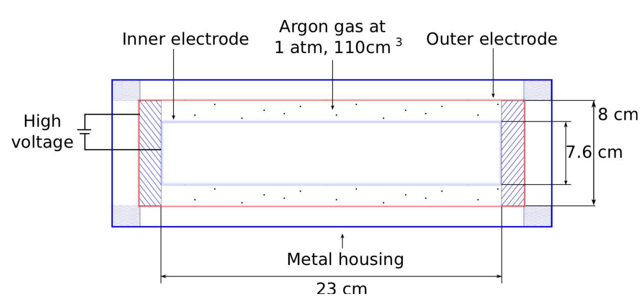

Figure 3: ESS prototype ionization chamber.

OTHER DETECTORS

At the ESS there is a need to use other detectors than just ionization chambers. Therefore few other types of detectors are considered based on the following requirements.

When the pulse micro structure has to be resolved a scintillator-photomultipliers will be used. Scintillator detector calibration changes very much in time, but the detector is very fast and will be used to monitor the loss structure within individual pulses.

At the ESS a continuous cryostat might be used. In that case, there will be a need for using loss detectors at cryo-temperatures. An ionization chamber or a diamond detector is considered. Currently cryo-ICs are under development at FNAL and CERN. Even if there won't be a continuous cryostat at the ESS, the cryo-ICs can be used in the middle of the cavity-cryostats, since if an IC is placed outside of a cryostat, no signal will be generated; this location of the IC is too far from the beam and well shielded with the cryostat. Diamond detectors might be used at both room and cryo-temperatures. Their size and speed is very attractive for the ESS BLM system, however, they have a limited dynamic range and further investigation of their radiation hardness is required.

RESPONSE FUNCTIONS

Detector response function simulations were performed using the particle transport code MARS [8, 9]. The response functions of the Argon gas of the detector were calculated for different incident particles, energies and angles. In Fig. 4 the plot is given for zero incident angle.

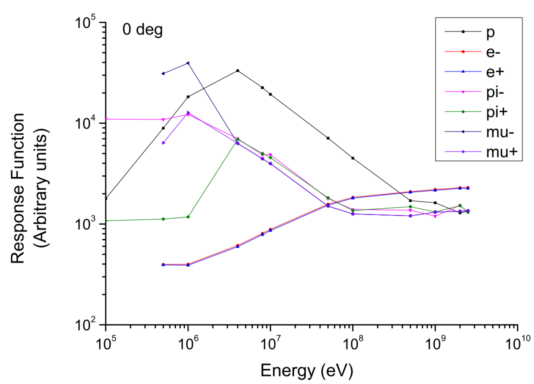

Figure 4: ESS prototype ionization chamber response function as a function of incident particle type and energy. For zero incident angle.

SYSTEM DESIGN

One ionization chamber will be placed at every quadrupole across the linac. Additional cryo-ICs will be installed in each cryostat if they prove positive to work at such conditions. Also, several photomultiplier tubes will be used in the low-energy part of the accelerator. A movable detector stand will be constructed for further measurements at other locations, if/when needed. Table 1 shows the preliminary distribution of the main ESS ICs [10].

Part of ESS	Number of IC
DTL	30
SRF (spoke)	45
SRF (elliptical, low beta)	30
SRF (elliptical, high beta)	42
HEBT	22

Table 1: ESS main beam loss detector distribution. Numbers are preliminary.

SUMMARY

A new, faster loss detector is designed for the ESS compared to the existing one used at SNS. A conceptual design of the new prototype ionization chamber is given and the response functions of the detector are calculated as a function of incident particle type, energy and angle.

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