BEAM INSTRUMENTATION IN THE ESS COLD LINAC

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Abstract

Parts of the linac of the European Spallation Source (ESS) will consist of cryogenic cavity modules. In between these will be warm sections at room temperature to host amongst others the beam instrumentation. Each of the warm sections will host two beam position monitors and one or two other instruments, which might be a beam current monitor, invasive and non-invasive transverse beam profile monitor, bunch shape monitor, or halo monitor. The concept of the warm section layout will be shown and the planned instrumentation will be presented.

INTRODUCTION

The ESS is a multi-disciplinary research center based on the worlds most powerful neutron source. This new facility will be around 30 times brighter than today's leading facilities, enabling new opportunities for researchers in the fields of life sciences, energy, environmental technology, cultural heritage and fundamental physics.
The ESS is an accelerator-driven neutron spallation source, using a linear accelerator. While the first part of the linac is at room temperature, accelerating protons to 90 MeV, the final energy of 2 GeV will be reached by a cryogenic linac. This part is constructed in a way that between two cryogenic modules, hosting a certain amount of cavities, a warm section at room temperature is located, shown in Figure 1. The total length of this warm section will be 1373 mm. It will contain of two quadrupole magnets with a gap in between, giving 460 mm space in between them to host beam instrumentation and vacuum instruments.

MODULE LAYOUT

The space between the cryogenic modules is filled with a standardized module. This gives the flexibility to decide on the specific location for a beam instrumentation instrument in a later stage of the construction process. All modules host vacuum systems, bellows, the vacuum pipe within the quadrupole magnets and two sets of BPMs. The middle part, between the quadrupole magnets, hosts one or more of the following beam instrumentation instruments:

- Beam Current Monitor
- Bunch-Shape Monitor
- Halo Monitor
- Non-Invasive Beam Profile Measurement
- Wire Scanner

In addition, but not in the focus of this paper as they are not integrated in the modules, are several beam loss monitors installed close to the beam pipe. Details are presented in [1].
The cryogenic linac is devided into three parts. At this moment it is foreseen that at the beginning of each part a module hosting a beam current monitor and a bunch shape monitor is located. Afterwards there will be another bunch shape minitor module and then 4 modules hosting the beam profile monitors. As example the layout of the middle part is shown in Figure 2.

Profile Measurement

One module will be hosting the beam profile measurement devices. This will be an invasive and a non-invasive device co-located within the same module. It has been found necessary to combine two profile measurement devices. First, during commissioning the beam will start with a low current and short pulse length, which later is increased to the full production beam. While with the production beam an invasive device will be damaged, the necessity for a non-invasive device is given. On the other hand, usually the cross sections for non-invasive devices are rather low, making it hard to archive profiles during the low current / short pulse phase of the commissioning. For the invasive device a wire scanner based on the LINAC4 [2] development has been chosen as a possible baseline for the development . For the non-invasive profile monitor as baseline an ionization profile monitor based on the FAIR development has been chosen [3]. Still, there have to be major modifications done to the ionization monitor in order to fulfill the requirements of the ESS linac. One modification that seems to be necessary is to avoid the usage of Multi-Channelplates. These devices show usually a strong aging behavior, making constant calibrations and replacements necessary. Through the positioning between cryogenic cavities, at least the replacement could become an issue. Therefor the direct usage of a phosphor screen or a scintillation crystal together with an image intensified optical readout seems to be a promising option. The other modification is the increased electrical field to guide the generated residual gas ions to the detector. Because of the intense electric field of the ESS primary ion beam the trajectory of the secondary ions will be deviated from the intended path. First simulation showed that an electric field strength of 600 kV/m give a reasonably good image of the initial beam. To avoid to big high voltages a symmetric voltage of $\pm$ 30 kV is planned.

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ISBN 978-3-95450-127-4

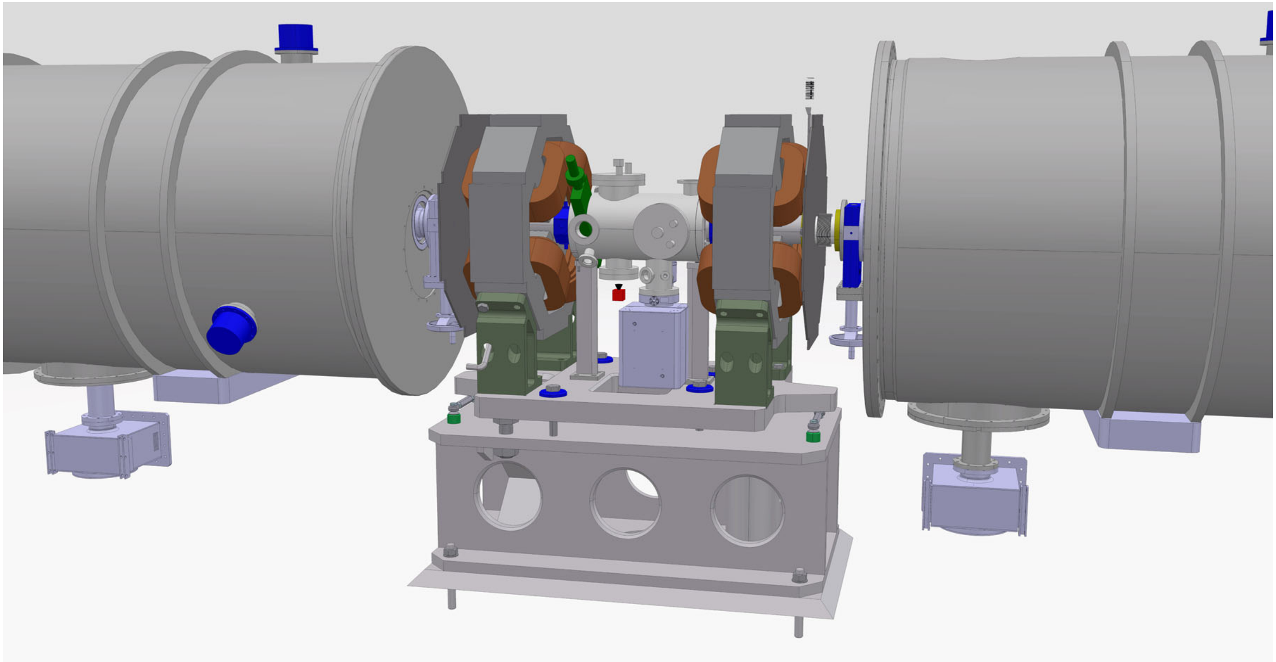

Figure 1: Example of a warm section between two cryogenic modules. The total length of the module will be 1373 mm. Within the extend of the quadrupole magnets there will be two sets of beam position monitors installed (dark blue). In between the magnets there is 460 mm of space hosting the beam instrumentation and vacuum components (partly shown). This module is a early prototype of a beam profile measurement device hosting a wire scanner and an ionization profile monitor. On the outside there will be magnetic shields to shield the cavities from the magnetic field of the quadrupole magnets.

Halo Monitor

The beam halo is the beam profile far away from the beam core. Using a single device for this measurement, e.g. a beam profile monitor, requires a very high dynamic range of the instrument. One idea is to use the existing wire scanners [4], which can not be used during full production beam for profile measurements anyway, as a halo monitor. Other devices under consideration are vibrating wire monitors [5] or diamond detectors [6]. However, the usage of the wire scanner is preferred, as this would save longitudinal space of the linac.

Beam Position Monitor

The pulsed ESS Linac will include BPMs with a European XFEL style button design. The required accuracy and resolution of the position measurement are 100 μm (rms) for the low current commissioning beam and 20 μm (rms) with the production beam at 62 mA and 2.86 ms length. In addition to the position measurement, the BPM system needs to measure the beam phase in the nominal pulse as well as several low current commissioning modes. After a study of the possible electronics platforms, MTCA.4 is now considered as the main prototyping platform for the high performance subsystems at ESS. It is foreseen to prototype a Rear Transition Module for IQ-based RF signal measurements intended for both the BPM and LLRF systems. The detailed requirements and specifications of the BPM system are presented in [7].

Bunch Shape Monitor

The bunch shape, also called longitudinal profile, will be the most difficult to measure. The length of the bunch, depending on the ion energy, will be as short as 3 ps. For measuring the profile several methods have been developed, based on secondary emission. At one method [8] the emission of electrons from a wire in the proximity of the beam is used. Another [9] uses the emission of x-rays from e.g. a gas jet target. But then again the signal is converted to a electron signal by a photo cathode. This electron signal is then converted from a time to a length information, using a RF-deflector. The length can then be measured with traditional methods like a phosphor screen. While these methods has been proofed to be working [10], it had been never used with such short pulses as expected at the ESS linac, and therefor further investigations have to be performed if the method is efficient enough to measure the bunch shape in the expected environment.

Beam Current Monitor

Most of the installed Beam Current Monitors will be of AC Current Transformers (ACCT) type, to measure the average current over the beam pulse, the pulse charge and the longitudinal pulse profile. It is also planned to use a few Fast Current Transformers (FCT) to check the performance

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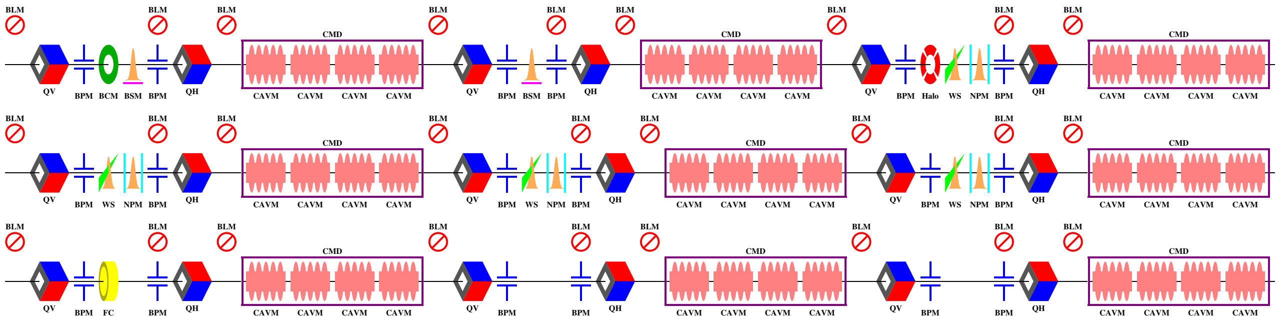

Figure 2: Example of a layout of beam instrumentation in respect to other linac components in the medium β section [11], the second of the three cryogenic sections. In the first warm cell a bunch shape monitor and a beam current monitor are co-located. This is followed by another bunch shape monitor. Then followed by 4 beam profile monitor sections, consisting of a wire scanner and an ionization profile monitor. It is planned that the wire scanners can as well serve as halo monitor. Almost at the end of the section a Faraday Cup will be inserted, but only to be used with a beam up to 200 MeV during commissioning. Due to the modular design, the locations of each instrument can be changed easily till the final construction of the linac, if the necessity will be given.

of the fast beam choppers with a rise time as short as 10 ns. In addition to the absolute current measurement, the BCM system needs to measure the differential beam current and act on the Machine Interlock System if the difference exceeds some thresholds. But this differential current measurement is mostly important in the low energy part of the Linac, where Beam Loss Monitors cannot reliably detect beam losses. In [12] a detailed overview of the ESS BCM system is given and some preliminary test results with a commercial ACCT and MTCA.4 electronics are presented.

UPGRADE SECTION

The last 170 m of the planned ESS linac are be reserved for further upgrades. But the principle structure will be maintained in this part as well. The only difference will be, that as a placeholder for the cryogenic modules a simple beam pipe will be inserted. In terms of beam instrumentation the same structure as before will be built and inserted. The only difference will be in the non-invasive beam profile measurements. For this measurement a residual gas luminescence device [13, 14] is foreseen to be inserted in this part, because the residual gas pressure is expected to be much higher than between the cryogenic modules, giving a sufficient signal rate which can not be archived in between the cryogenic modules. But as the ionization monitor in the cryogenic part is foreseen to be read out with an image intensified optical system, this might be, slightly modified, used also for the luminescence monitors.

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