ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME167

DEVELOPMENT OF NON-INVASIVE TRANSVERSE PROFILE MONITORS FOR THE ESS LINAC

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Abstract

The European Spallation Source (ESS) consists of a partly superconducting linac which will deliver a 2 GeV, 5 MW proton beam to a rotating tungsten target. In this way, the ESS will be the world's most powerful neutron source. To measure the proton beams transverse profile at high intensity, the ESS is developing two types of non-invasive profile devices. The first monitor is based on luminescence of the residual gas, the second one on ionization of the same gas. The latest developments of these profile monitors will be presented.

INTRODUCTION

The ESS accelerator is a linac which will accelerate protons to 2 GeV with an average power of 5 MW in order to produce neutrons. The linac design consists of:

- a ECR source which will produce 75 keV protons,
- a warm linac, made up of a Low Energy Beam Transport line (LEBT), a Radio Frequency Quadrupole (RFQ), a Medium Energy Beam Transport line (MEBT) and a Drift Tube Linac section (DTL), which will accelerate the protons up to 90 MeV,
- a cold linac, made up of a spokes section and elliptical cavities (called Medium β and High β)) which will accelerate the protons up to 2 GeV,
- and a High Energy Beam Transport line (HEBT) and upgrade part which transport the beam to the target.

This linac will produce a beam of 62.5 mA with a pulse of 2.82 ms and 14Hz.

Beam transverse profile monitors are an important tool in proton beam diagnostic as they insure that the lattice parameters are set and the beam emittance is matched. In the ESS linac, the beam transverse profile measurement will be performed by two different kinds of device [1] [2], an invasive and a non-invasive one, located in the same module. The invasive device, used during the commissioning at low current and short pulse, will be a wire scanner [3]. The development of a non-invasive device appears necessary as the wire scanner will be damaged at full beam power and as non-disturbing measurements of the beam profile are required during normal operations.

NON-INVASIVE TRANSVERSE PROFILE MONITORS

The ESS Non-invasive transverse Profile Monitors (NPM) are based on the interaction processes between the proton beam and the vacuum chamber residual gas. Two designs are being developed:

- a Beam Induced Fluorescence monitor (BIF) will be used in the warm linac and the HEBT, where the pressure is around 10^{-7} to 10^{-8} mbar;
- while an Ionization Profile Monitor (IPM) is planned for the cold linac, where the pressure is around 10^{-9} mbar.

In both cases, this diagnostics techniques exploit the excited/ionised particles produced by interaction of primary beam particles with the residual gas. Table 1 includes the location and quantity of the two NPM types. It also contains the main parameters which influence the design of these devices, i.e. the beam energy, the space allocated for the devices and the temperature and pressure in the beam pipe.

The residual gas in the beam pipe is expected to be primarily composed of H_2 (65-80%) with the rest being a mixture of CO, CO_2, CH_4, Ar and H_2O. Therefore, for simplification, the gas taken in consideration in the ionization process is only H_2.

BEAM INDUCED FLUORESCENCE PROFILE MONITOR

The BIF monitor [4] is based on the fluorescence emission of the excited residual gas. One of its advantages is that it allows to use a simple optical design, which can be easily changed since all the device components, except for the beam pipe viewport, are outside the beam pipe. The other advantage of the BIF is that measurements can be performed for both horizontal and vertical profiles at the same place. This last point fits well to the constraint on the available space for the NPM in the warm linac, which is about 10 cm. The BIF monitor is a technology already well developed by others facilities [5] [6] though they are mainly used with injection of specific gas or with residual gas as N_2 or He. In the case of ESS the main gas present in the beam pipe will be H_2 so further investigations are required.

Three issues are currently under investigation. The first one investigates the fluorescence yield and the H_2 wavelength spectrum. The second point under investigation is the lens/mirror system, which will transport photons from the viewport to the detector. Finally, the third one is the choice of the photon detector. This one depends on the amount of photons reaching the detector, their wavelength which is required to fit to the detector quantum efficiency and also on the radiation background present in the linac tunnel.

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Table 1: Current NPM Layout at ESS with Relevant Parameters Which Influence the NPMs' Design

Location	Type	Quantity	Energy [MeV]	Space [cm]	Temperature [K]	Pressure [mbar]
LEBT	BIF	1	0.075	100	300	10^{-7}–10^{-8}
MEBT	BIF	2	3.6	100	300	10^{-7}–10^{-8}
DTL	BIF	1	3.6 to 90	100	300	10^{-7}–10^{-8}
Spokes	IPM	1	90 to 216	359	2	10^{-9}
Medium β	IPM	3	216 to 571	327	2	10^{-9}
High β	IPM	1	571 to 2000	327	2	10^{-9}
HEBT & Contingency	BIF	4	2000	327	300	10^{-7}–10^{-8}

IONIZATION PROFILE MONITOR

The IPM monitor uses the charged particles, produced during the interaction of the beam with the residual gas, to obtain the profile of the beam. Like the BIF, the IPM technology is already well established in facilities [7] [8] [9]. However the IPM have to be adapted to the ESS parameters constraints.

The current ESS IPM design produces a 600 kV/m [2] via 2 symmetric plane electrodes on which a voltage of ± 30 kV is applied. This electric field accelerates the secondary ions produced at the IPM center to a scintillator screen in 42 ns. It also decreases the space charge effect of the beam which would disturb the ions trajectory and distort the profile. The design of the electric cage, which has to produce a field as flat as possible, is currently under investigation. Since the field produced by this device is quite high, experimental studies of the electric breakdown danger have to be performed too.

Different solutions already exists to collect the secondary ions. Scintillator screens are prefered due ot the fact that the dose rate in the cold linac (see Table 2) is expected to easily damage electronic components.

Optical systems, which will be located outside the beam pipe, will collect the photons produced by the screen through a viewport. Its design is mainly dependent on the radiation level. Table 2 shows the dose rate in PTFE material for the cold linac at 70 cm away from the beam pipe. The density of an optical detector (camera, PMT) is close to the one of PTFE, thus these number can be used as a first approximation. These results show that cameras should be able to survive with a proper shielding in the spoke cavities, while in the elliptical cavities radiation hard optical detector is preferred. Deeper investigation is needed to determine the lifetime of the different types of detector and their degradation for such dose rates.

Efficiency Tests of Scintillator Screens

The choice of the scintillator screen is one of the critical point of the IPM optimization. The screen choice depends on its efficiency and its radiation hardness. This article presents the experimental study of the efficiencies.

The scintillator screen datasheet gives the efficiency in terms of number of photons produced per incident electron. Since the screens will be hit by 30 kV H^+ ions, the efficiency must be known in terms of number of photons produced per incident proton. For this reason, experiments have been conducted at the DESIREE facility of the Stockholm University.

The accelerator was delivering a proton of 20 nA and four energies: 10, 20, 30 and 40 kV. Four screens were tested:

- a P47 screen with a ITO layer (emission wavelength = 420 nm),
- a P47 screen with an Al layer (emission wavelength = 420 nm),
- a YAG:Ce screen with a conductive layer (emission wavelength = 550 nm),
- a CaF2:Eu screen with a conductive layer (emission wavelength = 435 nm),

The results, presented in Fig. 1, shows that the efficiency of the P47 screen is two times higher compared to the others. The relative uncertainty is about 15% and is due to the beam current fluctuations.

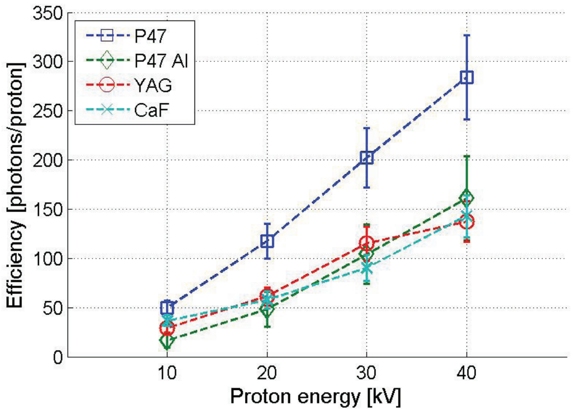

Figure 1: Screens efficiency in terms of number of photons per proton.

With this results, the P47 screen with the ITO layer seems to be the preferred choice as a scintillator screen for the IPM. However this choice depends on the screen radiation hardness as well. Tests will have to be performed in order to be able to answer the question concerning the screens efficiency and its radiation hardness. The third parameter which influences the choice of the screen is the quantum efficiency of the optical device.

Only the P47 screen with an Al layer will not be part of the next studies since it gives twice as less photons per proton

Table 2: Dose Per Year in PTFE at 70 cm of the Beam Axis [10].

Location	Energy [MeV]	Dose Rate [Gy/year]
Spokes	90	30
Spokes	125	70
Spokes	220	280
Elliptical cavities	220	500
Elliptical cavities	500	1300
Elliptical cavities	1000	1000
Elliptical cavities	2000	1000

than the P47 screen with the ITO layer for the same level of radiation hardness and the same emission wavelength.

CONCLUSION AND FUTURE WORK

Two designs are under development for the ESS NPM. The first one is a BIF monitor which will be used in the warm linac and the HEBT section. Its design requires to study the fluorescence yield and development of the optical system in order to fit the ESS constraints, i.e. space allowed for the devices, radiation hardness, photon sensitivity. The second NPM type is an IPM monitor which will be used in the cold part of the linac. Tests of the screen efficiency were carried out at the DESIREE facility. The results showed that, for the efficiency parameter, the P47 screen with a ITO layer is the preferred choice for the IPM at ESS. The next main study which has to be done is to experiment the radiation hardness of the scintillator screens and optical components.

ACKNOWLEDGEMENT

We are grateful to Anders Källberg and the team of the DESIREE facility to allowing us to perform our experiment using their machine and for all their help. This project (oPAC) is funded by the European Union under contract PITN-GA-2011-289485.

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