# OVERVIEW OF THE EUROPEAN SPALLATION SOURCE WARM LINAC BEAM INSTRUMENTATION

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*Abstract*

The normal conducting front end of the European Spallation source (ESS) [1] will accelerate the beam coming for the ion source up to 90 MeV. The ESS front end will consist in an ion source, a low energy beam transport line, a radio frequency quadrupole, a medium energy beam transport line and a drift tube linac. The warm linac will be equipped with beam diagnostics to measure the beam position, the transverse and longitudinal profile as well as beam current and beam losses. This will provide efficient operation of ESS, and ensure keeping the losses at a low level. This paper gives an overview of the beam diagnostics design and their main features.

## INTRODUCTION

### *ESS Normal Conducting Linac*

The ESS ion source is based on ECR technology and its currently develop at INFN-LNS in Catania. The beam will be extracted with an energy of 75 keV. The ion source will be followed by a magnetic Low Energy Beam Transport line (LEBT), which consists of 2 solenoids, a pre chopper system and a set of beam diagnostics. A Radio Frequency Quadrupole (RFQ) will accelerate the beam up to 3,6 MeV and will be followed by a Medium Energy Beam Transport line (MEBT), fully instrumented and also equipped with a fas beam chopper . The last section of the normal conducting linac consists in 5 Drift Tube Linac (DTL) tank which accelerate we beam up to 90 MeV. It employs a permanent magnet FODO lattice leaving empty drift tubes for diagnostics. The inter-tank regions will each house a set of diagnostics.

### *Beam Instrumentation*

The warm linac will be equipped with beam diagnostics to measure the beam position, the transverse and longitudinal profile as well as beam current and beam losses.This will provide efficient operation of ESS, and ensure keeping the losses at a low level. A list of the different type of monitor foreseen to be used in the ESS warm linac are presented in Table 1.

The interceptive devices can not be used with the full beam power, special beam modes have been determined for commissioning and machine tuning, in these modes, all the diagnostic can be used. The beam parameters for the different modes are summarized in Table 2.

The beam instrumentation layout foreseen for the ESS warm linac are represented in Fig.1, Fig. 2, Fig. 3.

## BEAM POSITION MEASUREMENT

21 BPM will be installed in the warm linac they will measure (a) the absolute beam position, (b) the relative beam current among monitors, (c) the average beam energy via the time-of-flight between two monitors. In order to maximize the space available in the MEBT, the BPM electrodes will be inserted between the quadrupoles pole tips.

In the DTL, 3 BPM per tank are foreseen and will be installed in the drift tube. The design of the electrode will be similar to the SNS shorted striplines design.

The BPM front-end will include a fast analogue front-end, where the BPM signals are picked up by some sensitive electronics, level-adjusted, down-converted (to be confirmed), filtered and conditioned. The signals are then digitized and fed into an FPGA for position, phase and intensity calculations, linearization, memory read/write etc. The BPM electronics will be integrated into the future EPICS control system [2].

## BEAM CURRENT MEASUREMENT

Two Beam Current Transformer (BCT) will be installed in the LEBT, a first one is positioned before the first solenoid, for ion source monitoring. The second BCT will be installed before the RFQ input and will measure the beam transmission in the RFQ with another BCT installed at the beginning of the MEBT. The time resolution shall be less than 1 $\mu s$, and the effect of the pulsed magnetic field in the MEBT shall be studied.

At the end of each DTL tank, a BCT will be inserted in the tank flange,. The requirement for these devices are similar to the other BCT installed in the linac [3].

A FC will be positioned between the two solenoids in the LEBT, where the beam sizes are larger in order to reduced the thermal stresses on the cup. The FC shall be design to measure the beam current at full duty cycle, the signal shall be sampled at 1 MHz.

In total 5 FC will be installed in the DTL section, each Faraday cup will be equipped with an energy degrader, in order to study the transmission of the beam in function of

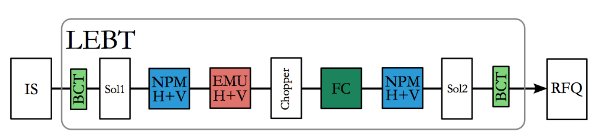


Figure 1: Beam instrumentation layout in the LEBT.



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Table 1: List of Diagnostic Foreseen in the ESS Warm Linac

| Location | Energy $[MeV]$ | BPM | BCT | profile | FC | Emittance | BSM | BLM |
|---|---|---|---|---|---|---|---|---|
| LEBT | 0.075 | - | 2 | 2 | 1 | 1 | - | - |
| MEBT | 3.6 | 6 | 2 | 4 | 1 | 1 | 1 | - |
| DTL | 3.6 to 90 | 15 | 5 | 5 | 5 | - | 1 | 7 |

Table 2: ESS Beam Parameters

| | Nominal | Fast tuning mode | Slow tuning mode |
|---|---|---|---|
| I $[mA]$ | 6 to 70 | 6 to 70 | 6 to 70 |
| Pulse length $[\mu s]$ | 2860 | 10 | 100 |
| Repetition Rate [Hz] | 14 | 14 | 1 |

the RF phase in the DTL cavity. The material and the thickness of the energy degrader are summarized in Table 3 .

Table 3: Material and Thickness of the Energy Degrader of the Different FC Installed in the DTL

| | Material | Thickness [mm] | $E_{threshold}$ [MeV] |
|---|---|---|---|
| FC1 | carbon | 1 | 13 |
| FC2 | carbon | 6 | 34 |
| FC3 | Molybdenum | 4 | 53 |
| FC4 | Molybdenum | 7 | 73 |
| FC5 | Molybdenum | 10 | 88 |

The transmission of the beam is not 100 % and at the end energy of the DTL, the transmission is around 90 %. In consequence, these monitors will not be used for absolute current measurement.Fig. 4 shows the transmission as function of the beam energy for the 5 FC.

The FC will be used only during the slow and fast tuning mode, nevertheless, mechanical stresses induced by the thermal load can be huge as well as the induced activation at high energy. These issues will be studied in the next months.

The last FC will be installed in the MEBT, and will also used as a beam stopper for dedicated studies in the injector (IS, LEBT, RFQ and MEBT). It will be positioned at the end of the MEBT, the mechanical integration is challenging, the longitudinal length of the cup shall be less than 5 cm, to fit between two quadrupoles.

## TRANSVERSE PROFILE

In the LEBT, 2 profiles measurement (H+V) based on rest gas luminescence are foreseen to be installed in the line. These devices will be used as primary diagnostic for beam profile measurement and to set up the steering strategy.

At higher energies, in the MEBT and in the DTL sections, transverse beam profile will be measured by wire scanner and non invasive technics. Due to lake of space in the MEBT, profile measurement by rest gas luminescence method is the preferred solution.

Thermal load is an issue for the wire scanner and as to operate at low duty cycle, while non invasive method can be used at full duty cycle. More details about wire scanner can be found in [4]. The luminescence monitor will be positioned in the same plane as the wire scanner. The type

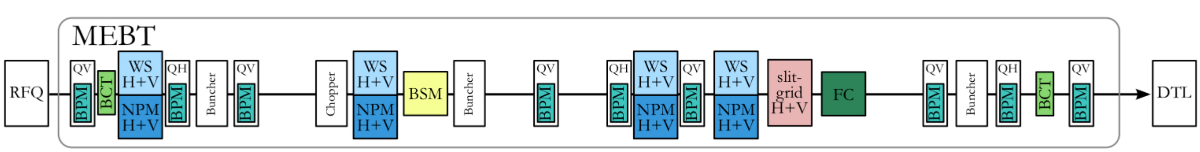


Figure 2: Beam instrumentation layout in the MEBT.

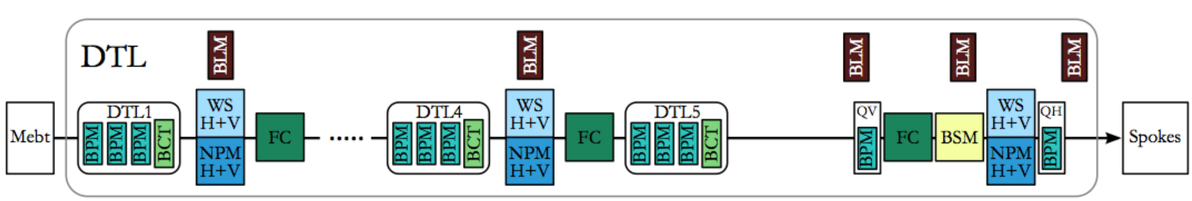


Figure 3: Beam instrumentation layout in the DTL.

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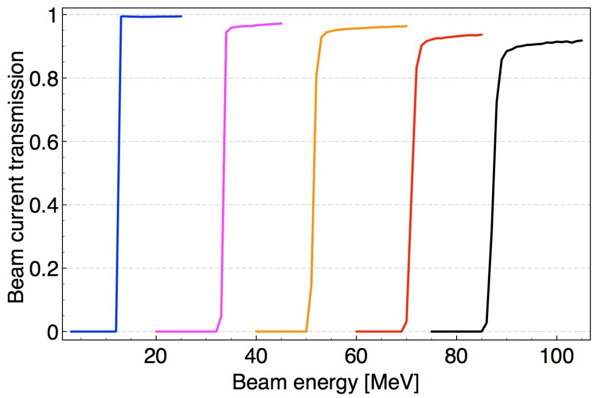


Figure 4: Transmission of beam for the 5 FC foreseen to be installed in the DTL.

of photon detector is still under discussion and the optical system will be developed during the next months.

## EMITTANCE MEASUREMENT

An Emittance Measure Unit (EMU) is foreseen in the LEBT, this device will be based on Allison scanner [5] and shall be able to measure the emittance at full duty cycle. Two Alison scanner are requested for emittance measurement in both transverse plane. The development is under going.

Transverse emittance measurement is also required in the MEBT and will be perform with a slit and grid system. The slit will not be able to stand the ESS beam power, therefore, the beam pulse has to be reduced to 100 $\mu s$ or less even with material with high melting point. From the studies done for the LINAC4 emittance meter [6], graphite is the best candidate for the slit material, in addition the slit has to be inclined w.r.t the beam axis in order to spread the energy deposition on a larger surface, a cooling system is also requested.

For emittance reconstruction, two profile monitors are needed. SEM grids equipped with tungsten wires are the primary option, nevertheless other detectors are also considered to increase the dynamic range of the emittance meter like Faraday cup and solid sate detector.

## LONGITUDINAL PROFILE MEASUREMENT

A bunch length measurement is foreseen in the MEBT, this device will be used during commissioning and operation in order to monitor the beam at the output of the RFQ. Due to the strong effect of the space charge at 3.6 MeV, the detector shall be installed as close as possible to the RFQ exit or to a buncher cavities. The exact location is still under discussion. The detector will probably be based of a Bunch Shape Monitor (BSM) [7].

A similar device will be installed at the end of the DTL section.

## BEAM LOSS MONITORING

The beam loss monitoring (BLM) is arguably the most important diagnostic system of the ESS linac [8]. It has the dual purpose of keeping the machine safe from beam induced damage and avoiding excessive machine activation by providing critical input to the machine protection system. Ionization chambers will be the main beam loss detector. Nevertheless, at low energies, ionization chambers are not effective to detect beam loss due to the self shielding from the copper cavities. In the warm linac, the differential current measurement between two consecutive BCT will be the primary input to the Machine Protection System.

Few neutrons detectors will be installed close to the line, in addition of the 5 ionization chamber positioned in between each DTL tank. The possibility of using detector inside the DTL tanks to measure $\mu-$loss is under discussion.

## OTHER TYPE OF DIAGNOSTIC

In addition of beam current and profile measurement, a 4 grids analyzer or a Hughes-Rojanski analyzer [9] can be installed in the LEBT in order to measure the degree of space charge compensation compensation. A measurement of the ions species fraction extracted by the ions source shall be also installed between the solenoids. A non invasive method based on Doppler shift measurement [10] are under study.

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