OVERVIEW OF THE ESS-BILBAO MOBILE DIAGNOSTICS TEST STAND

D. Belver,* I. Arredondo, I. Bustinduy, P. Echevarria, J. Feuchtwanger, J. Ortega Mintegui,
S. Varnasseri and Z. Izaola, ESS-Bilbao, Leioa, Spain

Abstract

A MObile diagnostics Test Stand (MOTS) is being designed at ESS-Bilbao in order to characterise the beam at the end of the Radio Frequency Quadrupole (RFQ) at 3 MeV. Injection of the beam from the RFQ to the Drift Tube Linac (DTL) tank and acceleration up to 12 MeV is a sensitive operation in the accelerating chain. The output beam of the RFQ should be fully characterised and tuned to optimise this operation. To perform this characterisation the MOTS is being designed with a set of diagnostic devices to measure also beam parameters after the Medium Energy Beam Transport (MEBT), and with minor modifications after the first tank of the DTL. The most important beam parameters that will be measured with the test stand are the beam current and the beam energy. Other important parameters are the beam emittance, the transverse beam position and the profile and bunch length. This contribution describes the beam properties that will be measured and the corresponding instrumentation devices, and presents a general layout of the MOTS.

INTRODUCTION

The current design of the ESS-Bilbao linac foresees a 3 MeV RFQ, a MEBT and a 50 MeV Drift-Tube-Linac (DTL). The whole DTL is divided into three tanks, being the output energy of the first tank 12 MeV.

The purpose of the Mobile Test Stand[1] (MOTS) is to help in the commissioning and fine-tuning of these acceleration structures. Therefore characterisation of the beam at the exit of these linac elements is mandatory.

Our design banks on previous experience gained from other accelerator laboratories (CERN, CEA-Saclay etc.) which have shown that it is possible to build a device equipped with a set of diagnostics tools to fully characterise the beam.

This paper presents the beam parameters to be measured and the diagnostics techniques that we intend to implement.

BEAM PARAMETERS

Table 1 lists the relevant beam parameters and their associated diagnostics instruments. The following subsections describes each of those parameters.

Table 1: List of Relevant Beam Parameters and Associated Diagnostic Instruments

Parameter	Instrument
Transverse plane	
Transverse position	Beam Position Monitors
Beam emittances	Slit-SEM Grid
Longitudinal plane	
Beam current	ACCTs and Faraday cup
Beam energy	FCTs/BPMs and spectrometer dipole
Energy spread	Dipole – SEM Grid
Beam phase	Beam Position Monitor
Bunch shape	Bunch Shape Monitor

Beam Current

The measurement of the beam current at the input and output ends of the RFQ will define its transmission. Sought values for this quantity for present-day RFQs are of 90 % or better. RFQ design and particle-tracking simulations show that ~ 55 mA of beam will be measured. source output [1]. For the first runs of the RFQ, measurements of µA are foreseen.

Beam Energy

The beam energy at the exit of the RFQ and first tank of the DTL, will be 3 MeV and 12 MeV. Calculation show that the time-of-flight (ToF) method, with a flight path of 1.5 m, is capable to measure a 3 MeV H^+ beam energy with a 0.3 % accuracy [2].

Energy Spread

The energy spread measurement could be carried out in a spectrometer line with a system composed of a dipole plus a Secondary Electron EMission grid (SEM grid). The grid is located at a certain distance from the centre of the magnet. The beam sizes are measured at this grid. The knowledge of the local dispersion allows the calculation of the energy spread.

The energy spread is not a critical beam parameter and a dipole is too expensive to be build for this propose. Therefore, only if we get a spare dipole we would build the spectrometer line.

Beam Position and Phase

Two Beam Position Monitors (BPM) made from sets of shorted stripline detectors are planned to be installed after

---

* `dbelver@essbilbao.org`

[1] MOTS is designed to measure beams up to 12 MeV and will be used after the MEBT and first tank of the DTL; hence the stand is mobile.

the RFQ in order to accurately measure the position of the beam. Beam position and phase monitors will be essential instruments at the time of commissioning to measure:

- The absolute beam position and beam phase.
- The relative beam intensity between BPMs.

The monitors should be located at positions along the test bench where the beam is not yet debunched.

Transverse Emittance

For the beam energy range under consideration we envisage to measure the transverse emittance using a slit-grid system, and scanning the beam which goes through it [3].

The transverse emittance for both horizontal and vertical planes are done separately with one scan per single pulse. These set of measurements should be made as close as possible to the RFQ exit to avoid effects of space charge.

A slit at the input of MOTS will reduce the space charge effects and the beam divergence. Placing the slit in horizontal and vertical planes would sample a small slice of phase space. By using the profile monitor, a SEM grid, at the end of the line, one can reconstruct the beam phase space and its transverse emittance. RFQ design simulations show that transverse emittance is around $0.3\,\pi$ mm mrad [1].

The slit should be able to scan through the whole beam width and must stand considerable heat loads during the beam pulse.

Bunch Shape

The direct measurement of the longitudinal emittance is less common than that related to its transverse counterpart. In contrast, one can gain access into this quantity by measuring the bunch shape and the beam phase, which are easier to perform. It is also worth remarking that the value for the longitudinal emittance is related to the beam energy spread and the phasing of the particle with the RF signal. The acceleration of the particles is sensitive to this two parameters.

BEAM DIAGNOSTICS AND LAYOUT

Layout

Figure 1 shows a schematic view of the preliminary layout. The basic idea for such a layout is taken from Linac4's 3 MeV Test Stand [4].

The following remarks are of interest:

- Most of the diagnostics instruments are to be located as close as possible from the RFQ exit.
- The current is measured with an AC current transformer (ACCT). A second ACCT will allow us to measure any beam loss within MOTS.
- To measure accurately the time at different positions for the ToF measurement, two Fast Current Transformers (FCT) are located with a separation of 1.0 m to 1.5 m [5].
- The transverse emittances are calculated varying the focusing of the quadrupoles and measuring the beam size in the SEM Grid located in the straight section.

Position Monitors

A versatile and configurable electronics system [6] has been developed, in collaboration with the Electronics and Electricity department of the UPV/EHU, in order to monitor the beam position monitors and to meet all the requirements of the future Linac of ESS-Bilbao. At the same time, the design has been conceived to be open and configurable so that it could eventually be used in different kind of accelerators. The design of the Beam Position Monitors (BPMs) system includes a test bench for both pick-ups and striplines, the Electronic Units and the control system (see Fig. 2).

The Electronic Units consist of two main parts: an Analog Front-End (AFE) unit where the RF signals are filtered, conditioned and converted to base-band; and a Digital Front-End (DFE) unit based in an FPGA board where the base-band signals are sampled, with a high sample frequency of 105 MHz, in order to calculate the beam position, the amplitude and the phase. The AFE unit includes two in-house boards, a logarithmic amplifier for measuring the position of the beam and an IQ demodulator for measuring the amplitude and the phase. To manage the system a Multipurpose Controller (MC) has been developed, including the FPGA management, the EPICS integration and Archiever Instances [7].

In order to characterise the BPM system different beam conditions have been measured. Several tests have been performed. The results have been satisfactory, leading to resolution and accuracy values fulfilling the ESS-Bilbao requirements. The beam positioning system measurements depicts an stability of less than 40 µm for both continuous and pulsed wave mode. The position resolution is less than 6 µm for both modes, and the phase resolution is less than 0.2°.

Current Monitors

There are a variety of devices for beam current and charge measurement in the accelerators. Current transformers (FCT, DCCT, ACCT,...) and Faraday Cups are the most common devices. Depending on the beam current and pulse width the appropriate device can be identified for the measurement system. In the case of MOTS, two devices which can meet the beam parameters are used as ACCT and Faraday Cup. FCTs will be used also for ion beam energy measurements through the ToF method. The control for the ACCTs will be done using an FPGA card into a National Instruments (NI) PXI. For the case of the FCTs, an oscilloscope will be used for the acquisition.

AC Current Transformers ACCTs shall be installed permanently in the entry of the MOTS and can measure the beam current in the nominal values. Two ACCTs should be installed on the diagnostics test bench: one at the entrance of MOTS, after the slit, and the second one after the dipole

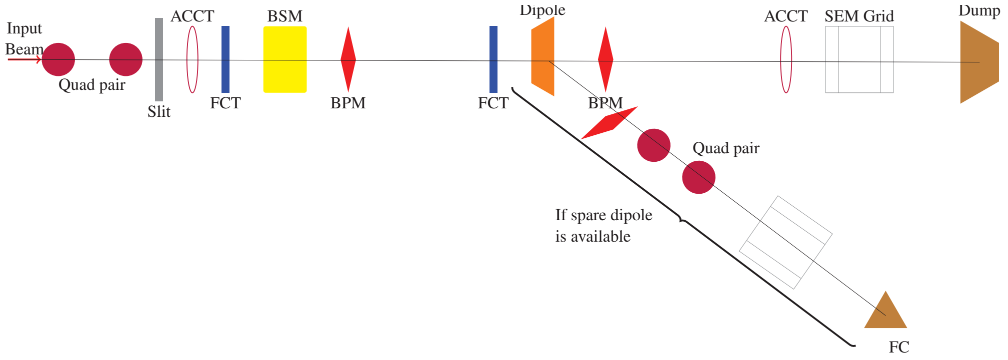

Figure 1: Schematic view of the MOTS layout. The spectrometer line is "optional" depending on the availability of a dipole.

magnet in the inline part. They require magnetic shielding to avoid electromagnetic coupling with the pulsed magnets that may be close to the detectors.

A test bench for the ACCT (HR-Bergoz) [8] has been installed in our laboratory (Fig. 3 top). The results show that it can measure the beam current down to 0.1 mA and pulse width from 10 µs to 2 ms without any drop [9]. However, larger pulse widths can be measured with a drop in the flat top of the pulse. The nominal bandwidth of the ACCT is 3 Hz and 300 kHz at the lower and higher cut-off frequencies.

Faraday Cup (FC) For very low currents, particularly during the conditioning of the accelerator, ACCTs can not measure the current amplitude. In this case a retractable Faraday Cup at the beam exit will give the information of the beam current and pulse. After amplification with a transimpedance current amplifier, a FC can measure currents of less than 1 µA.

A FC could be also used as a beam stop during conditioning of the beam, for the protection of devices which are installed downstream of the vacuum chamber. The maximum energy of 3 MeV protons can be stopped by the FC; however due to high beam power and high heat load on the copper surface, it can not be used as a permanent beam stop. The beam average power, up to 600 W and 10 kW pulsed, are in the working ranges of the FC-100 [10] model from NTG. A separate beam stop, already designed, will be installed for 3 MeV and higher energies.

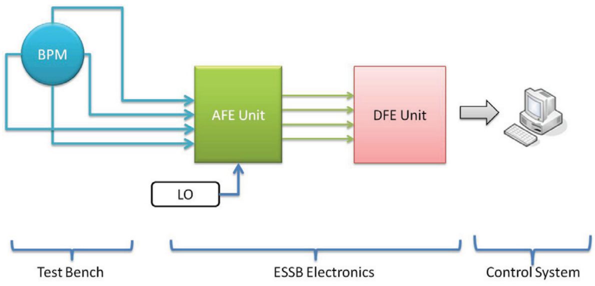

Figure 2: Schematic of the BPM electronics system.

Fast Current Transformers For the ToF technique two FCTs from Bergoz [11], with high bandwidth (up to 1.5 GHz) will be used. The high bandwidth of the FCT gives the possibility to have very short rise time and jitter, that is, of the order of nanoseconds. For MOTS, an in-flange type FCT is chosen, where the FCT is inserted between two standard flanges of the vacuum chamber (DN63), and does not require any extra shielding or ceramic insulation.

In order to investigate and check the ToF method with FCTs prior the installation on the MOTS, one ToF specific test bench has been installed at our laboratory (Fig. 3 bottom). The accuracy of delay mean value for many consecutive pulses is measured to be 17 ps. The accuracy of delay mean value for a single pulse is 100 ps [5]. These values show that the ToF scheme with corresponding FCT specs could be implemented for energy measurement in compliance with the required resolutions.

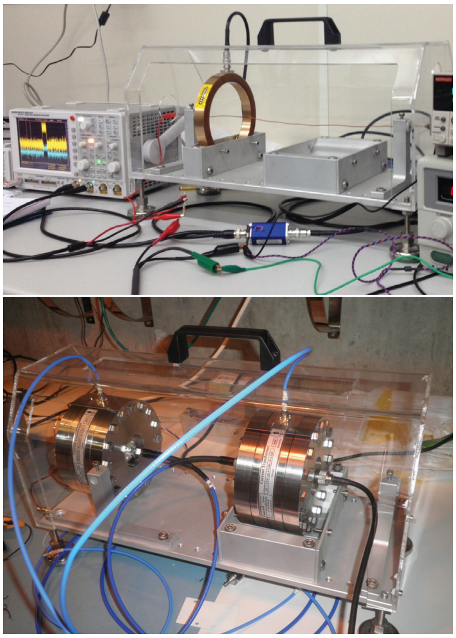

Figure 3: ACCT test (top) and FCTs assembled (bottom) in the test stand for current transformers.

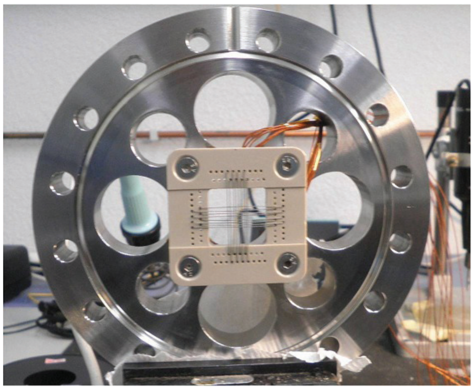

Figure 4: First prototype of SEM grid of ESS-Bilbao.

SEM Grid

There are a variety of methods for the transverse profile measurement. Not all of them are suitable for ion linac beam profile measurement. The scintillator monitor, SEM grid and the wire scanners are the most common systems and good candidates for MOTS profile measurement. Since the scintillator monitor is a destructive device, a SEM grid is proposed for the profile monitor of MOTS. As the ion beam in MOTS has a maximum radius of 5 mm, then a SEM grid coverage of $16\,\mathrm{cm}^2$ with wire distances of 0.5 mm could be used. The diameter of the wires can be about 100 µm in order not to deteriorate the beam emittance. Depending on the number of wires, the required number of I/Us and Mux channels will be selected.

In the framework of the ESS-Bilbao accelerator, with the collaboration of the Electronics and Electricity department of the UPV/EHU, a test stand for the development of SEM grids has been designed and manufactured as a part of the diagnostics system for beam profile measurements [12] (see Fig. 4). This test stand is a vacuum system based on an EQ 22/35 electron source from SPECS used as a beam injector. This electron source has an energy range from 0 keV to 5 keV and a maximum beam current up to 200 µA. Two prototypes of 16 Titanium wires (8 wires in each X and Y direction) of 250 µm diameter and spaced 1 mm and 2 mm, respectively, have been built. The secondary emission current from each wire is integrated and amplified, to provide a significant voltage signal that can be measured by our acquisition system based on a NI PXI card.

Bunch Shape Monitor

The Bunch Shape Monitor (BSM) has been developed by Feshenko [13], and consists of a wire which can be inserted into the beam. Secondary electrons created through the interaction of the beam with the wire are accelerated by HV applied to the wire. The electrons pass through an input collimator and are deflected by an RF deflector whose RF pulse is synchronous with the accelerating RF. The deflected electrons pass through an output collimator and are detected by an electron detector. The phase of the deflecting field can be shifted to scan the longitudinal intensity distribution of the incoming beam. The BSM will be able to monitor the full 1.5 ms pulse and the maximum peak current (75 mA after the RFQ).

FUTURE WORK

Simulations to define the final diagnostics specifications are in progress. Then, definitive devices and MOTS layout will be designed.

References

[1] F. J. Bermejo, I. Bustinduy, eds., "Technical Design Report", *ESS-Bilbao RFQ*, ESS-Bilbao, (2013).

[2] Z. Izaola, "Energy Measurement by Time-of-flight Measurement", Tech. rep. DIAG-CD-IR12-VF-ResolucionTOF-Izaola, ESS-Bilbao, (2012).

[3] B. Cheymol et al. "Design of the Emittance Meter for the 3 and 12 MeV LINAC4 H$^-$ Beam". *Proceedings of IPAC10,* MOPE052. Kyoto, Japan, 2010, pp. 1089–1091.

[4] F. Roncarolo, et al., "Overview of the CERN Linac4 Beam Instrumentation", *Proceedings LINAC2010,* THP007, (2010), pp. 770–772.

[5] S. Varnasseri, et al. "Test Bench Experiments for Energy Measurement and Beam Loss of ESS-Bilbao", *Proc. IBIC2013*, WEPF26, (2013).

[6] L. Muguira, et al. "A Configurable Electronics System for the ESS-Bilbao Beam Position Monitors", *Nuclear Instruments and Methods in Physics Research Section A* 721, (2013), pp. 50–59.

[7] I. Arredondo, et al. "Multipurpose Controller with EPICS Integration and Data Logging: BPM Application for ESS Bilbao", *Nuclear Instruments and Methods in Physics Research Section A* 726 (2013), pp. 127–138.

[8] *ACCT from Bergoz,* `http://www.bergoz.com/index.php?option=com_content&view=article&id=9&Itemid=466`.

[9] S. Varnasseri, D. Belver, I. Arredondo, "ACCT Characteristics Measurements for Carro-Movil Preparation", Tech. rep. DIAG-ND-CT00-ESS-00-DOC, ESS-Bilbao, (2012).

[10] *Faraday Cup from NTG*, `http://www.ntg.de/index.php?id=182&L=1`.

[11] *FCT from Bergoz*, `http://www.bergoz.com/index.php?option=com_content&view=article&id=23&Itemid=28`.

[12] D. Belver, et al. "Design and Measurements of a Test Stand for the SEM-Grid System of the ESS-Bilbao". *Proceedings of IPAC2012,* MOPPR040, New Orleans, Louisiana, USA, (2012), pp. 867–869.

[13] A. V. Feschenko, "Methods and instrumentation for bunch shape measurements", *Proceedings of the PAC2001*, ROAB002, (2001), pp. 517–521.

ISBN 978-3-95450-127-4