SYSTEM OVERVIEW AND CURRENT STATUS OF THE ESS BEAM POSITION MONITORS

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Abstract

It is planned to install more than 140 button BPMs along the ESS linac. The BPMs will be used to measure the beam position and phase in all foreseen beam modes and to provide input to the Machine Interlock System. The phase measurement is mainly intended for cavity tuning and Time-Of-Flight energy measurements. A customized BPM detector based on the European XFEL button style has been designed for the cold linac through a collaboration with DESY. Large buttons with diameters up to 40 mm are foreseen to provide enough S/N ratio not only with the nominal beam, but also with a low-current or a de-bunched beam. A demo MTCA.4 system has been procured and successfully integrated into EPICS. Also, a customized Rear Transition Module for down-mixing the BPM signals will be developed with SLAC. Electronics tests with a BPM test bench are currently going on at ESS. BPM installation in the linac is foreseen for 2017 and afterwards.

INTRODUCTION

The Beam Position Monitor (BPM) system of the ESS linac will be mainly based on electrostatic button type detectors. This is particularly valid in the spokes, elliptical, upgrade and accelerator-to-target sections where the current thinking is to use a button design similar to the European XFEL type button. The diameter, however, needs to be larger to provide enough signal-to-noise ratio especially in off-optimal conditions such as a low-current or a de-bunched beam. The exceptions to the button detectors are the BPMs of the low-energy linac including those of the Medium Energy Beam Transport (MEBT) and the Drift Tube Linac (DTL) where stripline detectors will be probably used.

The MEBT and DTL BPMs will be included in the in-kind contribution of these sections from the ESS member countries. The button BPMs will de developed in a collaboration with DESY-Hamburg. Also, a special raster BPM with more than 4 buttons is being developed in-house to measure the position of the expanded beam in a large beam pipe upstream of the target wheel [1].

Most of the BPMs will be installed in the quadrupole magnets and electronically centred with respect to the magnetic centre of the quadrupole. Figure 1 shows a drawing of the Linac Warm Unit (LWU) sitting in between each two cryomodules. The space between the two quadrupoles will be used for vacuum ports and diagnostics devices. A BPM detector will be installed in each quadrupole.

Computer simulations have been used to estimate the BPM signal level in time and frequency domains under optimal and off-optimal conditions as well as the trapped resonant modes of the buttons.

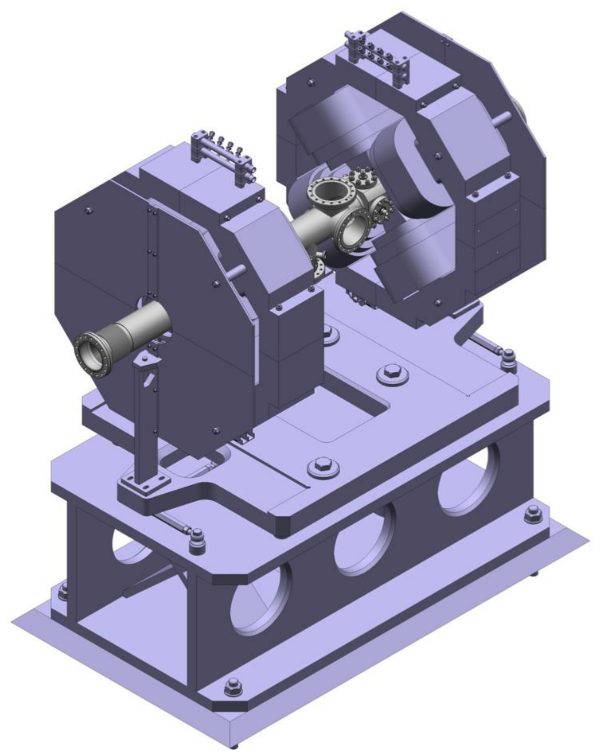

Figure 1: Draft design of the LWU including two BPMs. One of the BPMs can be seen in the quadrupole on the right.

The BPM electronics will be installed in the ESS klystron gallery, which will be extended in parallel to the linac tunnel over most of the linac length. The BPM signals will be processed at a frequency opposite to RF to minimize potential disturbances from nearby RF sources.

MTCA.4 has been chosen as the prototyping platform for the BPM electronics. A final decision for the platform is expected in Sep. 2014.

Based on the current design, the BPM electronics will include a Rear Transition Module (RTM) where the BPM signals will be filtered and processed by some analogue electronics as well as an Advanced Mezzanine Card (AMC) for analogue-to-digital conversion and

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FPGA processing. The AMC card will be commercial but the VHDL code for the BPM signal processing will be developed in-house with some support from the external partners especially in the early stage of the project.

The ESS BPM specifications and the main design considerations are presented in [2]. In this paper, the recent progress in the areas of BPM system design, simulation and prototyping will be reported.

BPM DESIGN AND SIMULATIONS

A preliminary version of the BPM design with 60 mm and 100 mm apertures has been received from DESY. Figure 2 shows the design of the larger BPM, which is intended for the LWU section of the cold linac.

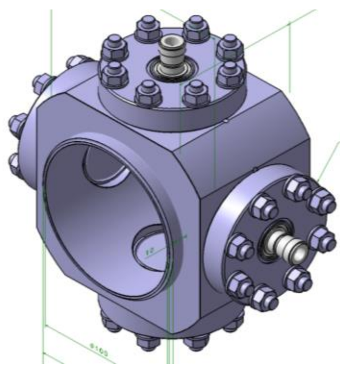

Figure 2: Design of the cold linac BPM with button and aperture diameters of 40 mm and 100 mm respectively.

Figure 3 shows a 60 mm BPM prototype received from DESY as well as a DESY-XFEL type button, which is currently being tested at ESS. The button will be redesigned by DESY to increase the diameter (currently 16 mm) thus providing enough voltage for ESS.

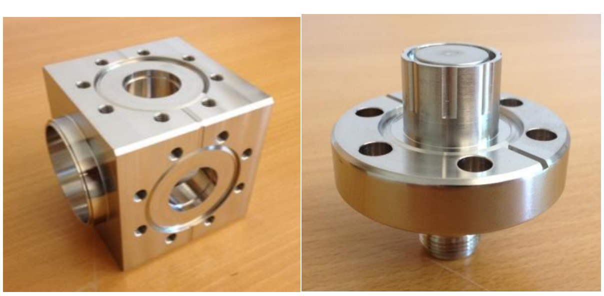

Figure 3: Picture of a prototype 60 mm ESS BPM (left) and the DESY-XFEL type button (right).

Figure 4 shows the calculated transfer impedance [3] of the BPM downstream of the spoke section assuming a button capacitance of 5.2 pF (DESY design for ESS). The cut-off frequency is 617 MHz and the button voltage at the processed frequency (i.e. 704 MHz) is about 2.5 dB smaller compared to the flat part of the transfer impedance. Larger button capacitances will further decrease the impedance resulting in a lower button voltage.

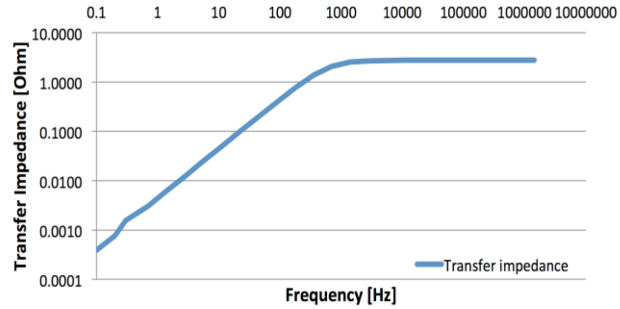

Figure 4: BPM transfer impedance downstream of the spokes. The horizontal axis is the freq. and the vertical one is the transfer impedance (from the beam current to the button voltage).

Shafer equations [4] have been used to calculate the BPM button voltage as a function of BPM number for button and stripline detectors (see Fig. 5). The stripline BPMs are expected to provide a larger and more uniform voltage along the linac at the expense of higher complexity and more space requirements.

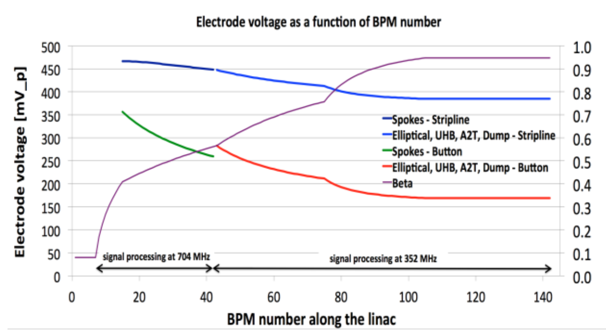

Figure 5: Calculated electrode voltage as a function of BPM number for button and stripline BPMs. The stripline length is assumed to be 12 cm in the spoke and 6 cm in the downstream sections. The azimuthal width of the stripline is 38 deg.

A series of CST simulations have been done by DESY to analyse the BPM signal in time and frequency domains in more details. Figure 6 shows the expected button voltage at 2.0 GeV with the beam moving horizontally from the centre to half of the beam pipe radius [5]. These simulations have revealed a possible trapped resonant mode at 5 GHz as well as some minor resonances at higher frequencies in the button. Thermal simulations have shown that the temperature rise of the button due to these resonances will be negligible. Also, these frequencies are not supposed to cause a problem for the receiving electronics, because the BPM cable and the analogue filters of the front-end card will easily filter them out.

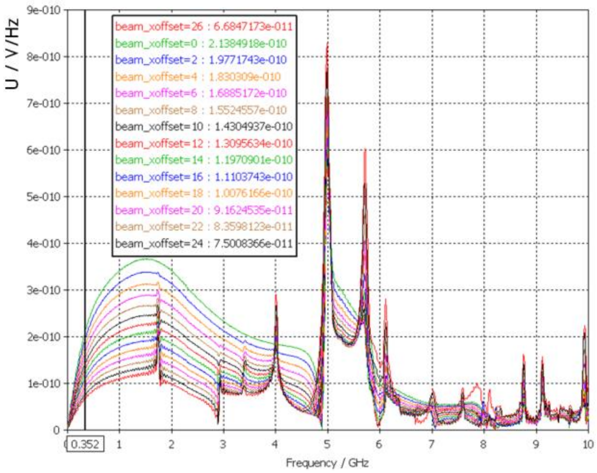

Figure 6: CST simulations showing the button voltage in frequency domain with the single beam moving horizontally in 2 mm steps to the edge of the measurement area.

BPM ELECTRONICS

MTCA.4 has been chosen as the prototyping platform for the BPM system. A prototype crate including a Struck SIS8900/SIS8300 RTM/AMC and a N.A.T. CPU-MCH has already been procured and successfully integrated into the ESS EPICS control system. A modified version of the hardware consisting of a DESY/Struck DWC8VM1 down-mixer RTM and a SIS8300-L AMC will be used to sample the 704 MHz harmonic of the BPM signal on a BPM test bench (see Fig. 7 and Fig. 8). Other options for the RTM include a 352 MHz direct-sampling card from DESY/Struck and a down-mixer card which is planned to be developed under a SLAC-ESS agreement [6]. Also, different options for the digitizer AMC will be evaluated before taking a final decision on the platform type and the electronics hardware. A VHDL code will be primarily developed in collaboration with DESY for the required BPM signal processing. This code will then be maintained and more functionality will be added to it by the ESS Beam Instrumentation group at later stages of the project.

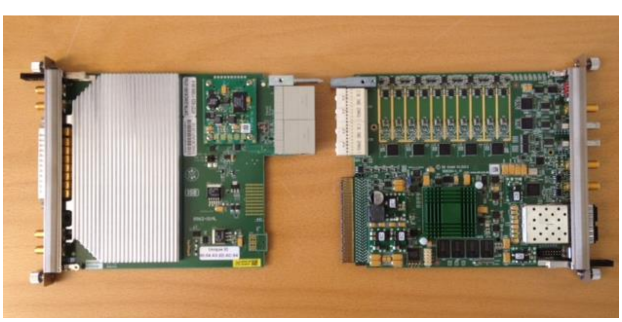

Figure 7: The DWC8VM1 down-mixer (left) and the SIS8300-L digitizer (right) from DESY/Struck.

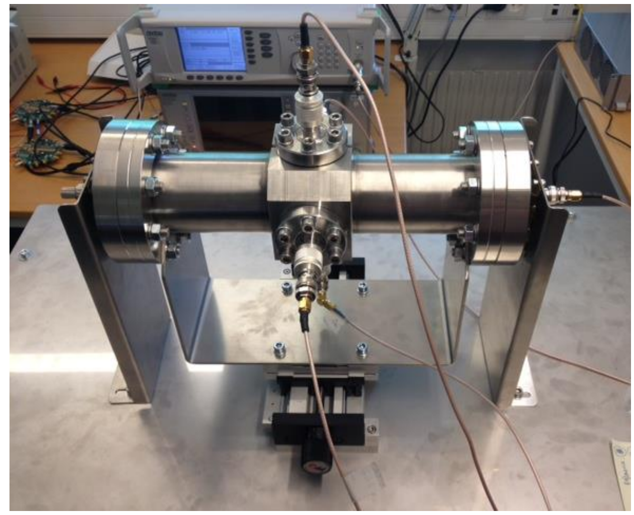

Figure 8: Photo of the BPM test-bench.

SUMMARY AND OUTLOOK

The ESS BPM system will be mainly based on electrostatic button type detectors. Most of the BPMs will be installed in the quadrupole magnets and electronically centred with respect to the magnetic centre of the quadrupoles. The exceptions are the MEBT and DTL BPMs where the current thinking is to use stripline detectors. It is planned to design and prototype the cold linac BPMs in collaboration with DESY-Hamburg. The button diameters will be larger compared to the European XFEL buttons in order to provide enough S/N ratio in particular in off-optimal conditions such as a low-current or a de-bunched beam during the linac commissioning. MTCA.4 has been chosen as the prototyping platform for the BPM electronics. Different options including commercial and custom-designed electronics will be evaluated at ESS using a BPM test bench before taking a final decision on the hardware. A VHDL code is being developed for the required FPGA signal processing including position, phase and intensity measurements. BPM installation in the linac and commissioning is expected to start in 2017.

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