A technical note on the expected ESS BPM performance with button and stripline detectors

(H. Hassanzadegan, 30 Jan. 2014)

1. Expected performance with short bunches and full beam

1.1 BPM signal level

For these calculations, the DC beam current is set to 62.5 mA. The beam pipe diameter is assumed to be 60 mm in the spokes section and 100 mm in the all the downstream sections including elliptical, upgrade high-beta, accelerator-to-target and dumpline. The button diameter is 24 mm in the spokes, and 40 mm in the downstream sections [1]. The azimuthal width of the stripline is set to 38° and its length to 6 cm in the spokes and 12 cm in the downstream sections. BPM signal processing is done at the opposite frequency with respect to RF (i.e. 704.42 MHz in the spokes and 352.21 MHz in the downstream sections). The button and stripline voltages are calculated using the equations presented in [2] and [3] respectively.

The following figure shows expected BPM voltage levels as a function of BPM number along the Linac:

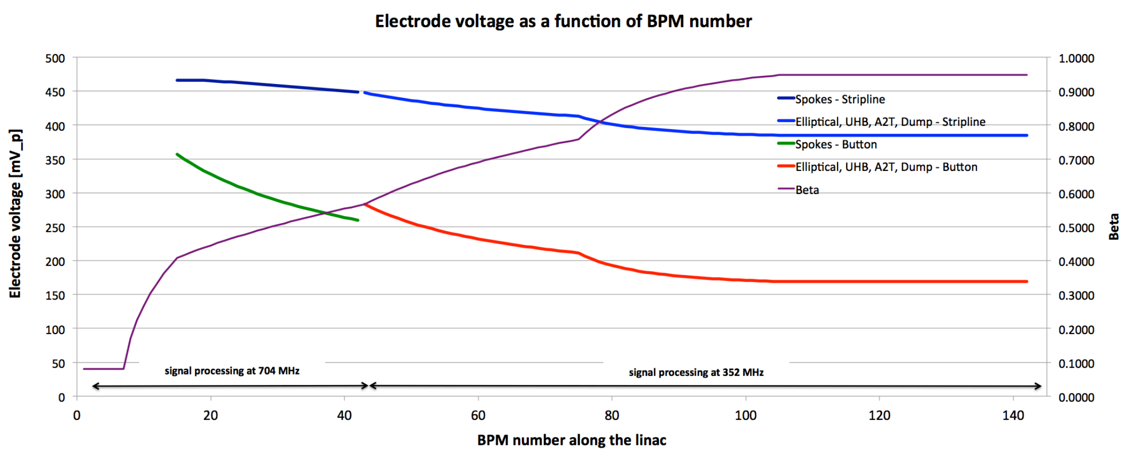

Figure 1: BPM voltage levels along the Linac with a centered beam. BPM no. 1 refers to the 1st BPM in the MEBT. Dumpline BPMs are added at the end of the Linac after the A2T section.

1.2 BPM resolution for position measurement

The noise on the BPM signals at the input of the RTM (i.e. front-end electronics) has been calculated as the sum of the thermal noise and the effective input noise of the

RTM [4]. The thermal noise has been calculated for an RTM analog bandwidth of 10 MHz and room temperature.

Four cases are considered:

Case A:	Beam pipe diameter = 60 mm, E = 92 MeV, Beta = 0.41
Case B:	Beam pipe diameter = 60 mm, E = 217 MeV, Beta = 0.58
Case C:	Beam pipe diameter = 100 mm, E = 217 MeV, Beta = 0.58
Case D:	Beam pipe diameter = 100 mm, E = 2 GeV, Beta = 0.95

For these cases, position resolution with a centered beam has been calculated based on the S/N ratio:

Case A:	Button: 3.32 μm,	Stripline: 2.53 μm
Case B:	Button: 4.69 μm,	Stripline: 2.64 μm
Case C:	Button: 6.20 μm,	Stripline: 2.29 μm
Case D:	Button: 10.16 μm,	Stripline: 2.67 μm

It should be noted that the maximum acceptable BPM voltage at the input of the front-end electronics is limited 1 V_p. Therefore, stripline voltages higher than 460 mV_p (centered beam) are expected to have a negligible effect on the performance improvement as they will have to be attenuated to avoid electronics damages.

1.3 BPM resolution for phase measurement

With a full beam, the noise, which is superimposed on the BPM signals, is expected to have a negligible effect on the resolution of the phase measurement. The dominant source of error will be the jitter of the ADC clock. Assuming 1 ps of clock jitter [5], a rough estimation of the phase error will be:

Case A:	0.13°	(direct sampling in 352 MHz)
Case B:	0.13°	(direct sampling in 352 MHz)
Case C:	0.02°	(sampling in IF)
Case D:	0.02°	(sampling in IF)

1.4 Time-Of-Flight measurement with the BPMs

For TOF measurements, the beam phase at two BPM locations will be compared to each other. The phase difference will be proportional to the beam velocity; hence, it can be used to calculate the beam energy. Here, it is assumed that two successive BPMs will be used for the TOF measurements. If the distance between the two measurement points is larger, the phase measurement error will be smaller, but the phase measurement range will become more limited as well. Also, the integer part of the RF periods between the two measurement points will be lost in the measurement. It is preferred to use two successive BPMs for the TOF measurements. Using distanced BPMs may technically add to the complexity.

Assuming that the distance between the two successive BPMs is 0.5 m, at E=2 GeV, the 0.2° phase resolution (BPM specifications) will translate into 1.2% of error in online energy measurements. At lower energies, measurement will be subject to a smaller error, ex. at E=217 MeV, the error will be 0.15%.

2. Expected performance under off-optimal conditions

Off-optimal refers to conditions such as a short pulse width or a low-current or a de-bunched beam.

The electronics settling time is expected to be about 1-2 μs (still to be verified). If the pulse width is shorter than the settling time of the electronics, measurements will be subject to large errors.

With no powered cavity after the spokes section, the longitudinal beam size will increase by 100 mm approximately within each 150 m of the Linac length [6]. This will result in a bunch length of 330 mm approximately in the A2T section. With this bunch length, there will be a large overlap between successive bunches and the 352 MHz harmonic of the beam current will be by a factor of 3600 smaller than a bunched beam. With such a small signal, the BPM resolution will be extremely poor (17 mm according to the calculations). If the beam current is decreased to 6.25 mA, the BPM signal will further decrease and it will go below the noise level.

At shorter distances from the spokes, the BPM system might still be able to give a rough estimation of the beam position. For example, at 150 m downstream of the spokes, the expected resolution with a 6.25 mA beam is about 200 μm.

3. Summary and conclusions

The current design of the ESS BPM system assumes button BPMs in the spokes and the downstream Linac sections. The design is based on the European XFEL button, but with larger diameters to provide enough voltage for the electronics. Calculations show that with a 62.5 mA bunched beam, position and phase resolutions of 10 μm and 0.2° respectively will be achievable.

With stripline detectors, the electrode voltage will be larger and the position resolution will be slightly improved. However, the additional cost and complexity that will result in from using stripline detectors might not be justifiable.

If the beam gets longitudinally de-bunched downstream of the spokes, when it reaches the A2T section, there will be a large overlap between successive bunches and the beam current will be very close to DC. The 352 MHz beam harmonic will then be extremely small, and in practice, it might not be possible to distinguish it from the noise. In this condition, regardless of the electrode type, the beam position cannot be measured successfully. The situation will get even worse if the beam current is reduced to 6.25 mA.

At distances up to 150-200 m downstream of the spokes, position measurement might still be possible, but the resolution will be significantly degraded compared to a bunched beam.

4. References

[1] Dirk Lipka, Simulation of Button BPM for ESS, Jan. 2014, power point file presenting results of the simulation work done by DESY for ESS

[2] Stephan R. Smith, Beam Position Monitor Engineering, SLAC-PUB-7244, July 1996

[3] Robert E. Shafer, Beam Position Monitoring, Los Alamos National Laboratory, 1990

[4] Cooperative Research and Development Agreement between SLAC and ESS, CRADA no. 13-219C

[5] DRTM-LOG1300 specifications

[6] De-bunching simulations by: R. Miyamoto (ESS, Beam Dynamics Group)