ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPA17

DEVELOPMENT, FABRICATION AND LABORATORY TESTS OF BUNCH SHAPE MONITORS FOR ESS LINAC

S. Gavrilov†[1,2], A. Feschenko[1], D. Chermoshentsev[1,2]

[1]Institute for Nuclear Research of the Russian Academy of Sciences, Troitsk, Moscow, Russia

[2]Moscow Institute of Physics and Technology, Moscow, Russia

Abstract

Two Bunch Shape Monitors have been developed and fabricated in INR RAS for European Spallation Source linac. To fulfil the requirements of a 4 ps phase resolution the symmetric λ-type RF-deflector based on a parallel wire line with capacitive plates has been selected. Additional steering magnet to correct incline of the focused electron beam is also used. Limitations due to a space charge of the analysed beam and due to external magnetic fields are discussed. Laboratory tests of the monitors are described.

INTRODUCTION

Bunch Shape Monitors (BSMs) are intended for the measurements of a longitudinal distribution of particles in bunches of the accelerated proton beam in ESS: the first BSM will be installed in MEBT at 3.6 MeV, and the second one – between the normal conducting and the superconducting parts of the linac at 90 MeV.

The operation principle of BSM, developed in INR RAS, is based on the technique of a coherent transformation of a temporal bunch structure into a spatial charge distribution of low energy secondary electrons through a transverse RF-scanning [1] and is clear from Fig. 1.

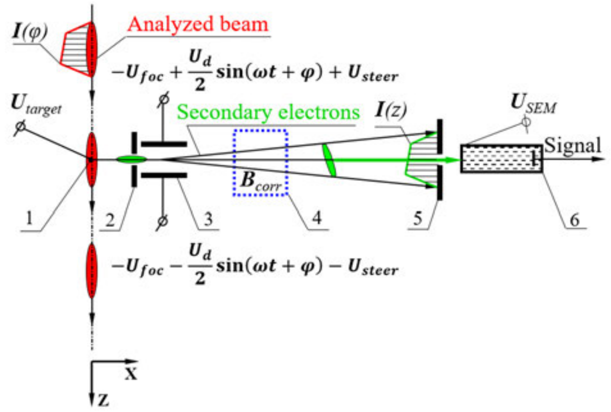

Figure 1: BSM scheme: 1 – tungsten wire target, 2 – inlet collimator, 3 – RF-deflector combined with electrostatic lens, 4 – correcting magnet, 5 – outlet collimator, 6 – secondary electron multiplier.

The series of the analysed beam bunches crosses the wire target 1 which is at a high negative potential about -10 kV. Interaction of the beam with the target results in emission of low energy secondary electrons, which characteristics of importance for bunch shape measurements are practically independent of beam energy, so the monitors are fabricated in practically the same design (Fig. 2), except for the beam aperture size.

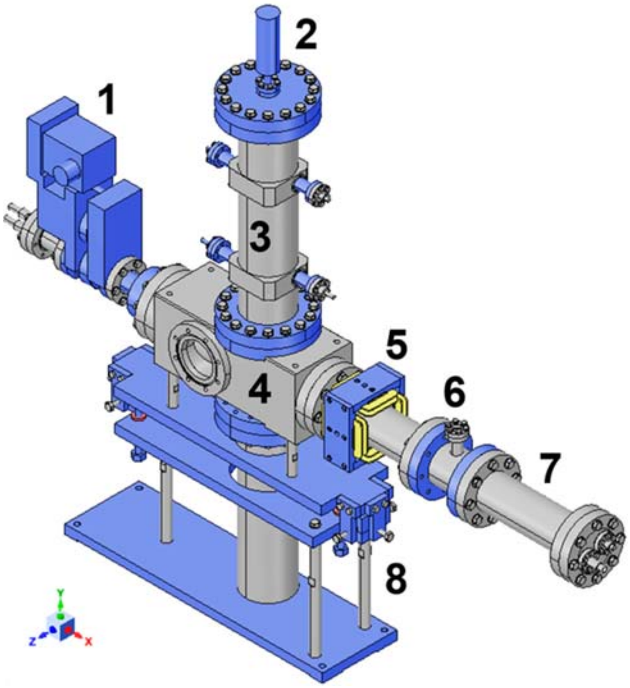

Figure 2: ESS BSM design: 1 – target actuator, 2 – tuner, 3 – RF-deflector, 4 – BSM box, 5 – quadrupole + dipole correcting magnet, 6 – viewport for optical control of e-beam, 7 – SEM-detector, 8 – support with 3D-adjustment.

The electrons are accelerated by electrostatic field and move almost radially away from the target. A fraction of the electrons passes through the inlet collimator 2 and enters the RF-deflector 3, where electric field is a superposition of electrostatic focusing and steering fields and RF-deflecting field with a frequency equal to the RF-field frequency in the linac: 352.2 MHz.

Passed electrons are scanned by the RF-field and an intensity of electrons passed through the outlet collimator 5 represents a fixed point of the longitudinal phase distribution of the primary beam. Other points can be obtained by changing the phase of the deflecting field with respect to the RF-reference. If the phase of the deflecting field is adjusted in a wide range, then the bunch can be observed twice per the period of the deflecting field.

By adjusting the steering voltage, one can change the measured phase position of the observed bunches and obtain the periodicity of bunches to be exactly equal to π. If the bunch duration is larger than π, the intensities corresponding the phase points differed by π are superimposes and the results of bunch shape measurements become wrong.

---

† s.gavrilov@gmail.com

MAGNETIC SHIELD AND CORRECTOR

Both monitors will be installed in a close vicinity of magnetic elements (quadrupole and corrector) with strong fringe fields. A magnetic shield is foreseen to provide a non-distorted e-beam transport inside the monitor.

The shield represents a sectional jacket made of 2 mm low-carbon steel. Additionally, the interior surfaces are covered with a 160 µm foil made of an amorphous cobalt-iron alloy with high μ_r. Figure 3 shows the effect of the BSM shield on the fringe field of a dipole corrector located close to the monitor. Even better results can be obtained if additional 2 mm low-carbon steel plate screens are added upstream and downstream of BSM – the remnant fields decrease to the level less, than the Earth's magnetic field, and their influence will be negligible.

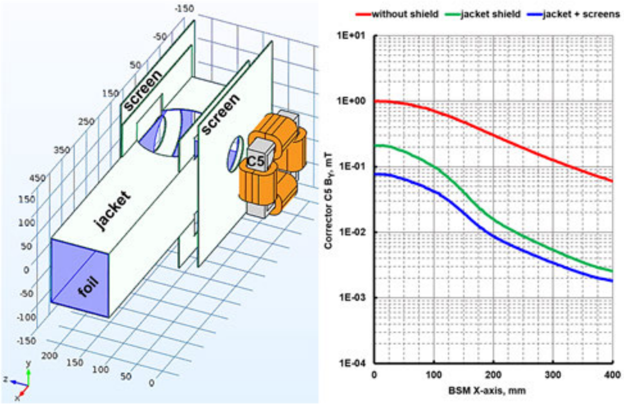

Figure 3: BSM shield layout and an example of dipole corrector B_Y distribution along BSM X-axis.

An influence of remnant moderate static magnetic fields inside the standard shield as well as unavoidable misalignments can be compensated by adjusting the steering voltage U_{steer} in Z-direction and by a special magnetic corrector in other directions. The correcting magnet with the combination of dipole and quadrupole fields (Fig. 4a) is implemented. The dipole field moves the electron beam along Y-axis. The quadrupole field enables to adjust the tilt of the e-beam in YZ-plane (Fig. 4b).

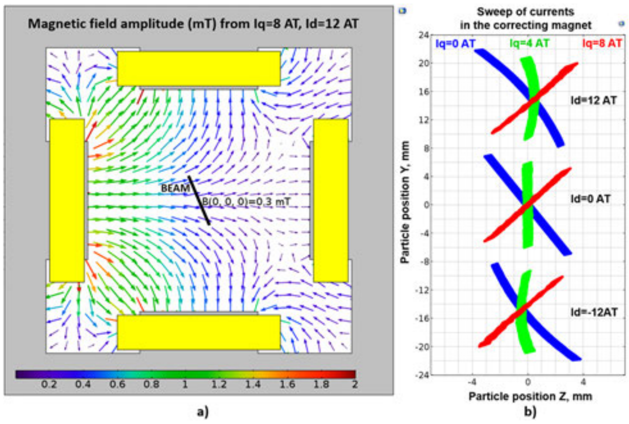

Figure 4: (a) Magnetic corrector with fields superposition. (b) E-beam in the plane of the outlet collimator for different quadrupole Iq and dipole Id coil currents (Ampere·Turns).

RF-DEFLECTOR

Typically, BSM deflectors are RF cavities based on parallel wire lines with capacitive plates. To improve the uniformity of both deflecting and focusing fields in Y direction, thus improving phase resolution, the λ-type symmetric cavity has been selected for ESS BSMs (Fig. 5).

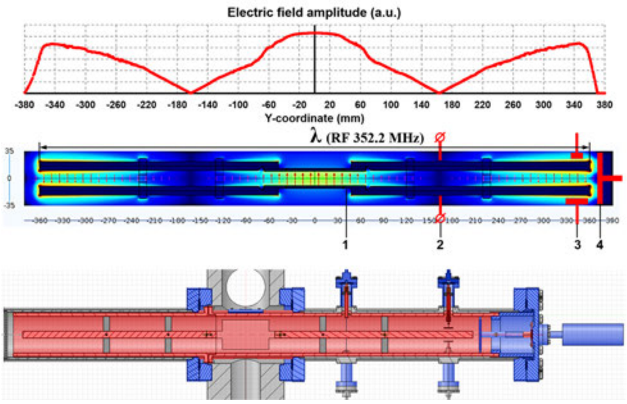

Figure 5: Electric field distribution and cut planes for the symmetric λ-type RF-deflector of ESS BSM.

The electrodes with deflecting plates 1 are supported by ceramic insulators. Focusing potentials are applied to the electrodes with spring contacts 2 at zero field point. Capacitive adjustable couplers 3 are used to drive the cavity and to pick up the RF signal. Fine tuning within the range of about ± 1 MHz is made from outside the vacuum with capacitive tuner 4 via manual actuator.

PHASE RESOLUTION AND ACCURACY

The symmetric deflector and the magnetic corrector provide an electron beam completely fitted with the 0.5 mm outlet collimator. Figure 6 shows the e-beams at the outlet collimator for three δ-function analysed bunches with the interval of 0.5° (352.2 MHz).

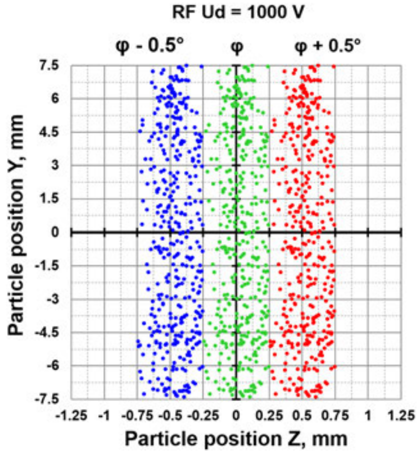

Figure 6: Transverse cross-sections of the e-beam in the plane of the outlet collimator for different phases of deflecting field with the step 0.5° at 352.2 MHz.

The double RMS size of the simulated focused beams equals $2\sigma_z$=0.25 mm, so in principle the size of the slit can be decreased to 0.25 mm, that provides the resolution $\Delta\varphi_0$=0.21°. However it was not done due to two reasons.

The first reason is decreasing of intensity of the detected electron beam. The second one is presence of one more crucial component of the phase resolution – time dispersion (delay) of secondary electron emission.

The value of the delay time is not known exactly. The theoretical value for metals is estimated to be about 0.01 ps [2]. The experimental attempts to measure the time dispersion give the upper limit of this value equal to (4±2) ps [3] rather than a real one. We assume the delay time of the emission to be uniformly distributed within the range of 0÷6 ps, so the double RMS delay equals 3.46 ps, which is equivalent to $\Delta\varphi_{SEE} = 0.44°$ for 352.2 MHz and the resulting phase resolution becomes 0.48°, that corresponds to 0.57 mm collimator.

Estimations described above were done with the assumption of a zero-intensity analysed beam, while a space charge of the real beam can strongly influence the secondary electrons trajectories. Besides a finite phase resolution, which smoothes measured distributions, there is a so-called phase reading error (accuracy). Due to the latter the measured phase coordinate along the bunch does not correspond to a real one because of electron energy modulation and the measured bunch shape becomes distorted. The methods of taking into account the space charge of the analyzed beam are described in [4]. The results of simulations with different beam currents for BSM at MEBT are presented in Fig. 7.

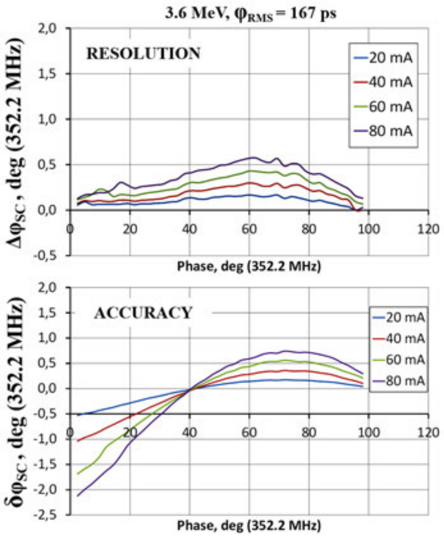

Figure 7: Space charge effects for various beam currents.

The phase resolution and the phase reading error are given as functions of a longitudinal coordinate along the bunch. The bunch head is at the left side in the figures. The electron emitted at the head of the bunch is firstly accelerated by the charge with positive X coordinate and then decelerated. The net effect appears to be decelerating. The electrons emitted at the bunch center or at the bunch tail are also firstly accelerated and then decelerated. However, for these electrons the decelerating effect becomes smaller compared with the bunch head because the moving bunch leaves the area. For bunches with 90 MeV energy and 16.4 ps rms duration space charge effects become five times smaller.

LABORATORY TESTS

After complete design and fabrication process BSMs have been assembled (Fig. 8), pumped, tuned and tested for proper operation of all systems: vacuum, RF, high voltage, electronics and control system. Electron beam optics was also tested with the help of thermal electrons: heating the wire target, it is possible to observe through the viewport the thermal electron beam on the phosphor covering the front surface of the outlet collimator.

Figure 8: Photo of assembled BSM with the magnetic shield and symmetric RF-deflector.

CONCLUSION

Two Bunch Shape Monitors have been developed for ESS linac. The symmetric RF-deflector has been fabricated for the first time to improve the uniformity of electric fields. The special magnetic shield for protection against external fringe magnetic fields and correcting magnet with the combination of dipole and quadrupole fields for compensation of remnant magnetostatic fields and misalignments of BSM elements have been implemented.

The estimation of BSM phase resolution for zero beam intensity of 0.5° for 325.2 MHz (4 ps) has been done in real 3D-geometry with inlet-outlet collimators of 0.5 mm, supposing the parameters for energy and time dispersion of secondary emission are known. Space charge effects can increase the upper limit of the phase resolution up to 0.7° and reduce the accuracy of bunch shape measurements in MEBT, but practically do not influence the resolution and the accuracy for 90 MeV beam.

REFERENCES

[1] A. Feschenko, "Technique and instrumentation for bunch shape measurements", in *Proc. RUPAC'12*, Saint-Petersburg, Russia, Oct. 2012, pp. 181-185.

[2] I. M. Bronstein and B. S. Fraiman, *Secondary Electron Emission*, Moscow, Russia: Nauka, 1969 (in Russian).

[3] E. Ernst, H. Von Foerster, "Time dispersion of secondary electron emission", *J. of Appl. Phys.*, vol. 26, no. 6, pp. 781-782, 1955.

[4] A. Feschenko and V. Moiseev, "Peculiarities of bunch shape measurements of high intensity ion beams", in *Proc. IPAC'10*, 2010, pp. 1065–1067.