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BUNCH SHAPE MONITORS FOR MODERN ION LINACS

S. Gavrilov†, A. Feschenko
Institute for Nuclear Research of Russian Academy of Sciences, Troitsk, Moscow, Russia

Abstract

In recent years several Bunch Shape Monitors were designed for new modern ion linacs, such as Linac4 CERN, Proton and CW-linac FAIR GSI, FRIB MSU, ESS ERIC. Each of these accelerators has its own requirements for a phase resolution, mechanical design and operating conditions of the monitor. An overview of the most interesting features of different monitors is presented. Some results of laboratory tests and on-site beam measurements are discussed.

INTRODUCTION

The technique of a coherent transformation of a temporal bunch structure into a spatial charge distribution of low energy secondary electrons through RF-modulation was initially implemented by R. Witkover [1] for BNL linac. An energy (longitudinal) RF-modulation of secondary electrons was used. In the Bunch Shape Monitor (BSM) [2], developed in INR RAS, a transverse RF-scanning is used. The general principle of BSM operation has been described many times previously and is clear from Fig. 1.

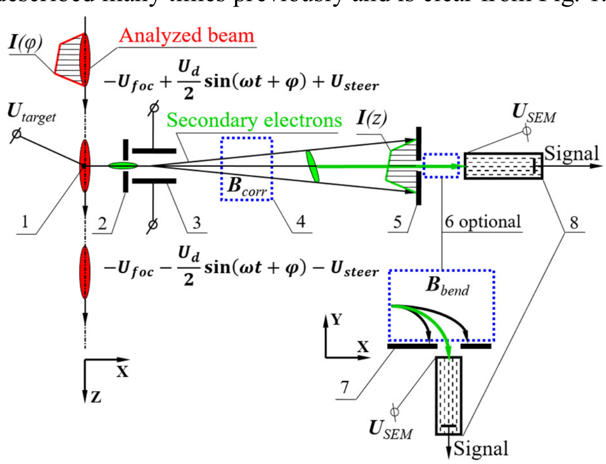

Figure 1: BSM scheme: 1 – tungsten wire target, 2 – inlet collimator, 3 – RF-deflector, 4 – correcting magnet, 5 – outlet collimator, 6 – optional bending magnet, 7 – registration collimator, 8 – secondary electron multiplier.

The series of the analysed beam bunches crosses the wire target 1 which is at a high negative potential. Interaction of the beam with the target results in emission of low energy secondary electrons. The electrons are accelerated by electrostatic field and move almost radially away from the target. A fraction of the electrons passes through inlet collimator 2 and enters RF-deflector 3. The field in the deflector is a superposition of electrostatic focusing and steering field and RF-deflecting field Ud with a frequency equal (or multiple) to the bunch sequence frequency.

† s.gavrilov@gmail.com

CURTAIN RANGE EXTENDER

Two groups of electrons passing the deflector with the phase shift of 180° get through the outlet collimator and their intensity is detected (Fig. 2).

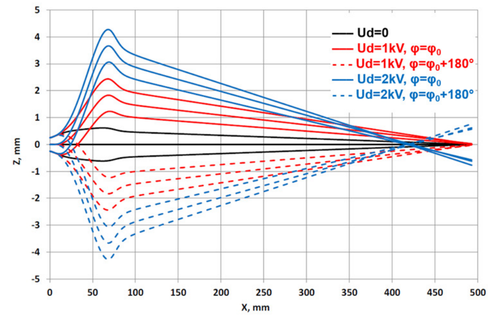

Figure 2: Trajectories of electrons in BSM.

If the bunch length is bigger than 180°, then the signals corresponding to two longitudinal points shifted by 180° are superimposed and the results of the measurements are distorted. Hence the standard phase range of measurements of BSM is equal to half a period of the deflecting field. The range of the measurements can be increased to a full period if one of the two groups of electrons is blocked. To do it the flag-type rotatable curtain can be used at the exit of the RF-deflector. The idea of the curtain was initially proposed by A. Tron and one of the paper's authors, however it was realized in practice for the first time in BSM for FAIR GSI linacs (Fig. 3).

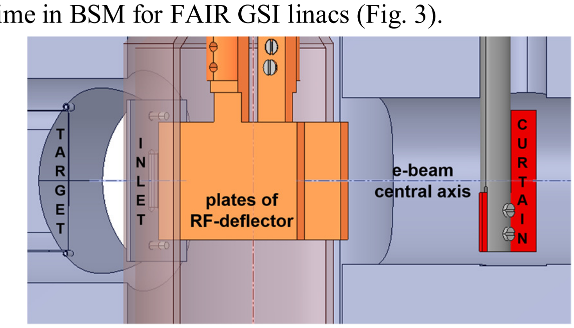

Figure 3: Internal layout of BSM for GSI with curtain.

Rotating the curtain, one can absorb the electrons (Fig. 4) corresponding to one of the two half-periods of the deflecting field thus avoiding superimposing of the signals corresponding to the particles shifted by half a period.

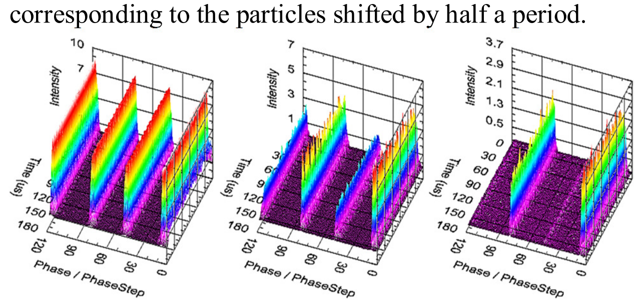

Figure 4: Experimental results for curtain rotation.

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λ-TYPE RF-DEFLECTOR

The opposite problem arises at linacs with rather short bunches, like ESS ERIC, which is foreseen to operate with RMS bunch lengths of about 1.5°÷2.5° at medium energies and even shorter at high energies, so at least 0.5° phase resolution is required, that corresponds to about 4 ps time resolution for 352.2 MHz operating RF.

To achieve such resolution the uniformity of both deflecting and focusing fields in a RF-deflector must be improved. Typically, BSM deflectors are asymmetric RF-cavities, based on parallel wire lines with capacitive plates. An electrical length of the deflectors is usually λ/4 or λ/2. To improve the phase resolution, a new λ-type symmetric cavity has been developed for ESS (Fig. 5).

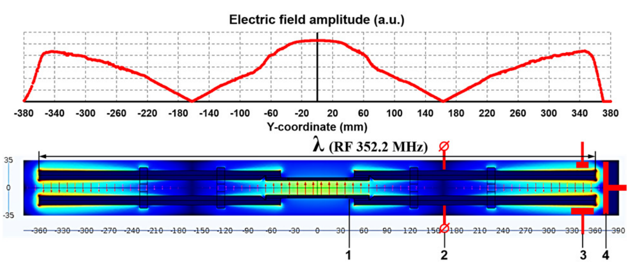

Figure 5: E_Y-field distribution in a λ-type RF-deflector.

The electrodes with deflecting plates 1 are supported by ceramic insulators. Focusing potentials are applied to the electrodes through spring contacts 2 at zero field points. Capacitive adjustable couplers 3 are used to drive the cavity and to pick up the RF-signal. The fine tuning of the resonant frequency is provided with capacitive tuner 4 via the manual actuator from outside the vacuum.

Figure 6 shows the distribution of the RF-field E_Z-component in YZ-plane (X = 0) in non-symmetric (λ/2) and symmetric (λ) RF-deflectors. The non-uniformity of the field in a zone of the electron beam passage is an order of magnitude less for the symmetric type.

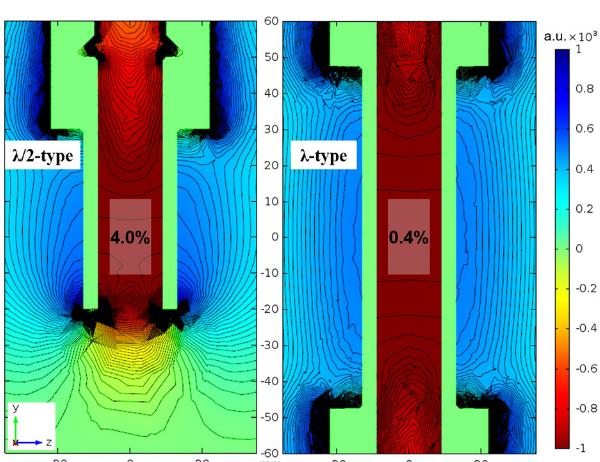

Figure 6: RF-field E_Z-component distribution in YZ-plane (X = 0) of λ/2- and λ-type BSM deflectors.

The λ-type deflector is a crucial feature for BSM resolution improvement up to the fundamental level, determined by a time dispersion of secondary electron emission with the measured upper limit equal (4±2) ps [3].

VIBRATION DAMPERS

At low operating frequencies RF-deflector becomes longer and consequently more sensitive to external vibrations originated from mechanical vacuum pumps, installed at beam pipes, especially in case of λ/4 or λ/2-type design with electrodes extended in cantilever. Vibrations result in oscillations of the electrodes at their mechanical eigenmodes (Fig. 7a), that change the total capacitance of the deflector and as a result spread the resonance frequency and the phase response function of the deflector.

This effect was observed in the deflector 108.408 MHz of BSM for FAIR GSI with the length 610 mm and the main mechanical eigenfrequency about 61 Hz. In fact, the electrodes cannot be identical so their eigenfrequencies must be a bit different, that results in a low frequency modulation. During measurements the range of phase $\Delta\Phi$ and the time Δt required to adjust the phase within this range are related as: $\Delta\Phi=\delta\varphi\cdot F_b\cdot\Delta t$, where $\delta\varphi$ is a phase adjustment step, F_b - beam pulse repetition rate.

Fig. 7b shows the experimental measurements done with the 0.1° phase step at F_b=3.6 Hz. The period of modulated oscillation equals about 3.2 s. The spread of the phase modulation can be estimated about 4°, that means the modulation amplitude of 2° per 0.8 s. The deflecting field phase is adjusted by about 0.3° at the same time, so there are oscillations superimposed on the smooth bunch shape. The modulation can still be distinguished for 0.5° (Fig. 7c) and absolutely disappears for 2° phase step (Fig. 7d).

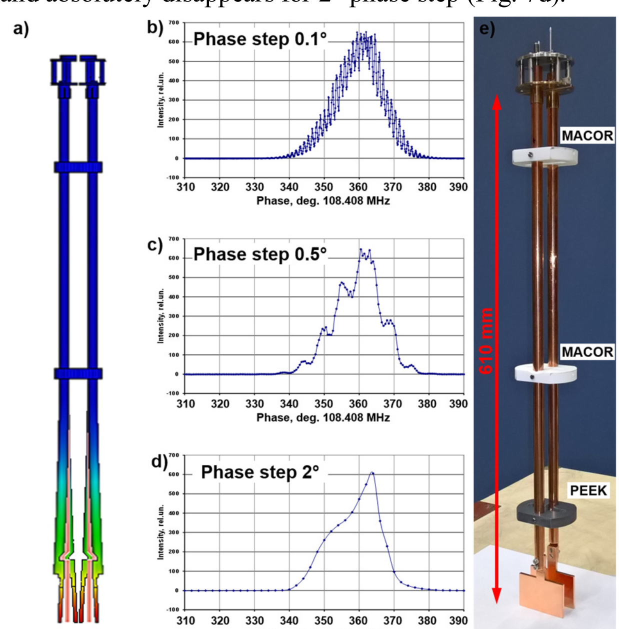

Figure 7: a) Simulated main eigenmode of the electrodes oscillations in a λ/4-type deflector. b-d) Experimental bunch shape measurements in the presence of vibrations. e) Photo of the RF-deflector with extra PEEK holder.

To damp parasitic oscillations the third electrode holder made of PEEK™ was added close to the plates (Fig. 7e). PEEK™ has twice smaller permittivity and loss tangent, than MACOR™ used for prime holders, it is meaningful because of abrupt increase of E-field in this region.

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MAGNETIC SHIELD AND CORRECTOR

Often BSMs are installed in a close vicinity of magnetic focusing elements with strong fringe fields both static and alternating. In this case a magnetic shield must be used to provide a non-distorted e-beam transport inside BSM.

Typical BSM 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. Fig. 8 shows the effect of the BSM shield on the fringe field of a quad located close to the BSM ESS. 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.

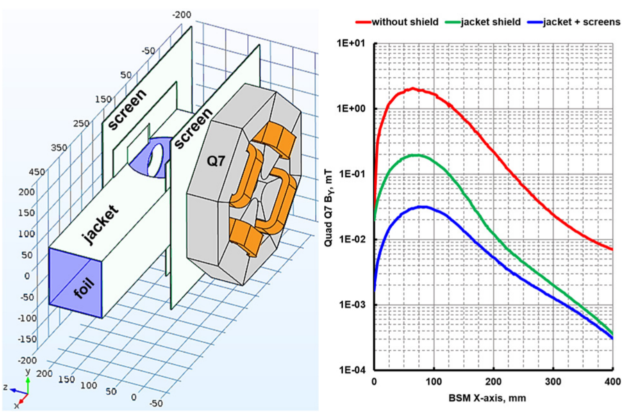

Figure 8: BSM shield design and the quad B_Y distribution.

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. 9a) was foreseen firstly in BSM for FRIB MSU. 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. 9b).

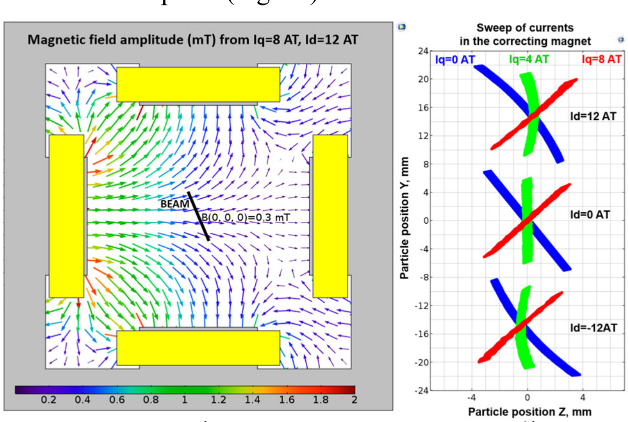

Figure 9: (a) Magnetic corrector with fields superposition. (b) E-beam in the plane of the outlet collimator for different quadrupole Iq and dipole Id coil currents (Ampere·Turns).

CONCLUSION

Bunch Shape Monitor is a reliable tool for longitudinal diagnostics during optimization of beam dynamics in ion linacs. It plays a unique role for the commissioning stage, because allows to observe an evolution of charge longitudinal distribution in bunches within a beam pulse.

Fig. 10 shows the experimental results from the commissioning of LINAC4 CERN. The behaviour of the bunch shape (Fig. 10a) in time reveals a strong instability of longitudinal distribution at the beginning of the beam pulse (Fig. 10b), that can be explained by data about the beam loading in DTLs of the linac (Fig. 10c).

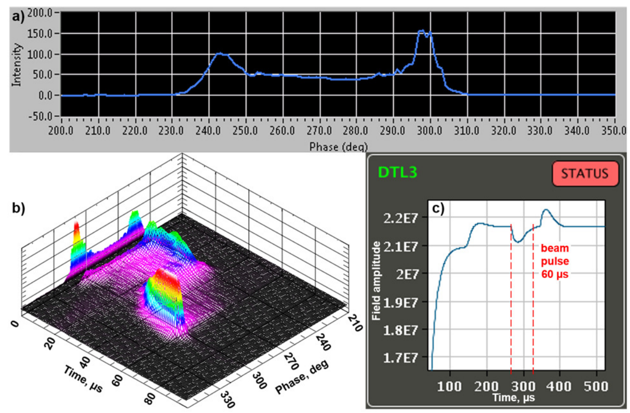

Figure 10: Experimental data from LINAC4 CERN. a) A bunch shape with 1° resolution. b) Evolution of a bunch shape during a beam pulse. c) Behaviour of the field amplitude in DTL3 in the presence of the beam.

A beam microstructure, measured by BSM, allows to tune parameters of bunchers and accelerating cavities (Fig. 11) and also to define some other beam parameters, for example, a longitudinal emittance.

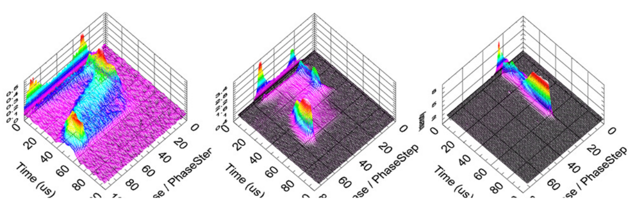

Figure 11: A bunch shape constriction by tuning the phase of the field in PIMS 11-12 LINAC4.

Developed improvements enable to achieve about 4 ps time resolution, that corresponds to 0.5° for hundreds of MHz, and to use the monitor for all typical ion beams of existing and forthcoming linacs.

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