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BEAM MAPPING LINEARITY IMPROVEMENT IN MULTI-DIMENSIONAL BUNCH SHAPE MONITOR*

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Abstract

RadiaBeam is developing a Bunch Shape Monitor (BSM) with improved performance that incorporates three major innovations. First, the collection efficiency is improved by adding a focusing field between the wire and the entrance slit. Second, a new design of an RF deflector improves beam linearity. Finally, the design is augmented with both a movable wire and a microwave deflecting cavity to add functionality and enable measuring the transverse profile as a wire scanner. In this paper, we present the design of the BSM and its sub-systems.

INTRODUCTION

Direct measurement of the full multi-dimensional phase space is crucial for the operation and development of linear accelerators. Obtaining an accurate initial distribution of the beam entering the linac system is required for realistic simulations of the beam dynamics [1]. The Bunch Shape Monitor (BSM) is a device used to measure the longitudinal bunch distribution in hadron linacs, originally developed by A. Feschenko at the Institute for Nuclear Research (INR) in Moscow [2].

The principle of operation of the BSM is shown in Fig. 1. The primary ion beam with a longitudinal structure passes through a tungsten wire biased at high voltage (- 10 kV) and generates a low-energy secondary electron beam with an equivalent temporal profile. The electron beam is accelerated towards the input slit (anode) and is focused with an electrostatic lens (focusing system). Then, an RF deflector with a superimposed electric potential is used to focus, steer, and deflect the electrons. Hence, the temporal distribution is converted into a spatial distribution via an RF deflecting field. Finally, the electrons are measured by a multichannel plate detector (MCP) and a phosphor screen.

Modern hadron linacs require several BSMs to suite their beam diagnostics [3]. For example, the Spallation Neuron Source (SNS) at Oak Ridge National Laboratory (ORNL) has seven BSM systems originally delivered by INR [4]. Although these systems have been operational for several years, they have technical limitations such as poor electron collection efficiency, beam mapping non-linearity, and are limited to one-dimensional measurement of the phase coordinate [5]. An improved design of the BSM is needed to solve these issues and could potentially be used to perform more advanced beam dynamics experiments using the six-dimensional phase space scan technique developed at SNS [1].

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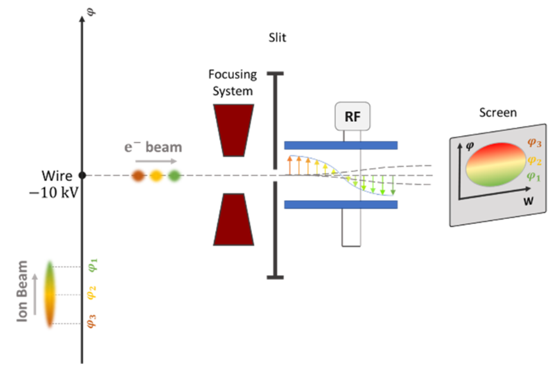

Figure 1: BSM operation principle.

RadiaBeam is developing an improved multi-dimensional BSM to be used at SNS. The specifications for this system are the following: 402.5 MHz operating frequency, 2.5 MeV ion energy, and phase resolutions smaller than 1°. The design includes three major innovations: focusing system to improve collection efficiency, new RF deflector to improve beam linearity, and a moving mechanism to enable measurement of the transverse profile [6]. Recently, we have developed and fabricated the focusing system to improve the electron collection efficiency and beam linearity for the current BSM at the SNS Beam Test Facility. This focusing system prototype was tested at SNS and demonstrated excellent vertical focusing properties, improved electron collection efficiency by a factor of 2.9, and improvement in the measured signal-to-noise ratio.

In this paper, we report further progress, which includes the following innovations: a new RF deflector cavity that allows improved vertical beam focusing and provides a linear horizontal beam mapping from wire to the screen, and a movable wire system that allows proton beam scan in the transverse dimension.

RF DEFLECTOR

One of the major improvements of the BSM design is the addition of a new RF deflector cavity. This deflector allows a symmetric geometry to reduce distortions in the vertical focusing, which was an issue with the original BSM. Its design also facilitates moving the wire and deflector together for transverse beam measurements.

The new RF deflector was designed by ORNL [7] and provided to RadiaBeam for RF testing. This deflector consists of an RF cavity with input and output slits, and two electrode plates that are attached to two pairs of support rods for a symmetric geometry as displayed in Fig. 2. The target operational frequency for the cavity is 402.5 MHz. However, ORNL manufactured the cavity with longer

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support rods to allow tuning, hence, a frequency shift with respect to the target frequency was expected. We received the model of the manufactured RF cavity and simulated it using CST Microwave Studio. Initial results showed a ~20 MHz frequency shift.

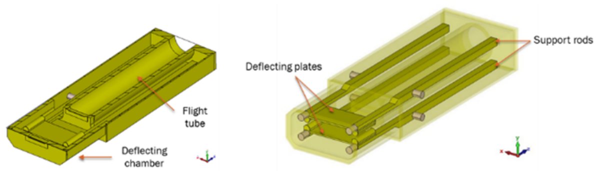

Figure 2: ORNL design of new RF cavity.

The cavity was designed with two RF couplers: coupler 1 to provide power, and coupler 2 for field probing. The requirements for these couplers were: coupling of ~1 for coupler 1, and attenuation of -40 dB or lower between both couplers. However, to satisfy the latter requirement we designed new couplers for the cavity (Fig. 3) and tuned the frequency by reducing the length of the support rods. Figure 4 shows the S-parameters of the tuned model that indicate coupling of 1.1 and attenuation of -42 dB. A summary of the main RF parameters of the tuned model is shown in Table 1.

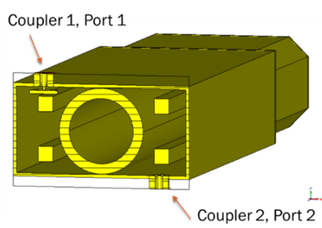

Figure 3: RF couplers of the new deflector.

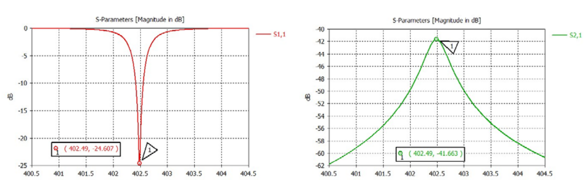

Figure 4: S-parameters of the tuned RF cavity model.

The new couplers were built and installed in the cavity to perform RF tests. The experimental setup is shown in Fig. 5. The measured resonant frequency of the cavity as received from ORNL is 377.6 MHz, which is within the range of the initial estimations from the model and confirms that tuning of the cavity is required. The main RF results from this measurement are presented in Table 1. The lower Q-factor from the measurement is most likely caused by losses in the SMA cables and the connection of the couplers to the cable. We do not consider this a significant issue given that the cavity will operate at low power (up to 10 W) with a duty factor of ~0.02, which makes the average dissipated power on the order of milliwatts. The good agreement of the resonant frequency from the model and measurement will be helpful in the next steps, where we will modify the cavity to tune the frequency to 402.5 MHz.

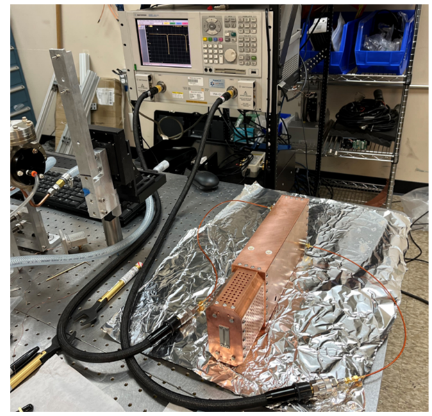

Figure 5: RF test setup of the new deflecting cavity.

Table 1. RF parameters of the new RF deflecting cavity.

Parameter	Simulation (tuned)	Measurement (as received)
Frequency, MHz	402.5	377.6
Q-factor	2668	1582
Coupling (coupler 1)	1.1	1.7
Attenuation, dB	-42	-41

BEAM MAPPING LINEARIZATION

Beam mapping linearity is important to have a good correlation of the position and energy of the primary beam at the wire and the secondary electron beam at the screen detector. We have performed beam tracking simulations to improve beam mapping in the new BSM system. In this system, the position of the wire with respect to the RF cavity is fixed by using a wire support system composed of ceramic standoffs and metallic clamps as shown in Fig. 6. We considered electron emission from the wire with initial energy of 2 eV and zero energy spread, and electrostatic potentials at the wire (-10 kV) and the deflector electrode plates (~-5 kV). RF fields were not included in this study.

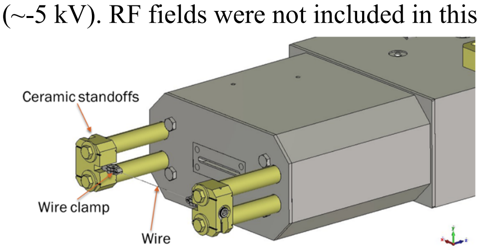

Figure 6: Wire support system of the improved BSM.

In the initial design, the horizontal beam trajectories showed strong beam overfocusing. This was the result of distortion of the electrostatic potential lines caused by the four support rods and the metallic components of the wire support system. To solve this issue, we added two electrostatic screens, which consist of two parallel plates located between the wire and the input slit, and between the deflector plates and the output slit. as shown in Fig. 7.

We optimized the design of the electrostatic screens to adjust the horizontal focusing of the beam (Fig. 8) and improve the point-to-point mapping. To characterize the beam

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mapping linearity, we plotted the horizontal position of the electrons at the wire and the detector (Fig. 9). Then, we performed a polynomial fit of these traces. The first order term in the initial design was -0.63, and in the optimized design 0.98. By comparing these results, we can demonstrate a 40% improvement in the beam linearity achieved with the addition of the electrostatic screens. Additionally, we adjusted the electrostatic potential of the deflector to -5.2 kV to vertically focus the beam. A vertical resolution of ~0.5 mm at the detector was achieved with the improved design (Fig. 10).

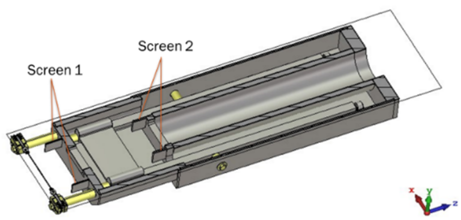

Figure 7: Electrostatic screens in the BSM cavity.

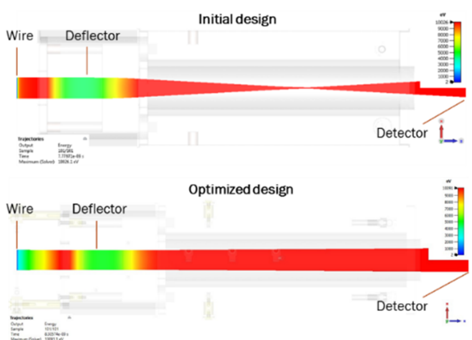

Figure 8: Horizontal electron beam trajectories of the initial (top) and optimized (bottom) design of the BSM.

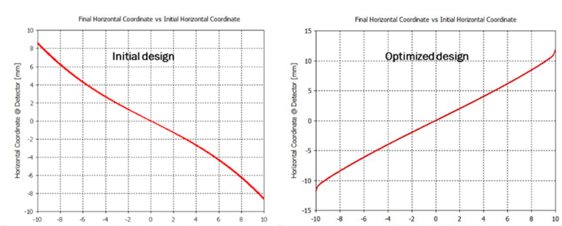

Figure 9: Point-to-point wire-to-detector map of the electrons in the initial (left) and optimized (right) designs of the BSM.

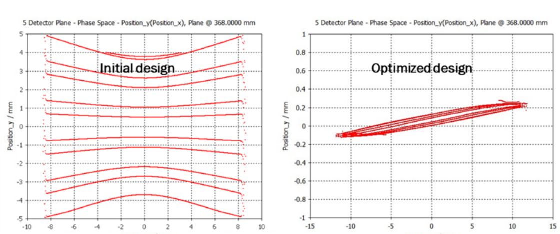

Figure 10: Electron beam position at the detector in the initial (left) and optimized (right) designs.

MOVABLE WIRE SYSTEM

We have also designed a system that will allow moving the wire across the ion beam (i.e. beam profile scanning) while keeping the distance between the wire and RF cavity fixed. Given that the electron beam transport depends on the distance from the wire to the deflector, a constant distance between them preserves the optics and thus the linearity of the system. This improvement adds the capability of beam scanning in the directions perpendicular to the wire, allowing 2D geometric scans of the bunch, and consequently 3D scans, since the temporal profile of the secondary electron beam is related to the longitudinal profile of the primary proton beam.

The conceptual engineering design of the moving system is shown in Fig. 11. In order to move the wire relative to the primary beamline, a set of bellows is incorporated into the main chamber between the ridged mounting points of the target assembly and the beamline port. Motion is achieved via a linear actuator and is further controlled by a follower linear bearing assembly mounted 180 degrees opposite to the linear actuator. The range of motion is currently limited by the throw of the bellows, which is +/- 19mm.

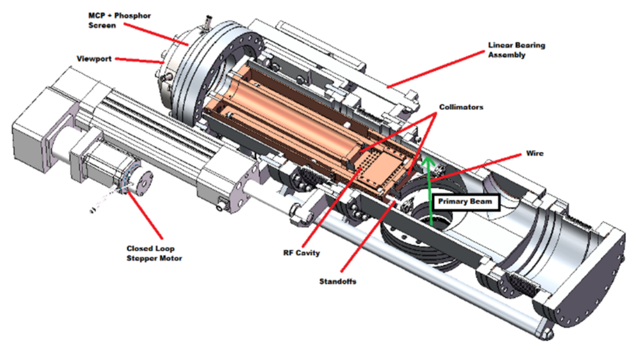

Figure 11: Simplified engineering model of the movable wire system.

Under vacuum, with a single set of bellows, the linear actuator sees a large compressive force, which puts strain on the actuator and linear bearing mounting locations. In order to rectify this, a second set of bellows is mounted below the main chamber, and the two sets of bellows are rigidly coupled by a set of standoffs. In this way, the standoffs see all vacuum forces and the actuator only needs to overcome the weight of the top half of the assembly and spring forces of the bellows.

SUMMARY

We have designed the improved multi-dimensional BSM with a new RF deflector cavity that allows superior vertical beam focusing and horizontal beam mapping. We have improved the beam linearity by 40% by implementing an optimized optics system. The new design will also allow transverse 2D scanning of the proton beam thanks to a movable wire/resonator assembly. The prototype is currently being fabricated.

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