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PRESENT STATUS AND UPGRADES OF THE SNS ION BEAM BUNCH SHAPE MONITORS*

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Abstract

Six interceptive Feschenko-style longitudinal bunch profile monitors have been deployed in the normal conducting part of the SNS linac and HEBT. They have been operational for more than 10 years and although their performance has been satisfactory, reliability and parts obsolescence must be addressed. The upgrade plan focuses in mainly two areas, electronics architecture modernization and improvement of measurement resolution. In the first phase that is presented here the objective is to improve the control and readout electronics taking advantage of more recent technology. This will primarily address the obsolescence issues with older components, the frequent RF power failures, the non-trivial maintenance and troubleshooting and will lead to a simpler and more reliable system. This contribution describes in detail the implemented upgrades and presents the first experimental data.

INTRODUCTION

The beam Bunch Shape Monitor (BSM) or Feschenko-style monitor has been developed at INR [1] based on a detector built by R Witkover for the BNL Linac BSM's [2] are used in several proton machines [3], [4] for measuring longitudinal profiles of short bunches where faraday cups cannot be used. The operating principle of the BSM is shown in Fig. 1. Beam bunches hit a wire biased at high voltage (10 kV) which results in emission of low energy secondary electrons. These electrons maintain the temporal distribution of the impinging beam. As the wire is biased at high negative potential, it accelerates the electrons radially away from itself. A small fraction of them passes through an aperture and enters a region where superimposed electrostatic an RF fields focus, steer and deflect the electrons. Depending on the phase of the RF field with respect to the beam RF the electrons are scanned by the RF field and their positions depend on the RF phase. This way, the longitudinal structure of the electron bunch is transformed into a spatial distribution due to the RF deflecting field. For a complete profile the entire bunch must be scanned by the second aperture. The typical Feschenko monitors use a secondary electron multiplier for electron detection. There are 4 BSMs at the SNS, 4 at the CCL and 2 at the HEBT. Additionally, the Beam Test Facility which is a replica of the SNS accelerator front end with some additional elements for specific beam studies is equipped with a BSM too. The BTF BSM was chosen for this development as it is more readily available compared to the main accelerator. The BTF BSM system is slightly different that the others, it is equipped with a multi-channel plate detector (MCP) and a phosphor screen. In this configuration the last aperture is eliminated so a complete bunch profile measurement doesn't require scanning and it is taken in one shot. One shot in this context implies imaging several bunches under the assumption that they are identical.

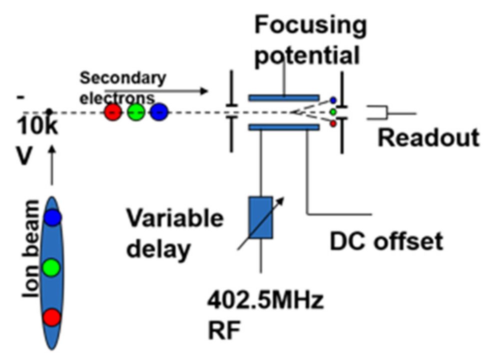

Figure 1: BSM working principle.

The original BSM systems as delivered by the Institute of Nuclear Research have been operational for several years but there are certain shortcomings that needed to be addressed. This R&D effort presented here was motivated by several reasons that had to do with the systems reliability, ease of maintenance, easy of configuration and component availability. The existing BSM suffers from frequent RF amplifier failures due to overheating as it operates in continuous mode. Replacing components is not a trivial task as many of them have become obsolete. Moreover, the system is not modular and thus subsystems cannot be swapped out easily. The focus of this effort is to simplify the high voltage power supply configuration, have the RF amplification chain operating in pulsed mode, use modular off the shelf components where possible and resort to custom hardware only when necessary. This will simplify the entire system making maintenance easier and faster

HARDWARE DESCRIPTION

Figure 2 shows the BSM electronics chassis, all components are contained in a single assembly. The main discrete sections are RF, high voltage power supplies, AC-DC, Timing and triggers and constant current power supplies.

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RF Section

RF manipulation is a critical component of the BSM. With reference to Fig. 3, the incoming 402.5 MHz signal passes through a voltage control phase shifter. This stage allows to vary the RF phase with respect to the incoming signal. The phase shifters are controlled by a National Instruments I/O card which also supports other functions of the BSM. Past the phase shifter the signals splits via a RF couples which provides a readback point. Next the RF switch with external trigger makes the following RF amplifier to operate in pulsed mode addressing the frequent amplifier failures of the past system.

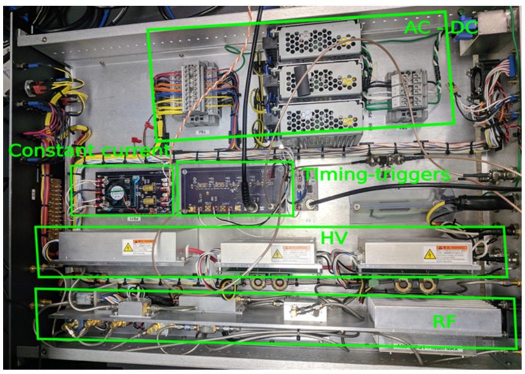

Figure 2: BSM electronics.

A custom-made trigger card provides delayed signals, so the amplifier ramps up and stabilizes before the RF signal passes through the switch. Finally, a second coupler feeds the RF deflector and at the same time provides another readback point. At the other end of the deflecting cavity there is the last readback point.

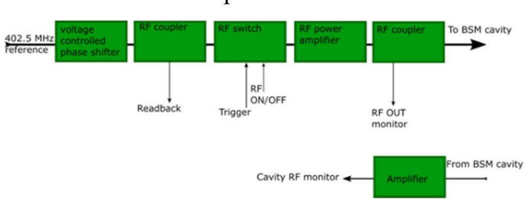

Figure 3: RF block diagram.

After careful calibration of the phase shifters using a network analyser the system has a usable range of 0º - 500º which can be adjusted in steps of 0.5º. The entire RF chain is built with off the shelf components from MiniCircuits.

High Voltage Section

The BSM high voltage configuration, see Fig. 4 consists of off the shelf adjustable power supplies provided by Matsusada. The wire bias is supported by a -10kV unit while the focusing and steering utilizes 2x -6kV units. To simplify steering and focusing the two power supplies are combined, each attached to the opposite sides of the deflector. Focusing is achieved by setting both at the same value and steering by adding an offset to the one and subtract the same offset from the other. The remaining two power supplies are used for the SEM and phosphor screen depending on the application.

Custom hardware

In order to trigger the pulsed operation of the RF amplifier and for synchronization purposes a custom card was developed based on pulsed stretchers and programmable delay gates with components from Linear Technologies. With reference to Fig. 5 the main input pulse from the timing master triggers a 10 ms long window during which all the BSM relevant events occur. A 6 ms long pulse enables the RF amplifier and after a 4.5 ms delay for stabilization the RF switch is activated for 1 ms.

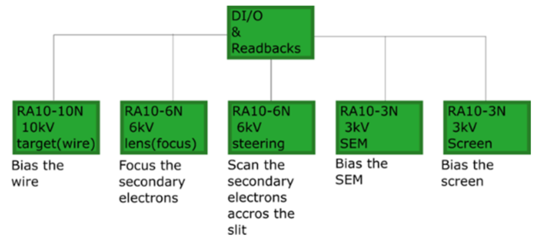

Figure 4: High voltage block diagram.

This ensures reliable operation of the RF amplifier and addresses the overheating issues of the past. Finally, within the last 1 ms pulse the ADC trigger occurs. Since at the BTF a screen images the electrons instead of an SEM the ADC timing is not relevant.

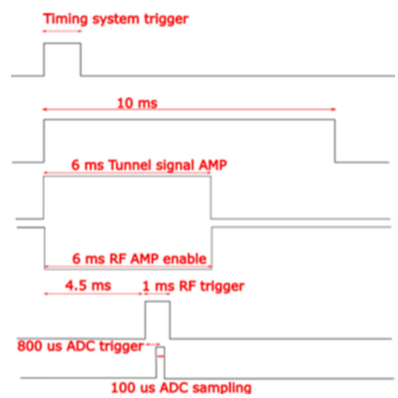

Figure 5: Timing and triggers.

Another application where custom hardware was developed for the BSM is a set of adjustable bipolar constant current power supplies for the corrector and banding magnets. They are used to adjust the position of the electrons on the screen and to filter out higher energy electrons produced by the H^- beam on the main accelerator. They are based on the LTC188 operational amplifier from Linear Technologies which target similar applications. It accepts a 0-5 V input from the analog output of the I/O card and adjusts the magnet current in the range of -500 to 500 mA.

SYSTEM EVALUATION

RF Section

After the first prototype of the BSM electronics was put together and verified that it operates properly the phase shifter had to be calibrated. This is done by connecting a network analyser usually at the first RF coupler or at the return from the cavity. The other port is used with an oscilloscope to monitor the RF amplitude. Phase is set in the

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control screen in fine steps and the phase at the network analyser is recorded. After several measurements it was established that the measured phase differs less than 0.5°from the set phase and it is not affected by the input power. The RF amplitude on the other hand has a dependence on the RF phase as shown in Fig. 6. It varies by around 10% while stepping through the phase. This is caused entirely by the phase shifters, for different phase they show different attenuation with a non-linear dependence There is an almost linear area that spans across almost 200° of phase shift. In the case this range will not be enough the acquired data can be corrected based on the phase-amplitude measurements.

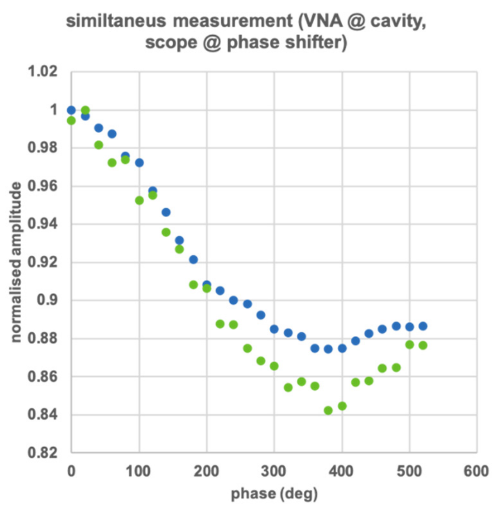

Figure 6: RF amplitude dependence on RF phase.

BSM Sample Measurements

Figure 7 shows the main BSM control screen on the left and sample images of beam profiles on the right. The new screen simplifies BSM operation for users offering a quick and intuitive way to select setpoints. Since the system has been operating already, the users at the BTF are aware of the best operating settings so minimum tuning is required.

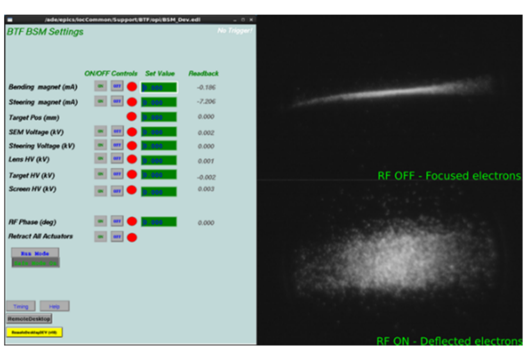

Figure 7: Screenshot of the BSM control screen with sample measurements.

The already developed BSM control software based on NI LabVIEW was used as a basis and simplified for the BTF BSM since using a screen instead of a SEM does not require a phase scan. A LabVIEW-Epics gateway allows integration with the general SNS control system which extends to the BTF as well. Several new EPICS process variables were created for the additional controls, setpoints and readbacks of the new hardware. Fig. 7 on the right shows two sample beam profile measurements. On the top, the RF deflector is deactivated, and the focused bunch of electrons is imaged on the screen. Here the operator can adjust the focusing field where the signal intensity is maximized if there is no distortion, the steering electric field is used to centre the image. On the bottom part of Fig. 7 the RF deflector is activated and spreads the electron bunch across the screen. The vertical profile as imaged on the screen is the longitudinal beam profile transforming the temporal structure of the impinging proton beam to spatial structure on the screen. The vertical dimension of the profile corresponds to the 35 ps of bunch length. Different beam energies can be selected by inserting a slit in the beamline and scan the proton beam on the slit with a dipole magnet.

CONCLUSION

The Bunch Shape Monitor at the Beam Test Facility was successfully upgraded using modern electronic components. The main shortcomings of the past system have been addressed and rectified. From the so far user experience the system is extremely stable and easy and quick to setup. From the maintenance perspective, the use of off the shelf components mainly allows to swap out parts quickly too. Currently there are four more devices being built based on the BTF prototype getting ready for deployment at the main accelerator. Looking forward, the nest steps of this effort include the design of an improved light collection system, a new design for the RF cavity and migration of the control system to the NI compact RIO platform.

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