BUNCH SHAPE MEASUREMENTS AT THE NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY ReAccelerator (ReA3)*

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Abstract

The longitudinal bunch shape of a reaccelerated heavy-ion beam at the National Superconducting Cyclotron Laboratory's (NSCL) ReA3 beamline was measured using an Ostrumov-type bunch-shape monitor. The phase of the last accelerating cavity was varied to change the bunch length, while the energy was kept constant by adjusting the amplitude of the voltage on the cavity. Two peaks were observed in the longitudinal projection of the bunch shape distribution. The widths of the two peaks did not vary much when the cavity phase was changed, while the peak separation decreased to the point that the two peaks became unresolvable as the bunching was increased. The relative amplitudes of the two peaks was very sensitive to tuning parameters. This, coupled with a lack of information about the transverse profile of the bunch, complicated the analysis and made a simple width assignment difficult. Measurements were also made with an MCP timing grid for comparison. The general shape and trend of the two data sets were similar; however, the widths measured by the timing grid were about 30-50% smaller.

INTRODUCTION

We have utilized a borrowed bunch shape monitor (BSM) [1] to perform measurements at the ReAccelerator (ReA3) facility at the National Superconducting Cyclotron Laboratory (NSCL) [2,3]. For this measurement, a beam of ^{42}Ar was stopped in a gas stopper and subsequently reaccelerated by ReA3. The beam had a pulse structure at 5 Hz with a duty factor of 20%, and an average current of about 6-30 epA.

The ReA3 accelerator uses prototypes of the RF cavities for the Facility for Rare Isotope Beams (FRIB). Bunch-shape measurement is required at the charge-stripping area of the FRIB accelerator. The experience and understanding gained in this set of measurements will help to reduce future development cost of the bunch-shape monitoring system for FRIB.

A schematic showing the principle of operation for the BSM is shown in Fig. 1. Secondary electrons are emitted when beam ions strike a tungsten wire. The wire is held at a large negative potential (up to -10 kV), which causes the electrons to accelerate away. A collimating slit selects a narrow beamlet of electrons. These collimated electrons pass between RF deflection plates which provide transverse modulation of the electrons. The deflector is synced to the accelerator frequency (ω = 80.5 MHz).

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The electrons, now spread transversely, impinge on an MCP, and a camera is used to view the electron distribution on the phosphor screen. Varying the phase offset (φ_0) between the deflector and accelerator shifts the spatial distribution on screen.

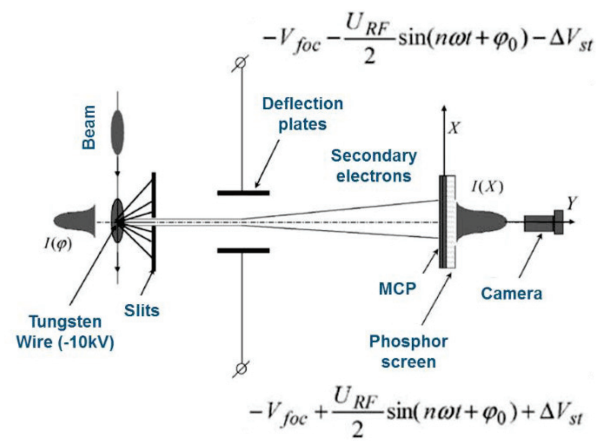

Figure 1: Schematic of bunch-shape measurement technique, adapted from Ref. [1].

DATA

The raw greyscale images from the camera are averaged over 127 captures, and then a threshold is applied on the intensity to produce black and white images as shown in Fig. 2 (top). These are projected onto the horizontal axis to produce a one-dimensional waveform of the longitudinal bunch shape, as shown in Fig. 2 (bottom). Three waveforms were recorded at each RF deflection phase, with a variance of about 10% of the peak intensity. A running average reduces this to about 3%.

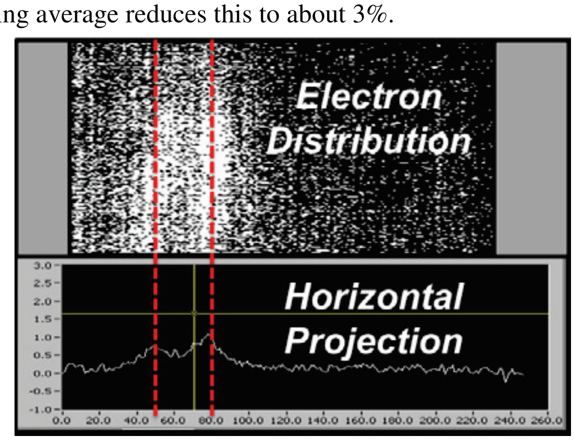

Figure 2: (top) Raw camera image showing the electron distribution intensity. (bottom) Projection of the distribution onto the horizontal axis.

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ANALYSIS

Background Subtraction

For each measurement, the RF deflector has a fixed phase offset relative to the beam. As the deflector phase is varied, the position of the electron distribution on the screen changes. To extract the background, we first adjusted the phase so the peak (corresponding to beam bunch) was on the far left (to get the background for right side). Then we changed the phase until the peak was on the far right (to get background for the left side). These two measurements are shown in Fig. 3, along with the extracted background.

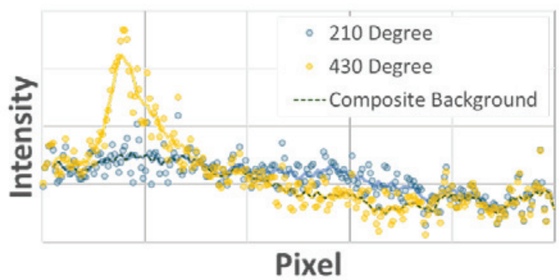

Figure 3: Background from two measurements.

Calibration

The calibration of the camera image "pixels" to equivalent "degrees" of phase in the beam bunch can be obtained by plotting the position of the bunch in the image against the deflector phase. An example of this is shown in Fig. 4. This relationship is actually sinusoidal, as shown in the top of Fig. 4, but we get better phase resolution (more pixels per degree), as well as almost linear calibration, if we stick to phases near the inflection point of the sine wave, shown with the blue box in Fig. 4. Using the position of either peak in the distribution gave similar calibration, as can be seen in the bottom of Fig. 4.

Experimental Complications

One issue we faced was the low duty factor of the pulsed beam, coupled with the lack of trigger for the camera and data acquisition. Practically, this meant that half or more of the acquired images were taken between pulses, greatly decreasing our signal to background ratio.

Another complication is illustrated in Fig. 5. During some of the measurements, the beam current dropped significantly. Retuning of the beam was required in order to continue taking measurements. Although the cavity phases were not adjusted, the beam shape changed, as can be seen in Fig. 5. There is one, taller peak in the distribution before the retuning, with perhaps a small shoulder. After retuning, the peak is smaller, and the small shoulder is approximately equal amplitude.

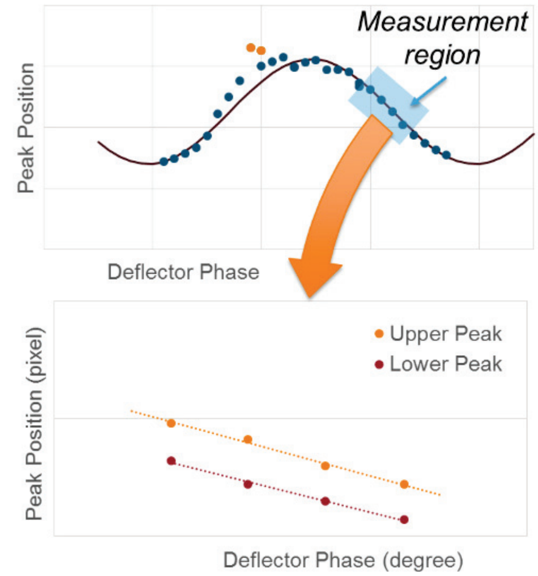

Figure 4: Calibration of the pixel-phase relationship.

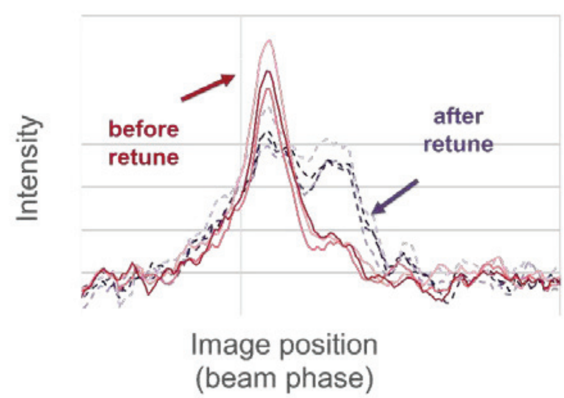

Figure 5: Bunch changes after tuning higher current.

RESULTS

Bunch Shape

The bunch shape measured for three bunching conditions are shown in Fig. 6. These bunching conditions are achieved by setting the last ReA3 cavity phase to -15, -30, and +15 degrees. The standard operating condition is at -15 degrees, while the bunching is increased for -30 degrees, and there is debunching at +15.

There are two peaks in the measured bunch shape distribution. A double Gaussian fit was used to approximate the bunch shape, and the systematics of the fit parameters were analyzed. The width of each peak did not vary much when the cavity phase was changed, but the peak separation decreased and peaks became unresolvable with increased bunching.

For comparison, measurements were also taken with an MCP grid timing system. These are shown in Fig. 6 as well.

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Bunch Width

The complex bunch shape means that typical width measures (e.g. FWHM) do not give robust values that reflect the overall size of the bunch. In addition, the sensitivity of the two peak amplitudes to tuning (Fig. 5) meant that it would be easy to underestimate the bunch width, if one peak amplitude was very small. Therefore, the width near the base of the bunch shape was used. These values are shown in Table 1 for both the BSM and the timing grid.

The systematics under different bunching conditions are as expected – there is more bunching, and thus a narrower width, when the ReA Cavity phase was changed from -15 to -30 degrees.

Table 1: Extracted Bunch Widths from BSM and Timing Grid (TG) for Three ReA Cavity Phases

ReA Cavity Phase:	**-15 deg**	**-30 deg**	**+15 deg**
BSM width	92°	84°	69°
TG width	70°	52°	50°

Comparison to Timing Grid Measurement

As mentioned above, measurements were also made with an MCP timing grid for comparison. The general shape and trend of the two data sets were similar, as seen in Fig. 6. There are two, well-separated peaks in the bunch at -15 degree cavity phase, while at -30 degrees, there is only one (or perhaps two closely overlapping peaks). The width at +15 degrees should be larger than that at -15 degrees, but for both measurement systems, the width was narrower at +15 degrees. Our guess is that this could be due to different tuning conditions during the measurements at the two phases.

Although the general shape and trend of the measurements were similar, the widths measured by the timing grid were about 30-50% smaller than those measured by the BSM. Again, this may be due to differences in tuning during the two sets of measurements.

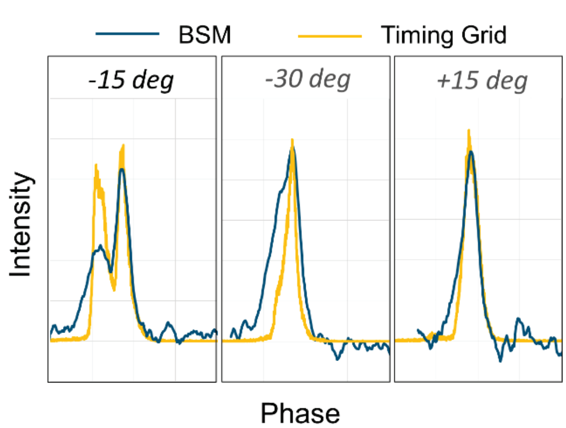

Figure 6: Bunch shapes measured by BSM and timing grid under three different bunching conditions (ReA cavity phases -15, -30, and +15 degrees).

CONCLUSION

Discussion

We successfully measured bunch shape at the NSCL Re-Accelerator. The beam was $^{42}Ar^{17+}$ pulsed at 5 Hz with a duty factor of 20%, and an average current of 6-30 epA. The shape and length of the beam bunch was changed by varying the phase of the last ReA RF cavity.

There was a significant effect on the bunch shape from uncontrolled tuning parameters, for example when tuning to increase the beam current. This made simple width assignment impossible, and made it difficult to compare between measurements.

Differences between the BSM and timing grid are about 30-50%. It is likely that this is partly related to differences in the tuning during the measurements, and possibly also non-linearity of the calibration.

Improvements

One very troublesome issue was the poorly understood effect of uncontrolled tuning parameters. In order to minimize this effect, we plan to take BSM and timing grid data sets under consistent beam conditions. In addition, we would like to take data at more ReA cavity phases (bunching conditions) to understand the systematic trends more clearly.

There are several areas for improvement possible in this bunch shape measurement. We can reduce the background by syncing the acquisition to the beam-pulse frequency, or triggering the camera image capture with the pulsed beam.

Additionally, taking more data for each measurement will result in a lower uncertainty and higher resolution. However, the acquisition system limits the number of image captures that are averaged into a single waveform. It also requires one to save snapshots manually. Switching to a continuous or automatic acquisition will streamline the data taking, and avoid both these problems.

ACKNOWLEDGMENT

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