

ELECTRON SCANNER FOR SNS RING PROFILE MEASUREMENTS*

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Abstract

An electron scanner has been commissioned to non-destructively measure the transverse profiles in the Spallation Neutron Source (SNS) Ring. The SNS Ring is designed to accumulate on the order of 1.6×10^{14} protons with a typical peak current of over 50 Amps. The electron scanner works by measuring the deflection of 50-75 keV electrons by the electric field of the proton beam. Two electron guns, one for each plane, with dipole correctors, quadrupole magnets and deflectors to shape the electron beam have been installed. This paper describes the system and the initial results.

INTRODUCTION

The electron scanner is the first instrument to measure the transverse beam profiles in the SNS accumulator ring. Alternative profile monitors such as wire-scanners were planned but not installed due to budget restrictions. The electron scanner projects electrons accelerated up to 75 keV through the proton beam as depicted in Fig.1.

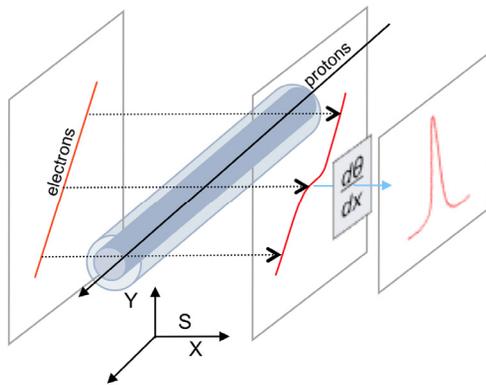


Figure 1: The deflection of the electrons.

The transverse profile is derived from the angle of deflection of the electron beam according to the following formula, see also [1,2,3]:

$$\frac{d\theta}{dx} = \int_L \frac{e}{mv^2} \cdot \frac{\delta(x,y)}{\epsilon_0} dy$$

where e , m are the electron charge and mass, respectively, v is the velocity, $\delta(x,y)$ is the proton beam density distribution, and θ is the electron beam deflection angle.

This assumes that the path of the electrons is approximately straight, the net energy change to the

* ORNL/SNS is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725

electrons by the proton beam is close to zero, and the effect of the proton magnetic field can be neglected.

ELECTRON SCANNER HARDWARE

The electron scanner layout is depicted in Fig. 2. The different parts are: (1) electron gun, (2) deflection scan system, (3) dipole correctors, (4) quadrupole magnets, (5) vacuum chamber for proton beam, and (6) the phosphor screen.

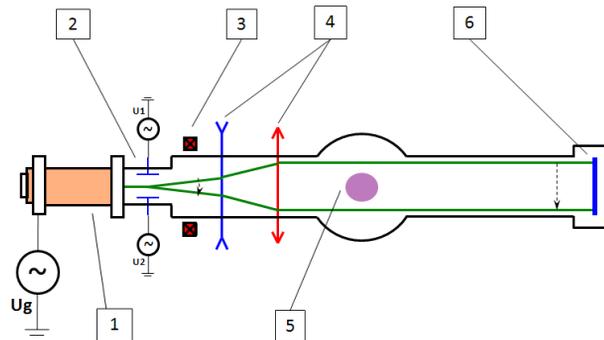


Figure 2: Diagram of electron scanner.

The electron gun produces a pulse of about 1 usec of up to 75 keV electrons with a maximum current of 5 mA. The scan system applies a 20 nsec long ramp to the deflectors to project the electrons on a diagonal line. The diagonal projection makes the deflection of the electrons by the proton beam visible as a deviation from a straight line. The first quadrupole extends the range of the deflection while the second quadrupole focuses the electron beam such that the electron beam is parallel. The electron gun is pulsed once a second but faster rep rates of up to 5 Hz are possible. The time line is shown in Fig. 3. To minimize the electron beam size, the cathode heating is turned off for a few milliseconds before the acceleration pulse.

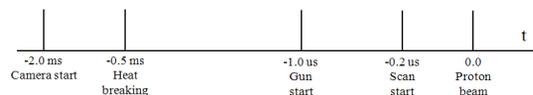


Figure 3: Time diagram.

One vertical and one horizontal scanner are installed in the tunnel, see Fig. 4. GigE Vision CMOS cameras acquire the images from the fluorescent screens. Because the scanners are located in a straight section of the ring, the radiation levels are low enough to not damage the cameras. A single PXI-based computer running LabVIEW controls the cameras, timing, pulse generators and power supplies of the electron scanner.



Figure 4: Electron scanner installation.

ELECTRON SCANNER SOFTWARE

The software for the electron scanner consists of four parts:

- Control software that controls the electron scanner hardware, including the timing.
- Simulation software that simulates the projection of the electrons and creates test images for the Analysis software.
- Imaging software that acquires the image of the projected electrons and analyzes the curve to determine the transverse profile.
- Scan software that manages the Control software and the Imaging software to perform multiple acquisitions and produces 3-dimensional images of the beam bunch, e.g. a longitudinally integrated profile.

Both the Imaging and the Scan software interface to EPICS so that the physics applications on the consoles can readout the results.

Image Analysis

The analysis has to take the derivative, dy/dx , of the curve to determine the profile. Because taking the derivative of data, especially pixel data from the camera, can provide noisy results, different analysis methods were tested ahead of commissioning using the Simulation software. These methods were: (1) find the peak in each column of pixels to find an (x,y) pair and take the derivative of all (x,y) pairs, (2) find the peak of a Gaussian fitted to each column of pixels to get an (x,y,z) pair (with z the intensity of the peak), then fit these pairs with a spline and take the derivative of the fit, or (3) fit a spline to all pixels weighted by intensity, and take the derivative of the fitted spline, see Fig. 5. The smoothing provided by the spline and Gaussian fit in method (2) most effectively mitigated the image noise problem and thus yielded the most reliable results. The spline fitting can find a profile even if there are gaps in the electron curve due to low electron density.

05 Beam Profile and Optical Monitors

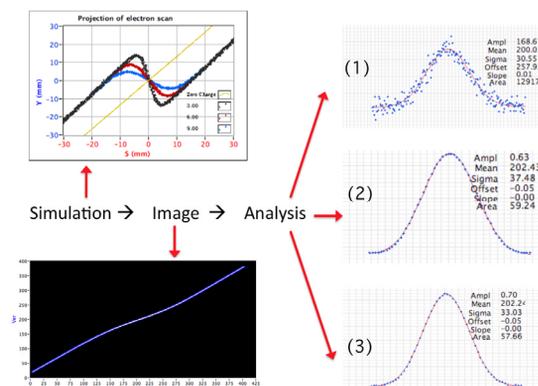


Figure 5: Simulated Electron projections, the generated image and the different profile analysis fittings.

RESULTS

An example of the horizontal projected electron curve is shown in Fig. 6. This data is taken at about 5uC. The bright spot on the right consists of electrons that are outside the 20 nsec deflection scan waveform but still are accelerated by the 1u sec long accelerating pulse.

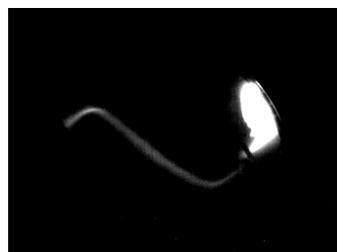


Figure 6: Image of the electron curve.

Because the length of the scan is short, 20 nsec, compared to the bunch length of 600 nsec, we can perform scans at different locations within the bunch. By performing scans at regular intervals throughout entire bunch length, we can create 3-dimensional plots of the bunch, as shown in Fig. 7. The double peak is in the longitudinal direction and is confirmed by the Ring Current Monitor waveform.

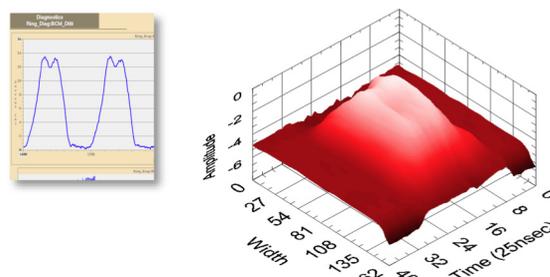


Figure 7: Shown on right is the 3-D profile for a 4 uC bunch in the accumulator ring. The width axis represents the transverse axis of the beam and is given in pixels with 0.3 mm per pixel. The time axis represents the longitudinal axis of the beam and is given in 25 nsec per count. Shown on left is the longitudinal profile as given by a ring beam current monitor.

In addition to viewing different profiles within a single turn, we can also view profiles for any turn during the accumulation cycle. Profiles from multiple accumulation turns, 50/100/200/300/400/500, are shown in Fig. 8. This figure also shows the projection in the longitudinal direction to show the equivalent beam current profile. For this proton beam configuration, the vertical range of the electron scanner is too small for the current proton beam accumulation and thus the profile is truncated.

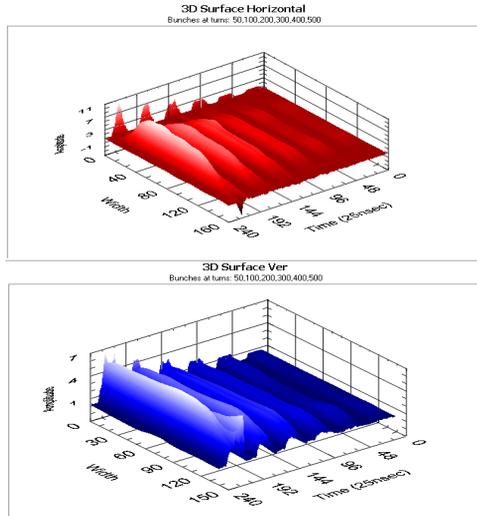


Figure 8: Multiple bunches from both the horizontal (red) and vertical plane (blue) are shown. Width is in pixels at 0.3 mm per pixel. The time scale is in 25 nsec per count.

Evaluation

To verify the results of the electron scanner, we have performed an initial comparison of profiles with the profiles from a Harp located in a downstream transport line for a number of beam configurations, see Fig. 9.

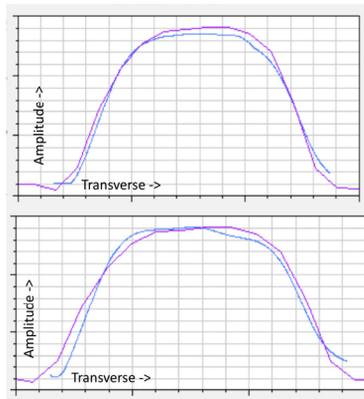


Figure 9: Integrated ELS profiles (purple) of 2.8 μ C (top) and 6.8 μ C (bottom) of beam at the 620th turn compared to Harp profiles (blue). Profiles are normalized in RMS and area in order to compare only the shape.

For accurate comparison with Harp results, the ELS profiles were integrated over the full pulse length (600 nsec) in the manner described in the previous

section. This comparison was performed for production-style ring beams of various intensities.

To account for optics differences between the ELS and the downstream wire scanners and Harp, the profiles were normalized to the same width and area. The shape of the profiles obtained from the ELS was generally in good agreement with downstream Harp data, especially at high intensity. At the lower intensity settings, the ELS profiles were somewhat broader, though the Harp data was rather noisy and possibly unreliable at these beam intensities.

Individual profiles from 20 nsec slices were qualitatively assessed for a number of beam configurations, including hollow beams and painted beams of various intensities. The profile shapes consistently reflected what was expected for the configuration at hand. A few issues of concern, which are currently under investigation, are the absolute scale of the ELS profiles (in mm), and an artificial tilt of the profile floors.

DISCUSSION

Despite the aforementioned minor problems, the electron scanner has been successful in providing a means of parasitically measuring the ring beam transverse profiles. The ability to obtain profiles for individual 20 nsec slices of beam anywhere along the 1 msec accumulation cycle is a useful feature unavailable in the downstream Harp and wire scanners.

Already some improvements have been made to the electron scanner. The timing jitter has been reduced to improve the accuracy of the longitudinal dimension of the 3-D profile. We replaced the cameras with more light sensitive cameras to improve the visibility of the projected electrons. We found that stray magnetic fields from the ring magnet’s bus bar and a nearby corrector dipole affected the path of the electrons. This likely is the cause of the tilt in the measured profile. We plan to magnetically shield the electron scanner. Also, the aperture for the vertical profile is too small and the next version of the electron scanner will remedy this.

SUMMARY

This paper described the successful commissioning of the prototype electron scanners with good qualitative results. Work is in progress to verify the absolute scaling of the profiles and install magnetic shielding.

REFERENCES

- [1] P.D. Goldan “Collisionless Sheath---An Experimental Investigation”, Phys. Fluids 13, 1055 (1970), DOI:10.1063/1.1693008.
- [2] E. Tsyganov et al, "Electron beam emittance monitor for the SSC", PAC1993, pp.2489-2491.
- [3] A. Aleksandrov et al, "Feasibility Study of Using an Electron Beam for Profile Measurements in the SNS Accumulator Ring", PAC 2005, pp. 2586-2588.