

SNS TARGET IMAGING SYSTEM SOFTWARE AND ANALYSIS*

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Abstract

A new Target Imaging System (TIS) has been installed to directly measure the size and position of the proton beam on the Spallation Neutron Source (SNS) mercury target. The proton beam, hitting a luminescent coating on the target nose, produces light that is transferred using a radiation-tolerant optical system to an image acquisition system integrated with the accelerator controls network. This paper describes the software that acquires and analyzes the image, how the system has been integrated with the SNS control system, and compares the TIS results with the indirect methods of calculating the peak densities of the proton beam.

INTRODUCTION

The Spallation Neutron Source at Oak Ridge National Laboratory now commonly operates with approximately one megawatt of beam power on the Mercury target. Each beam pulse, repeating 60 times a second, consists of about 10^{14} 1GeV protons and lasts less than 1 microsecond. The protons hit a stainless steel target filled with mercury to produce the neutrons for the experiments. The protons damage the target and this damage depends on the beam's peak power and transverse profile [1].

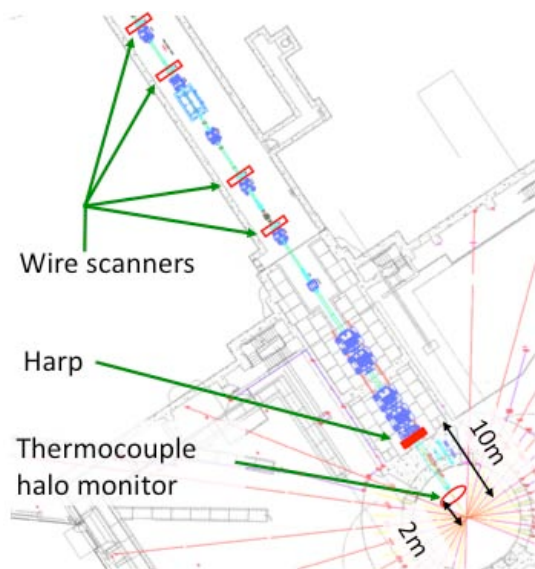


Figure 1: RTBT Instrumentation.

To assure the target lifetime, the operational procedure is to limit the beam's peak density on the target. The RTBT (Ring to Target Beam Transferline) Wizard program combines wire-scanner and harp measurements with the beam-line lattice parameters to calculate the

beam size at the target. The harp is the only instrument in the RTBT that measures the transverse profile of the beam during production, see Figure 1. The RTBT Wizard produces scale factors that allow conversion of the measured beam size at the harp to an estimated beam size on the target. The harp program can then calculate the estimated peak densities on the target. If these peak intensities start to exceed the administrative limits, beam power is reduced or the transverse size is increased.

With the TIS, we can now obtain a more direct measurement of the peak intensities and use this system to safeguard the target.

SYSTEM OVERVIEW

A target imaging system was available during the commissioning of SNS and measured the first beam on target. To keep the system simple, it consisted of a fluorescent screen mounted in front of the target and a camera in the target room. It was understood that this system wouldn't last long before the radiation damage would permanently disable the system. The system showed the first beam on the first installed target and its measurements were used to estimate the spread of the beam due to scattering of the protons when passing through the proton window. This success started the drive for a permanent target imaging system. After evaluating various configurations, the choice was made to coat the actual target nose with a layer of Cr:Al₂O₃ and to use mirrors and a fiber bundle to bring the light out to the camera in a non-radiation environment [2,3].

System Configuration

A radiation resistant aluminum parabolic mirror collects the light from the fluorescent coating of the target. This is followed by a turning mirror and then lenses that focus the image onto a fiber bundle. Figure 2 shows the optical path through the target shielding.

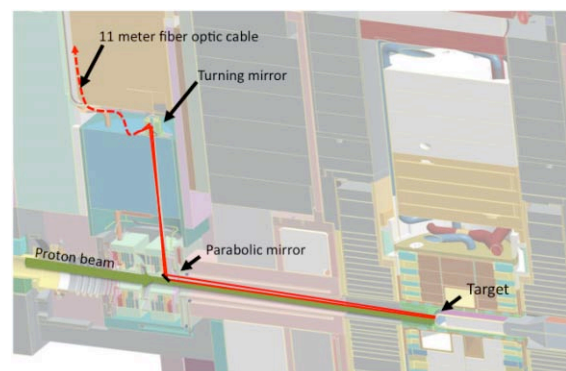


Figure 2: View of optical path with shielding.

The radiation resistant optical fiber bundle is made of 10,000 individual fibers and brings the light out to a non-

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radiation environment. This allows us to pick a camera that is not radiation resistant. The Prosilica GC750 camera was chosen for the initial installation because of previous experience with this camera and available acquisition and analysis software. Its light sensitivity was tested and found to be sufficient.

The camera is interfaced to a rackmount PC using the GigE Vision interface. The PC runs LabVIEW, which includes a driver to support the camera. A LabVIEW

program acquires and analyzes the images from the camera. The results are shared with the rest of the control system over Channel Access. The camera's acquisition is triggered 4 microseconds after the beam hits the target within which time the gas scintillation has died down but the coating is still fluorescing. The overall configuration is shown in Figure 3. The TIS has been in operation for over 2000 MWHrs with the second SNS Target [4].

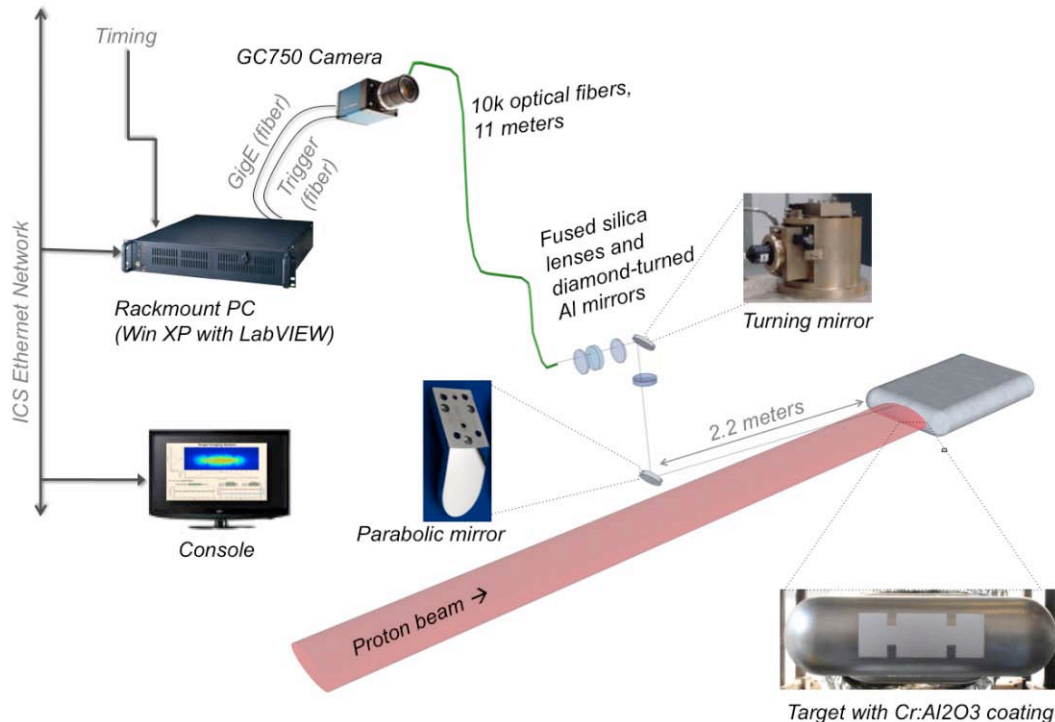


Figure 3: The configuration of the Target Imaging System.

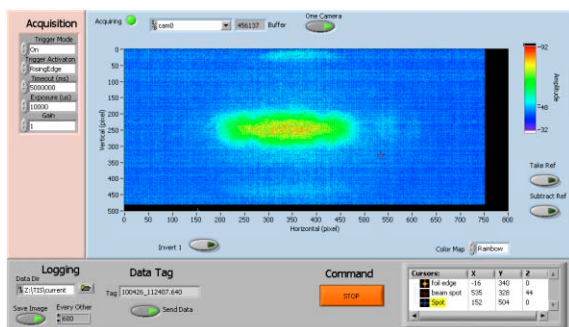


Figure 4: The image acquisition software.

IMAGE ACQUISITION

The image acquisition software, see Figure 4, allows the user to set up the camera exposure, trigger mode, and gain. The user can optionally save the images to disk. The SNS Timing card in the rackmount PC provides the trigger pulse to synchronize the camera to the proton beam.

ONLINE ANALYSIS

The goal of the online analysis is to produce RMS width, position, and peak density estimates during production. The light that is visible outside the coated area is ignored. If the beam is larger than the coated area the shape is extrapolated using the fitted function. The estimates are then calculated from the extrapolated fitted function. To calculate the peak density, we obtain the charge of the beam from the nearest beam current monitor but reduce this charge by 4% to account for estimated loss due to nuclear scattering from the proton beam window.

Preprocessing

The image analysis first optionally preprocesses the image to get rid of the fiber patterns by taking the average of the top pixel values of all pixels within a square window. The goal is to reduce the variation in profile values when the image data is projected vertically and horizontally as seen in Figure 5.

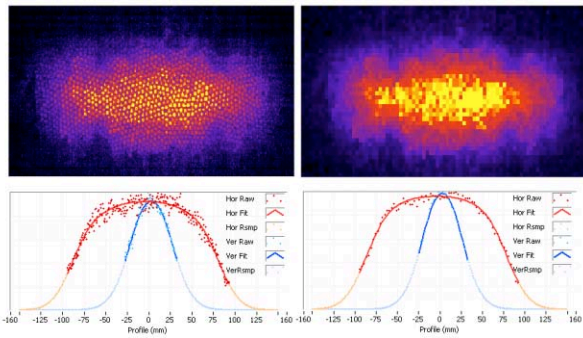


Figure 5: The fiber pattern in the image is removed by the preprocessing thus cleaning the projected profiles.

Profiles

To obtain a horizontal and vertical profile, subsections of the image are taken that are within the coating of the target but excluding the markers. The pixels in these subsections are projected to the vertical or horizontal axis to produce the profiles.

Fitting

The next step is to fit an analytical function to the profiles. Due to the injection scheme at SNS, the beam's transverse profile can significantly differ from a Gaussian function. Even a combination of two Gaussian functions cannot quite match the slope of the profiles. A super Gaussian function (with the absolute value taken of the term within the power within the exponent), however, can provide a good match for the profiles observed by the TIS and also by the upstream wire scanners and harp. The program used to evaluate different functions is shown in Figure 6. Several functions, including double Gaussians, quadratic modulated Gaussians, and super Gaussian functions were tested. The super Gaussian provided the

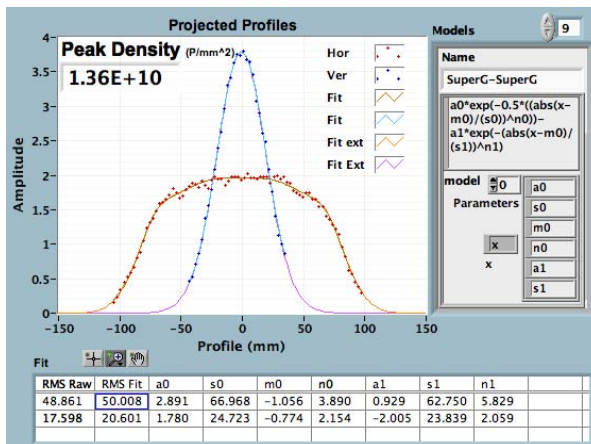


Figure 6: Program to evaluate different fitting functions for the TIS.

best results with the least amount of parameters, see also [5].

The super Gaussian function is as follows:

$$y = a \cdot \exp\left(-0.5 \cdot \left(\text{abs}\left(\frac{x - \mu}{\sigma}\right)\right)^n\right)$$

The background level is already zeroed using a default value or a value automatically derived from a part of the image and is not part of the fit. Varying the order of the super Gaussian allows adjustment of the flatness of the peak and the steepness of the slopes. The on-line analysis can fit a single super Gaussian or a double super Gaussian with a common centroid.

An example of the super Gaussian fit is given in Figure 7. The plot shows the fits, xFit and yFit, to the profile data xProj and yProj. The super Gaussian has typically an order of about 4 for the horizontal profile and an order of about 2 for the vertical profile. With the estimated parameters of the function the profile outside of the coating area is reconstructed, xFit Rsmpl and yFit Rsmpl, and the RMS width and peak density are calculated.

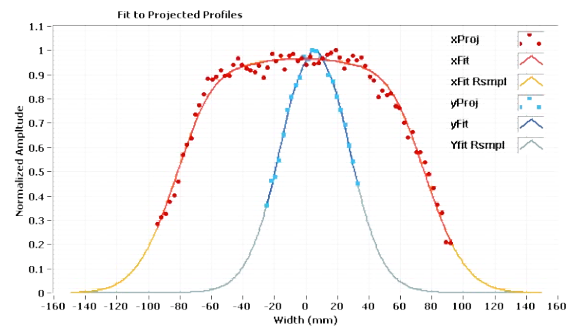


Figure 7: The reconstruction of the profile using a super Gaussian.

Under certain circumstances, such as fewer bunches in the Ring, the center of the profile can be hollow and the double super Gaussian is a good match for this situation, see Figure 8. Other more peaky profiles are possible as well but unlikely during normal operation and most studies.

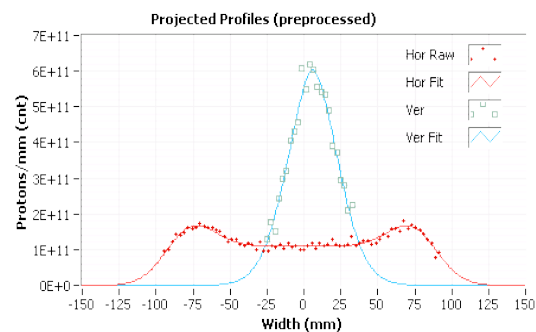


Figure 8: An example of a double super Gaussian fit for the horizontal profile.

The analysis program calculates for each image the beam parameters such as RMS width, position, peak density but also the efficiency of the image in terms of protons/count (count being the intensity of an image

Comparison with predicted beam properties

Data from the imaging system was analyzed with 3 independent fitting methods and then the results were compared to the RTBT Wizard predictions. Several cases of varying beam size and proton pulse intensity were analyzed. The TIS images were fit by super Gaussians functions with Mathematica and LabVIEW. Two-dimensional fits were also done over the entire coated region using Excel with either two or three Gaussian functions with different center locations. In general, good agreement was obtained between the three image fitting methods. In comparison to the RTBT Wizard predictions, the image system gave larger vertical RMS beam size by several mm and lower peak densities as shown in figure 12. The agreement with horizontal RMS sizes was closer, but still slightly larger for the TIS fits.

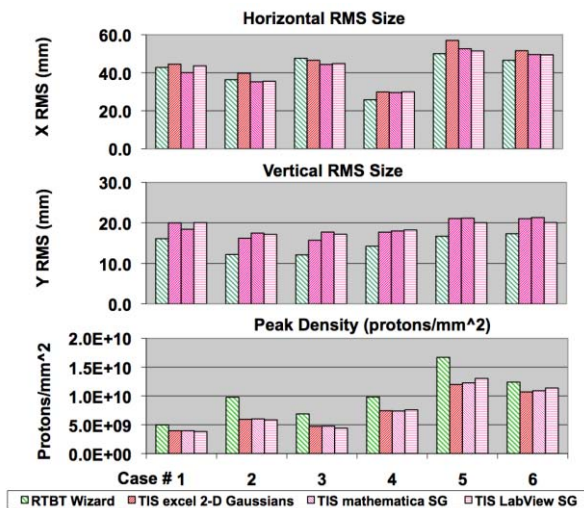


Figure 12: Comparison of size and peak density using the image system with 3 independent fitting methods and the RTBT Wizard projection.

Uncertainties

Additional studies are needed to evaluate effects that could broaden the profile measured by the TIS. Potential light sources include fluorescence caused by gamma and neutron backscattering from the target (which have a broader profile than the beam), reflections from uncoated regions and light from the helium in the beam path. Also, blurring of the image caused by chromic aberration or poor focusing could cause the apparent size to increase. There are also some uncertainties in the model used by

RTBT Wizard. For example, the lattice functions have an uncertainty of about 20%. Effort to understand the discrepancy continues and lessons learned will be incorporated into future deployments of the imaging system.

CONCLUSIONS

The TIS provides a new capability to track changes and make on-line measurements of the peak density during production. The system has a demonstrated lifetime of over 2000 MW-Hrs and the current rate of degradation is minimal. We still have to do further work to improve the agreement between the RTBT Wizard predictions and the TIS results to further reduce the uncertainty in the peak density. The desire is to make this the primary tool to align beam on the target and assure the target lifetime by monitoring the peak density.

ACKNOWLEDGEMENTS

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