ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP016

NEW CENTRING BEAM MONITOR FOR HIGH POWER PROTON BEAM ROTATING TARGET

P.-A. Duperrex†, P. Baumann, S. Joray, D. Kiselev, D. Laube, D. Reggiani
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

Abstract

The high intensity proton accelerator (HIPA) at the Paul Scherrer Institute (PSI) delivers 590 MeV c.w. proton beam with currents of up to 2.4 mA, i.e., 1.4 MW beam power. For experiments of nuclear and material research the beam is directed to the 4 or 6 cm graphite 1 Hz rotating target (Target E). Centring the beam on the target is an important task for the operation and has safety issues in case of beam misalignment. Transmission monitoring has been the standard method to optimize the beam position on the target, though not very sensitive. A new method is currently being tested that provides a more sensitive off-axis detection. It is based on the detection of beam intensity modulation from the milled grooves at the target edge. This paper presents the concept and preliminary experimental results that can be obtained with this method.

INTRODUCTION

At the 1.4 MW high intensity proton accelerator facilities (HIPA) at Paul Scherrer Institute (PSI), the proton beam is accelerated from a Cockcroft-Walton source followed by two cyclotrons: the so-called Injector 2 cyclotron accelerating the beam from 870 keV to 72 MeV and the so-called Ring cyclotron accelerating it to 590 MeV. The beam is then directed through 2 meson graphite targets (Target M and E) to the spallation neutron source SINQ [1]. The energy deposit on Target E is 20 kW mA^{-1} with a beam 2-sigma width of 1.5 mm in the horizontal direction and 1.7 mm in the vertical direction.

The correct centring of the beam on the Target E is important since the rim of the wheel is only 6 mm wide. Missing partly the target would not only reduce the meson production rate but also leads to a pencil beam hitting the SINQ target window, which could not withstand such power densities.

Transmission minimization has been the standard method to center the beam position on the Target. The transmission is the ratio of the beam current measured after and before the target. For this method, a beam position scan is performed to identify the range and the optimum position corresponding to the minimum transmission. This is however an indirect measurement and is not very sensitive.

The new method currently being tested allows a more sensitive detection of off-axis beam conditions. The method is based on the detection of beam current modulations induced by grooves milled at the target rim. Evidence of these modulations is indicative of off-axis beam conditions, the modulation amplitude giving some information about how far off-axis the beam is located.

† pierre-andre.duperrex@psi.ch

EXPERIMENTAL SETUP

The Grooved Target

The Target-E for this experiment is shown in Fig. 1. The tests took place in the summer 2019 during 2 months, the target then had to be replaced due to bearing problems.

Figure 1: The Target-E used for the experiment.

The 60 mm wide rim of the target is divided into 12 segments. Between the segments a 1 mm wide gap allows for thermal expansions as well as dimensional changes due to irradiation.

The grooves on each segments are easily visible in Fig. 2. The spaces between each groove have been calculated so that, for a target rotating at 1 Hz, a beam current modulation at either 114 Hz (left off-axis) or 138 Hz (right off-axis) will be measured. These two frequencies have been chosen so that they are located exactly between two harmonics of the 12 Hz signal generated from the target blades.

Four groove milling depths were tested on this target: 0.3, 0.5, 0.7 and 0.9 mm on groups of 3 elements distributed equally to investigate the sensitivity of the detection and the possible physical defects. One groove on each side was milled deeper (1 mm) to act as an absolute marker (see Fig. 2).

ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP016

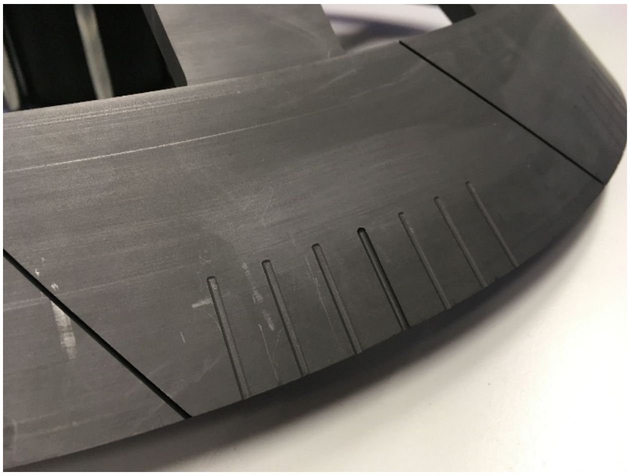

Figure 2: Detail of a segment showing the grooves. On that particular segment the middle groove is milled 1 mm deep (the other grooves of this segment are 0.3 mm deep). This groove acts as absolute marker.

Control of the Beam Position

The relative position of the beam on the target is controlled by a set of steering magnets. They have been used for this experiment to change the beam position on the target from -1.3 mm to 1.3 mm.

Beam Current Monitors

Two beam current monitors have been used for this study. They are resonators tuned at the 2nd harmonic of the RF (101.26 MHz). The first monitor, called MHC4, is located before the target and the 2nd one (MHC5) after it.

Measurement Chain

The beam current signals have been recorded using a 16-bit data logger at a 10 kHz sampling frequency. LabVIEW was used to remotely control the data logger, perform the modulation detection and to configure an EPICS server for easy access to the results.

Signal Processing

To detect the groove modulation on the MHC5 signal, it was necessary to filter the broadband noise already present on the signal. The MHC4 signal was used for that purpose. By subtracting the correctly weighted MHC4 signal from the MHC5 one, most of the noise contributions prior to the target E can be removed. An example of such filtering is shown in Fig. 3. The 12 Hz modulation from the blades are easily visible as well as a 1 Hz rotation wobbling.

The FFT of the filtered MHC5 is then performed to detect the possible presence of the 114 Hz or 138 Hz spectral lines, as well as their corresponding harmonics.

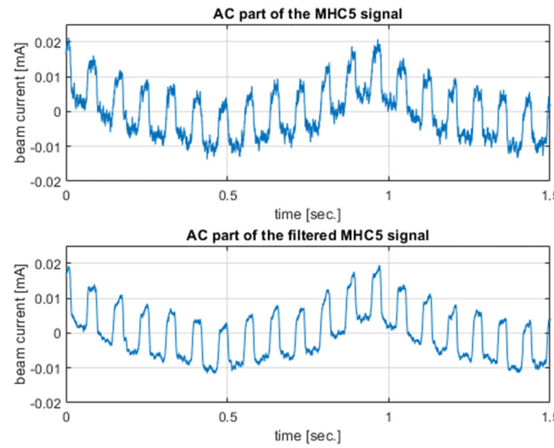

Figure 3: Raw and filtered MHC5 signals.

EXPERIMENTAL RESULTS

Figure 4 shows an example of the data for +1.3 mm beam off-set at beam intensity of 0.388 mA.

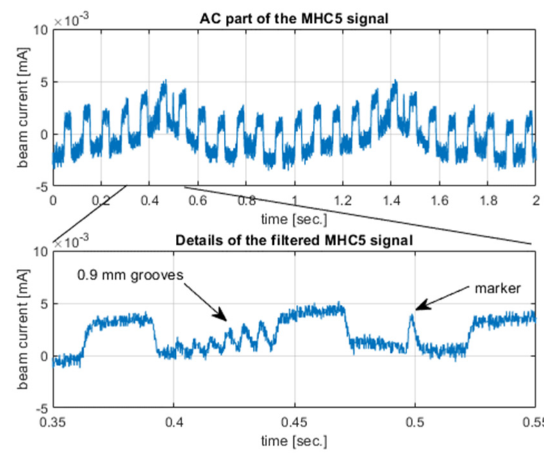

Figure 4: Example of modulations for off-axis position.

The beam intensity modulation due to the absolute marker on the first segment is clearly visible as well as the 138 Hz 0.9 mm groove effects.

The groove modulation level dependency on the off-axis beam position has been analysed for 1.6 mA beam intensity conditions. For this study, the beam position on the target has been changed from -1.3 to +1.3 mm with 0.1 mm increment. The 114 Hz and 138 Hz spectral line amplitudes have been measured for each position using the FFT routine and the results are shown in Fig. 5.

ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP016

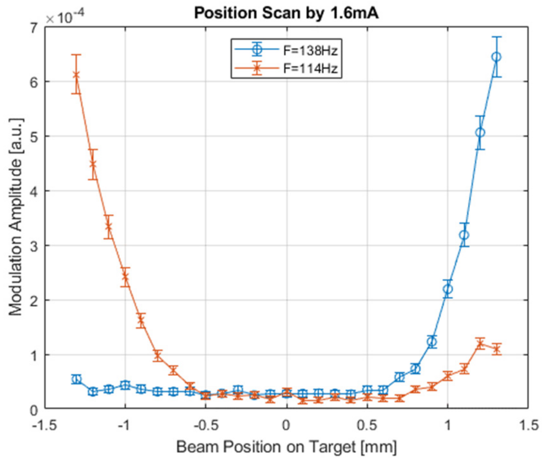

Figure 5: 114 Hz and 138 Hz spectral lines as function of the beam position on the target.

For centred beam conditions, no spectral lines at 114 Hz and 138 Hz are detected the noise level. For off-axis distance larger than 0.7 mm the spectral lines have been clearly detected. The non-linear dependency stems from the shape and profile of the beam.

To compare the performance of the new method with the transmission measurements, the transmission level as function of the beam position is shown in Fig. 6. The transmission is clearly much less sensitive compared to the groove modulation detection.

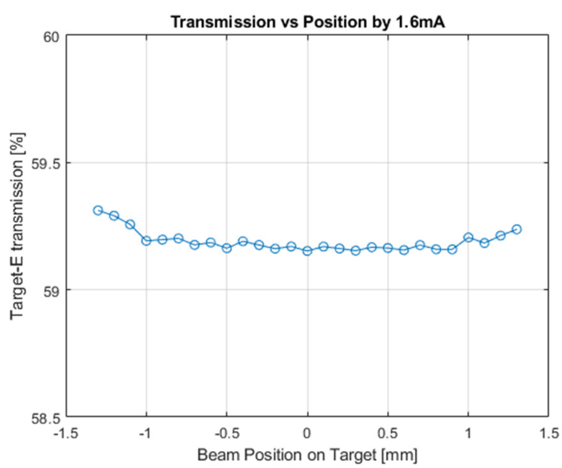

Figure 6: Transmission as function of the beam position.

DISCUSSION

The preliminary results show that the groove modulation method can detect an off-axis position of 0.7 mm or more in the present configuration. Using simple considerations, modulations are expected to appear for an off-axis position larger than 0.6 mm. Indeed, with a 6 mm target width, 2 sigma beam width of 1.5 mm and 0.9 mm deep grooves, one gets: 3 -1.5 - 0.9 mm = 0.6 mm.

Inspection of the target after 2 months of operation show no particular sign of damage like deformations or cracks even for the 0.9 mm grooves. It was a major concern that the milling of the grooves on both sides of the target rim would weaken the stability of the graphite.

This method may potentially lead to beam size estimate though more detailed analysis and simulation are needed. Indeed, measuring the exact modulation amplitude during a position scan should give an estimate of the beam width: a wider beam would generate a groove modulation for a smaller off-axis position, but the relative increase for larger off-axis position would not be as steep as for narrower beams.

This new method also overcomes some short-comings of the transmission measurements. It is more sensitive and it doesn't suffer from calibration issues faced by the MHC5 [2]. Indeed, the MHC5 resonator is exposed to the particles scattered from the Target-E. The resulting deposited power can heat up the resonator up to typically 130 °C. This has some direct impact on the stability of its calibration factor.

CONCLUSION

A method for measuring the beam position on the meson target Target-E has been tested during 2 months of beam operation in the summer 2019. It is based on the detection of beam intensity modulation from the milled grooves at the target rim. The results show that this method is sensitive enough to measure 0.7 mm off-axis conditions. These results motivate further development and optimisation to provide in the future a fully operational system.

REFERENCES

[1] D. Kiselev, P. Baumann, B. Blau, K. Geissmann, D. Laube, T. Reiss, R. Sobbia, A. Strinning, V. Talanov, and M. Wohlmuther, "The Meson target stations and the high power spallation neutron source SINQ at PSI", *in Proc. 27. Int. Conf. of the Nuclear Target Development Society (INTDS'14)*, Tokyo, Japan, Aug.-Sep. 2014, *J. Radioanal. Nucl. Chem.*, vol. 305, no. 3, pp. 769-775. 2015. doi:10.1007/s10967-015-3999-3

[2] J. Sun, P. A. Duperrex, and G. Kotrle, "Design of a new beam current monitor under heavy heat load", in *Proc. 54th ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams (HB'14)*, East Lansing, MI, USA, Nov. 2014, paper MOPAB48, pp. 154-156.