2D BEAM PROFILE MONITORS AT CPHS OF TSINGHUA UNIVERSITY

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Abstract

Beam profile is a key parameter for high current proton linac. Compact Pulsed Hadron Source(CPHS) has two type of detectors to monitor beam 2D beam profile: scintillator screen and rotatable multi-wire scanner. A retractable chromium-doped alumina (Chromox) screen is used as scintillator, emitted lights when impacted by proton are captured by a 12 bit CCD camera. Nineteen carbon fibre wires with a diameter of 30 μm, 3 mm separated from each other, are used to measure beam 1D distribution. Projection can be measured at different direction by rotating the multi-wire scanner about beam direction. 2D beam distribution is reconstructed from multiple projections with the help of CT. Different CT algorithms, Algebra Reconstruct Technique (ART) and Maximum Entropy algorithm (MENT), are applied to achieve accurate or quick reconstruction. The preliminary experimental results show the two profile monitors working consistently with each other.

INTRODUCTION

CPHS, a compact neutron source, consists of a 50-keV ECR ion source, a LEBT to match beam parameters between ion source and RFQ, a four-vane type RFQ that accelerates beam to 3 MeV, one DTL with permanent quadrupole and a beryllium target. Protons accelerated to 13 MeV hit on the Be-target to produce neutrons. In construction phase one only 3-MeV beam is obtainable so far due to the absence of DTL. In order to produce a neutron beam with uniform distribution and reduce target temperature, a uniform square shaped (35mm×35mm) proton beam is expected on the target. Thus monitoring beam profile, especially 2D profile, is essential for CPHS. As listed in Table 1, CPHS has two main features: low energy and high pulse current. A large number of studies at GSI show that ceramic scintillator is a good option for such beam [1-3]. Therefore, a chromium-doped alumina screen is used as a monitor screen. Since the screen totally intercepts beam during measurement, it can only work with low repetition rate and low pulse length. While rotatable multi-wire scanner only interacts with a small part of beam during measurement, it can work at high duty, high repetition rate condition. These two instruments can cover most of beam operation conditions, and they can check each other.

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Table 1: Main Beam Parameters of CPHS

Parameter	Value	Unit
Specials	proton	\
Beam energy	3	MeV
Peak beam current	~36	mA
Pulse length	20~100	μs
Repetition rate	1~50	Hz

SCINTILLATOR SCREEN

The schematic diagram of the scintillator monitor system is shown in Fig. 1. The screen, attached to a cylinder which is movable with a linear motor, is perpendicular to beam direction. The area of the screen is 80 mm×40 mm and the thickness is 1 mm. An image of light spot formed on the screen is captured by a digital CCD (basler Aca1600-20gm,12 bits) camera equipped with a lens with focal length of 20 mm. The minimum shutter time is only 25 μs. Since the screen is transparent, the camera is placed at the rear of the screen with an angle of 45 degrees with respect to beam line. A small sheet of copper with a centimeter grid is placed on the back of the screen to calibrate the magnification factor of the optical system.

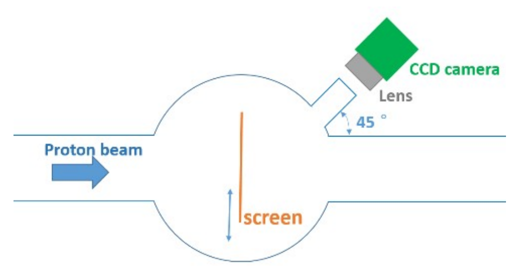

Figure 1: Schematic diagram of profile monitor based on scintillator screen.

ROTATABLE MULTI-WIRE SCANNER

As shown in Fig. 2, the scanner is composed of 19 carbon-fiber wires with a diameter of 30 μm, fixed and insulated by a strip made of PTFE. The front end of the scanner can rotate about its center using a step motor installed inside the vacuum box, and a serve motor is used

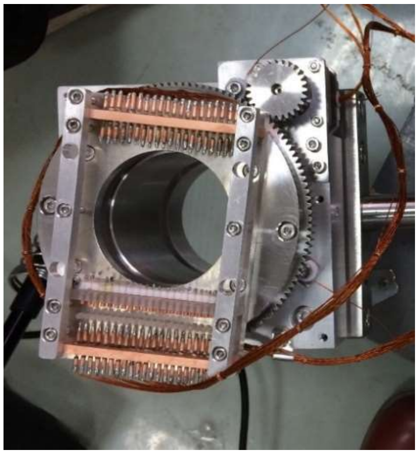

Figure 2: Front end of the scanner.

to retract the scanner when measurement is done. 19 wire signals are amplified, filtered and sampled by a purpose-built electronics. Due to gaussian like beam distribution, signal amplitude of each wire is different significantly. It's very difficult to cover the huge dynamic range with the same circuit. So, electronics has 3 gain switchable, as presented in Table 2, each channel can set proper gain independently. Sampled at 400 kS/s, all the signals are transmitted to a host computer through TCP/IP network.

To reconstruct 2D profile, ART [4] and MENT [5] methods are adopted. ART is commonly used in CT reconstruction especially with limited projections. ART is insensitive to noises and suitable for reconstructing from sparse projections, which is exactly our case. MENT is frequently used to reconstruct transverse emittance from data of several wire scanners [6,7], where only several projections are available. So MENT can be used to reconstruct profile quickly, especially in the situation that beam is not so stable.

Table 2: 3 Type of Gain of Electronics

Range	Gain（V/A）	Noise
1 nA ~10 nA	2E8	0.1 nA
10 nA ~ 1 μA	2E6	1 nA
1 μA ~ 0.1 mA	2E4	0.1 μA

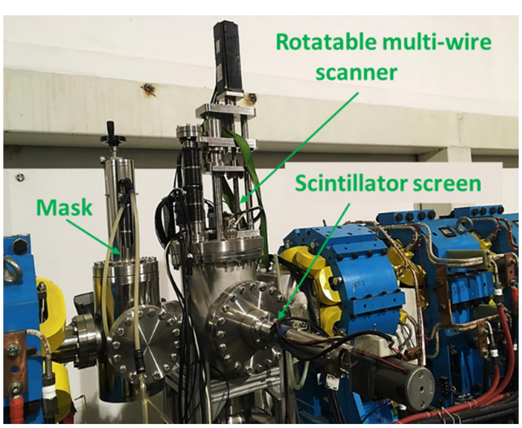

Figure 3: Experimental set-up.

EXPERIMENTAL SETUP AND RESULTS

The screen and the scanner are installed in the same location as shown in Fig. 3, they can perform the measurement alternatively. And measured results of the two monitors can be cross checked. With the help of an external light source, the focal length of lens is adjusted to obtain a clear image on the screen.

Result of the Scintillator Screen

At first, a large exposure time is set to illuminate the gridded copper sheet. As can be seen in Fig. 4, resolutions of horizontal and vertical directions are 109 μm/pixel and 35.6 μm/pixel respectively. Then exposure time is adjusted to 25 μs to avoid saturation. Beam profile is measured with beam parameters of current of 30 mA, pulse length of 40 μs and 1 Hz repetition rate. Result is shown in Fig.5. The horizontal projection is gaussian like shape as expected, while the vertical projection has double peaks, which is also observed in the phase space measured at the exit of low energy beam transport. Because we have limited knowledge about real beam distribution, it's difficult to evaluate the effectiveness of the measured profile. Therefore, Beam is shaped to a strips like beam distribution artificially by a mask located in front of the screen. As indicated in Fig.6, the mask, made of copper of thickness of 1 cm, has 6 strips with width of 2 mm and 2 mm spaced. A strip like image is anticipated on the screen after inserting the mask, and results, presented in Fig. 5, is consistent with expectation.

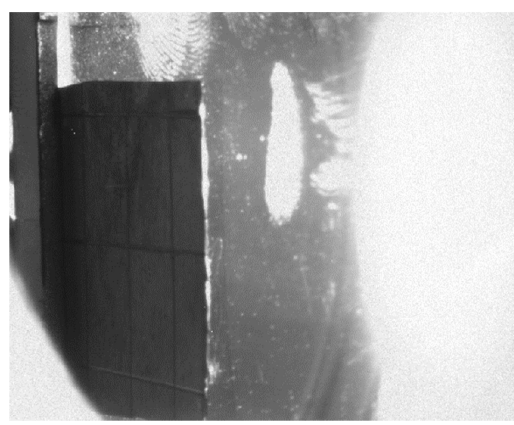

Figure 4: Illuminated gridded copper sheet.

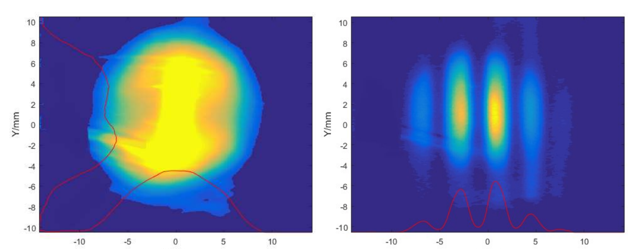

Figure 5: Beam profile monitored by scintillator screen. left: w/o mask, right: with mask inserted.

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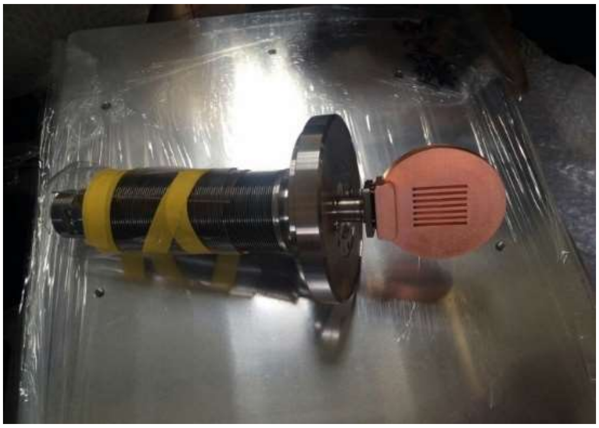

Figure 6: Mask made of copper.

Result of Rotatable Multi-wire Scanner

Due to the non-interceptive character of the scanner, it can work at 50 Hz repetition rate. Projections are sampled with step of 5 degrees from -80 degrees to 80 degrees. To improve accuracy of the measurement, the scanner scans the beam in steps of 0.1 mm with scan range of 3.2 mm at each direction. Since the scan range is larger than the distance between wires, measured range of a wire overlapped with that of the next wire. Data in the overlap region is used to calibrate inconsistency between wires online. Reconstructed images with ART using 33 projections and MENT using 5 projections are shown in Fig. 7. The result is basically consistent with profile measured by the screen. The main shape of the beam distribution can be reconstructed with MENT, but details of the reconstructed image is inaccurate due to limited projections used to reconstruct. Profile is also measured with the mask inserted. Only ART algorithm is adopted to reconstruct the strips like image. The reconstructed result is shown in Fig. 8. Although the reconstructed image is not so clear, 5 strips, the same as measured by the screen, are reconstructed, validating the functionality of the system.

To improve the performance further, the following issues are to be solved. The positioning accuracy of the wire should be improved. A collet-style fibre holding mechanism is anticipated to assure that positioning error of wire is less than 0.1 mm. At present, projection can only be measured at limited angle from -80 degrees to 80 degrees, which results in an incomplete data set. The limitation is caused by the scan procedure. The scanner can only move along vertical direction so far, real moving distance Δx corresponding to a step δx at angle of ϕ is $\Delta x = \frac{\delta x}{\cos\phi}$. The total moving distance exceeds the travel of the serve motor if $|\phi|$ is larger than 80 degrees. A linear motor is scheduled to install inside the vacuum box, and the front end of the scanner is attached the motor. Hence the scan procedure is achievable at any angle.

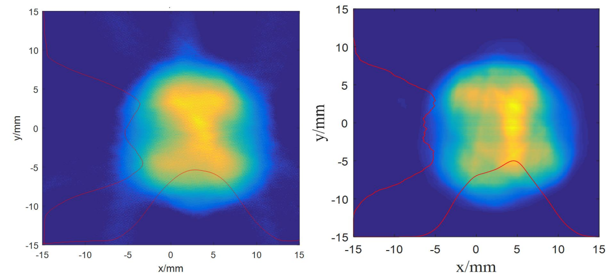

Figure 7: Reconstructed 2D beam profile. Left: ART algorithm with 33 projections, right: MENT algorithm with 5 projections.

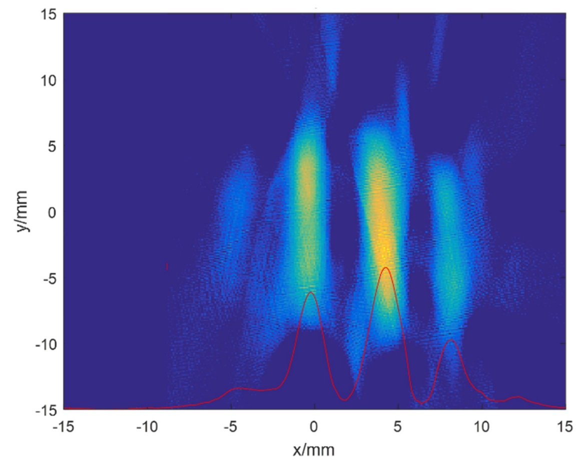

Figure 8: Reconstructed profile with ART algorithm from 33 projection with the mask inserted.

CONCLUSION

In this paper, two 2D beam profile monitors, scintillator screen and rotatable multi-wire scanner installed in CPHS, are introduced. Both of them can be used to monitor 2D profile of the low energy and high current beam. The experimental results of the two monitors are roughly consistent, but the differences need to be studied further. Rotatable multi-wire scanner is nearly non-destructive. So, it is a good candidate for measuring 2D profile of high current hadron beam. ART and MENT are both useful to reconstruct beam image, one can be used for accurate reconstruction and the other is preferred for quick reconstruction.

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