FIRST LIGHT FOR OPTICAL TRANSITION RADIATION MONITOR AT THE J-PARC*

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Abstract

We have continuously developed the Optical Transition Radiation (OTR) monitor with optics system based on the Newtonian telescope to measure a profile for a high intensity proton beamline. Now we installed the OTR monitors of production version on the J-PARC hadron beamline, and successfully observed a first OTR light. This led to the establishment of high S/N profile measurement with minimum beam disturbance. At this commissioning stage, beam intensity is expected to be as small as 1.2 KW, but expected to increase up to 750 kW, so that maintenance work becomes important. To improve ease of maintenance, we plan to replace the focusing lens system with reflective mirror system with higher resistance to radiation. A result of beam profile measurement, an estimation of dependence of an OTR background on a beam loss, and a future plan for an upgrade of our optics system will be presented.

INTRODUCTION

We have finished constructing first stage J-PARC hadron facility to provide high intensity proton beam whose design intensity is 750 kW for various particle and nuclear physics experiments such as strangeness nuclear physics, exotic hadron physics, kaon rare decay physics, and so on. A 50 GeV proton beam is slowly extracted via switchyard (SY) section into T1 target (Ni disk; 30 % beam loss). It is crucial to minimize a beam loss to observe the beam status by various monitors for such high intensity beamline. For this purpose, the OTR monitor is one of the best solutions because the OTR is a surface phenomenon so that we can minimize a screen thickness. Thus the OTR is widely used at electron and proton facility for the profile measurement [1-3]. We have developed the OTR monitor for a profile measurement at the upstream part of the SY section.

OPTICS DESIGN AND INSTALLATION

We performed a test experiment at KEK 12-GeV PS with proto-type OTR monitor, and realized that it is important to reduce background and radiation to detector system [4]. Therefore, we prepared an OTR optics system like Catadioptric-type telescope and planned to put this system 5 m away from a beamline. Detailed design and optimization are described in Ref. [4].

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After the fine tuning of each component of optics system, we installed the OTR chamber and optics system, and finely aligned them with a beamline. As shown in Fig. 1, OTR1 is installed just upstream of a q01 quadrupole magnet, OTR2 is just upstream of a q02 quadrupole magnet, and OTR3 is just upstream of a v04 vertical steering magnet.

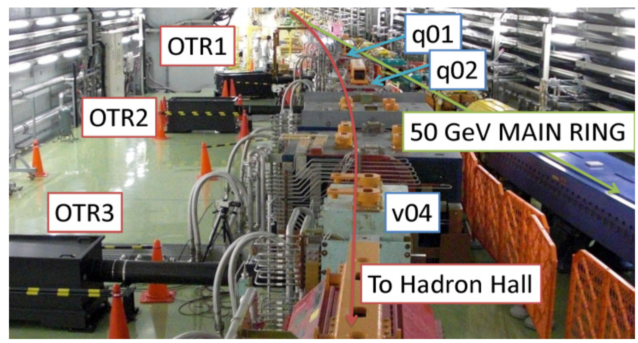

Figure 1: Layout of OTR monitors.

Figure 2 shows the OTR optics layout. There is an OTR screen (Al foil, 7 μm thickness) with rotating drive mechanism which enables to remove and install the screen remotely inside the OTR chamber. An OTR light emitted downward at the screen is first reflected by a planer mirror, and introduced into the dark box containing the OTR optics.

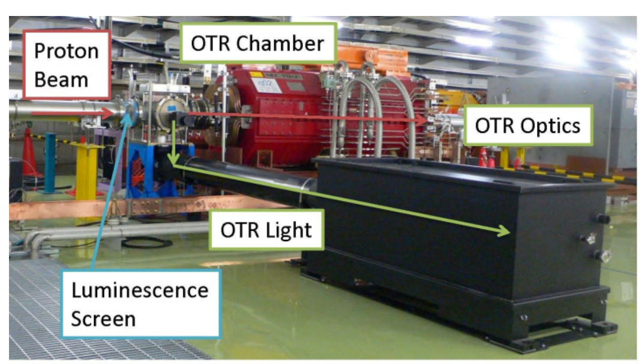

Figure 2: OTR optics installation upstream of q02.

For OTR2 and OTR3, a Luminescence screen composed of alumina ceramic is installed just upstream of OTR for a comparison of a beam profile. An Image Intensifier (IIT) is prepared to measure a weak OTR signal.

For OTR1, instead of an OTR screen, a Luminescence screen is installed to check the OTR optics. A light output of a Luminescence screen is expected too high to use IIT, so that we remove IIT for this layout.

FIRST OTR LIGHT AT THE J-PARC

The commissioning was started on January 27th, 2009. A proton beam is successfully transported to a beam dump at 19:35 on the same day. Slow extraction beam tuning was performed until the end of this past February. Final beam performance was as low as 120 W (1.5 x 10^{11} protons/spill) due to accelerator troubles. Spill cycle was 1/6 Hz, and beam duration was about 100 ms.

Despite this low intensity, we successfully measured the OTR light as shown in Fig. 3. Each shot is accumulated image for 40 ms. Consecutive three profile images reflecting the beam duration are measured. There is no long persistent component coming from such as the infrared ray, so that this signal should mainly come from the OTR.

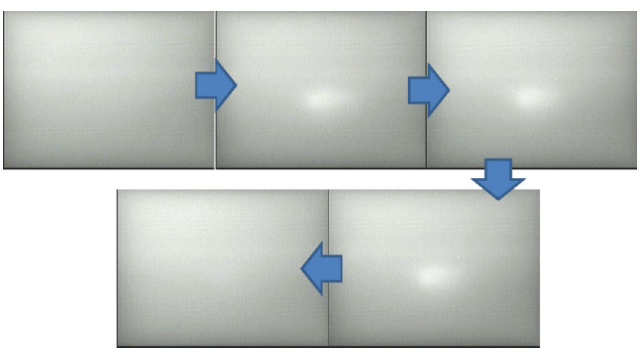

Figure 3: Typical sequential shots of the measured OTR light at v04.

ANALYSIS RESULT

Captured images are averaged, and its background is subtracted for both OTR data and Luminescence data. Figure 4 shows the resulting images for OTR data and Luminescence data, respectively.

We projected these image data into X and Y axis. We evaluated beam position and width by fitting resulting histograms with Gaussian signal + first order polynomial background function.

Figure 5 shows analysis result for beam position measured by the OTR and the Luminescence screen. Decay turtle [5] calculation result is also plotted for comparison. OTR data is in good agreement with Luminescence screen data within statistical and systematic error of about 1 mm. Measured position is deviated from turtle data due to lack of time for beam tuning.

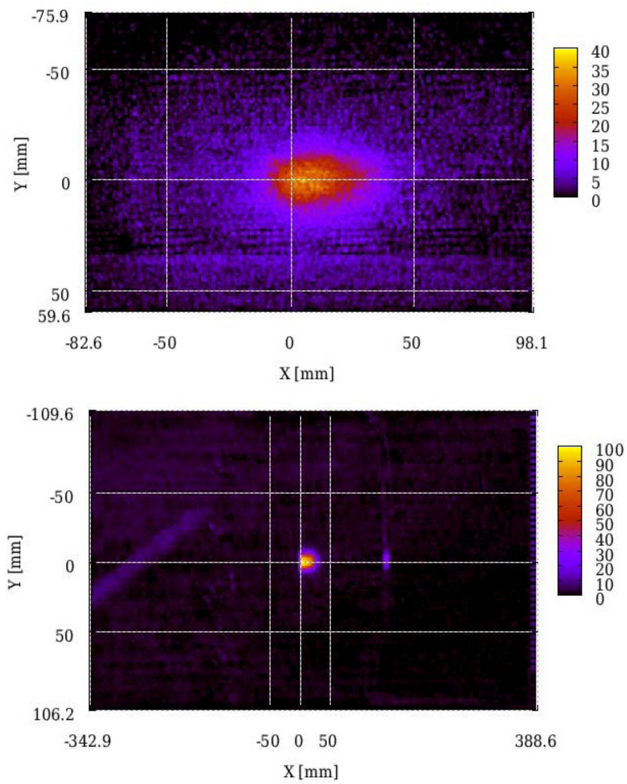

Figure 4: A typical OTR image (top) and a Luminescence screen image (bottom) at v04. Each screen size is 100 mm x 100 mm.

Figure 6 shows analysis result for beam width in the same way as the position result. Luminescence screen data coincide with decay turtle data except for q01-Y. We need to pay attention to data of OTR1 which is composed of Luminescence screen and OTR optics system. OTR1 data is in good agreement with turtle data so that it is expected that Luminescence screen at q01in probably has some problem. OTR overestimated beam width by 8 mm for q02, 14 mm for v04, respectively.

DISCUSSION AND FUTURE PLAN

Possible reasons of the OTR width overestimation is as follows.

- detector non-linearity
- OTR emission non-linearity

The other possibilities such as infrared ray effect, OTR at vacuum foil, OTR opening angle effect, diffuse reflection effect are estimated by computer simulation, and concluded that these effects are too small to cause such large width broadening . In the former case, we already checked a linearity of new optics system with J-PARC beam, so that IIT non-linearity is most suspected.

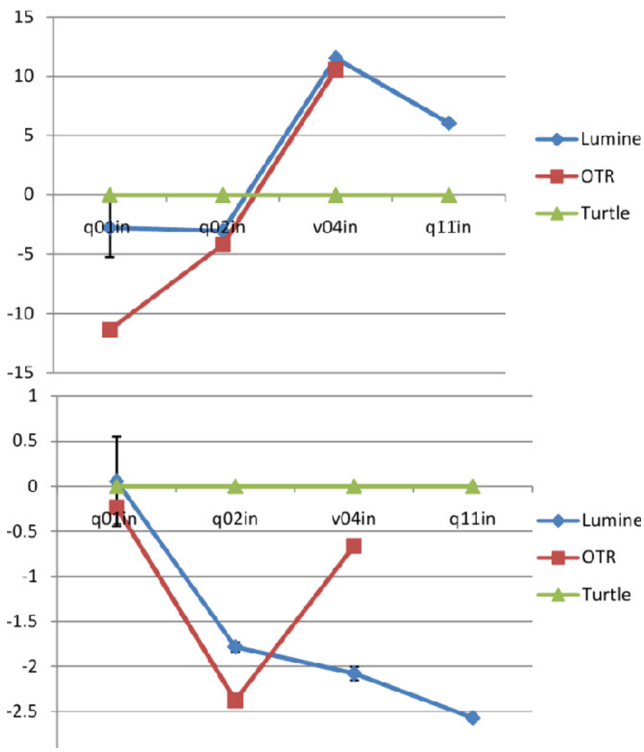

Figure 5: Position for X axis (top) and that for Y axis (bottom). Red line is for OTR, blue line is for Luminescence (Lumine), and green line is for turtle calculation.

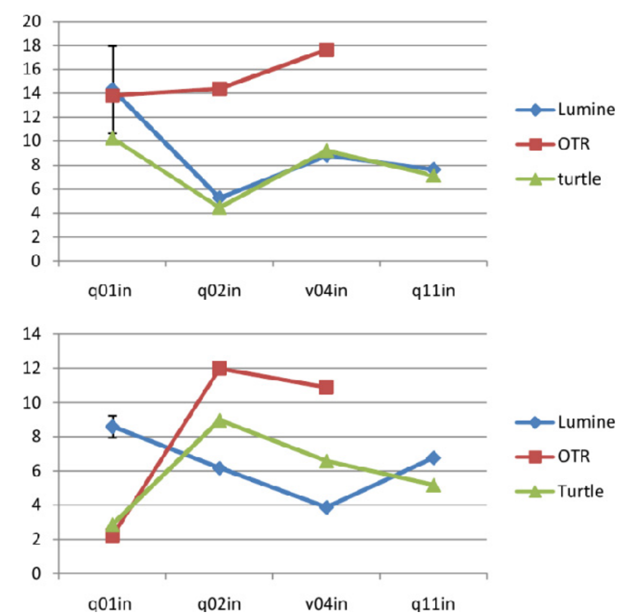

Figure 6: Width for X axis (top) and that for Y axis (bottom). Red line is for OTR, blue line is for Luminescence (Lumine), and green line is for turtle calculation.

This is probably caused by faster beam extraction of about 100 ms and spiky beam time structure due to the accelerator trouble. IIT has gain control system to protect MCP from strong light input, but this system is not enough quick for such rapid change of intensity. This can cause the instability of IIT gain leading to the non-linearity. We plan to check IIT linearity by standard light source. After the confirmation of detector non-linearity, we can check the OTR non-linearity in the next J-PARC beam time from this October.

We also have a plan to upgrade this OTR optics system. Our current optics uses coupling lenses to compensate insufficient magnification of main reflector. These lenses do not have good resistance to radiation, so that maintenance work will become a problem in the near future. To solve this problem, we now develop new OTR optics system without any lenses as shown in Fig. 7. Two reflectors are combined like Gregorian telescope, but sub reflector is placed nearer to main reflector to improve magnification. Design work including aberration minimization, magnification adjustment, and so on is completed with computer simulation, and new OTR optics system will be made and installed into J-PARC extraction beamline this Summer.

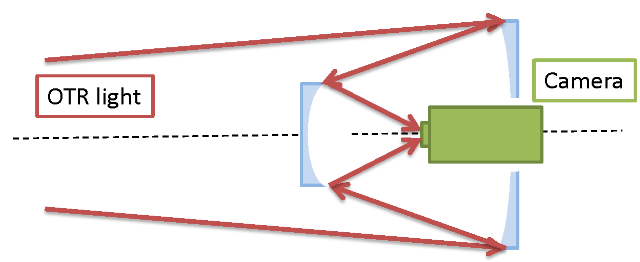

Figure 7: Conceptual design of new OTR optics.

SUMMARY

We successfully observed the first OTR light with our OTR detector at the J-PARC. Beam position for the OTR coincides well with that for Luminescence screen, but the OTR is confirmed to overestimate a signal width. We plan to recheck the detector response and perform a test experiment in the next beam time. New OTR optics system will also be tested in the beam time.

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