J-PARC 主リングにおける高残留線量と低ビーム損失信号のパズル

LARGE RESIDUAL RADIATION BUT SMALL BEAM LOSS SIGNAL AT J-PARC MR

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Abstract

In the ARC-A (downstream of the injection insertion section / INS-A) of J-PARC MR, we measured large residual radiations (a few mSv/h at ~four hours after beam stop) at the addresses 45 and 52, even though the beam loss monitor signals are one order of magnitude smaller. Residual radiation should be kept less than ~1 mSv/h for maintenance. Therefore the reason of the large discrepancy and the source of the beam loss is a big issue. The tentative understanding is reported here.

1. Introduction

We measured large residual radiations (a few mSv/h at ~four hours after beam stop) at the addresses 45 and 52 in the ARC-A (downstream of the injection insertion section / INS-A) of J-PARC MR, even though the beam loss monitor (BLM) signals are one order of magnitude smaller. Residual radiation should be kept less than ~1 mSv/h for maintenance. Therefore the reason of the large discrepancy and the source of the beam loss is a big issue. The measured data with big discrepancy is presented, dose distribution during machine operation with OSL dosimeters, BLM detector response simulation with PHITS code, and a particle tracking simulation with SAD are presented here.

2. Large discrepancy between a beam loss signal and a residual dose

Beam loss signals measured with the BLMs during FX (fast beam extraction) mode operation are plotted in Figure 1 with a bar chart. In the same plot residual radiations measured on the beam ducts with the handy dosimeter [1] are plotted where blue dots are measured in Mar. 11, 2015 and red dots in Mar. 17, 2015. The BLM signals are divided by 2000 to fit to the residual radiation. At addresses #45 and #52, discrepancies are large between the beam loss signals and residual radiations. The configuration of the BLM [2] and magnets are shown in Figure 2. The beam runs from the left side to the right side of the photograph. The BLM is set on the quadrupole magnet. The beam loss points are considered as the key of these discrepancies.

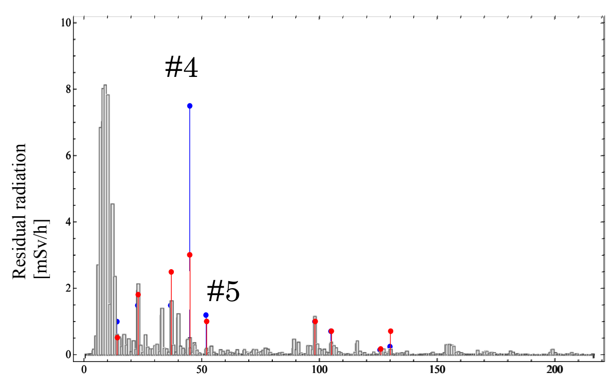

Figure 1: Beam loss signals during operation vs. residual radiation measured with the BLMs.

3. Doses measured with the OSL dosimeter

To clarify the dose distribution Optically Stimulated Luminescence (OSL) dosimeters “nano dots” [3] are put on the beam ducts. After one operation period of the machine the OSL dosimeters are replaced. The collected dosimeters are analyzed with the OSL dosimeter. The dose distribution at addresses #23, #45 and #52 are depicted in Figure 3.a and 3.b. Figure 3.a and 3.b correspond to the results of beam-loss irradiation during Jun. 17 – Jun. 29, 2015 and Jun. 29 – Jul. 1, 2015, respectively. The address #23 is a focusing position in the vertical direction and #45 and #52 are focusing in the horizontal direction.

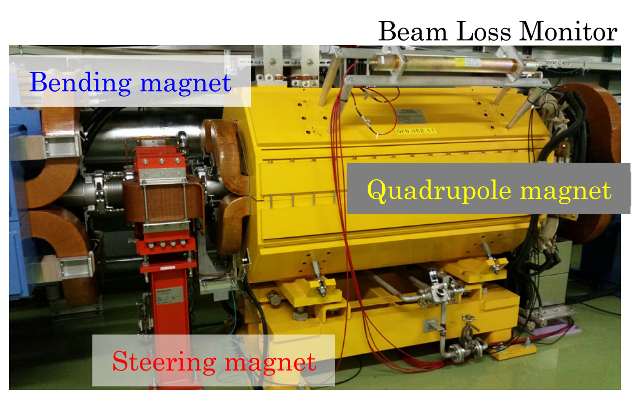

Figure 2: BLM setting on the quadrupole magnets.

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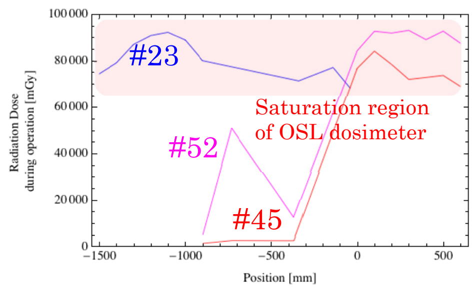


Figure 3.a: Dose measured with OSL dosimeters. Measurement was done Jun. 17 – Jun. 29, 2015.

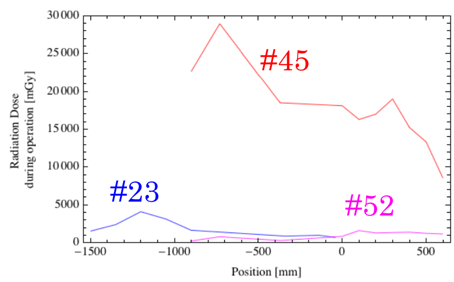


Figure 3.b: Dose measured with OSL dosimeters. Measurement was done Jun. 29 – Jul. 1, 2015.

At the address #23, the beam size grows in the vertical, especially at the exit of the bending magnet where the vertical aperture is the smallest, and then beam may be lost. Secondary particles from the loss point go to the BLM detector through the air, steering and quadrupole magnet. On the other hand, at the #45 and #52, the beam size has the maximum horizontally in the quadrupole magnet. Therefore the loss may occur in the quadrupole magnet. Secondary particles from the loss point go to the BLM detector through the thick quadrupole magnet core. The scattering angle seems nearly 90 degree, larger comparing with the #23 case. The dose measured with the OSL seems to agree with this picture.

4. Simulation with PHITS

Estimation of the BLM detector response / sensitivity is going on using PHITS simulation code [4]. The materials of magnets and the BLMs are simplified as cylindrical shaped irons. Two cases of beam loss points, at the entrance of the steering magnet and at the entrance of quadrupole magnet are simulated. The configuration is shown in Figure 4. In the input of the simulation the BLM detectors are placed in every 1-meter.

The particle flux and deposited energy at each BLM are plotted in Figure 5 and 6, respectively. By examining Figure 5, the flux of #45, #52 at the BLM detector position seems much smaller than #23. Serial num. of region 3 is the present BLM position in Figure 6. Others are the deposited energies if the BLMs are put at these positions. Comparing serial num. of region 3 for both configurations, the deposited energy of #45, #52 configuration is nearly four times smaller than #23. Even though more realistic geometry may be necessary for more precise discussion, tendency of both configurations may be understood as above.

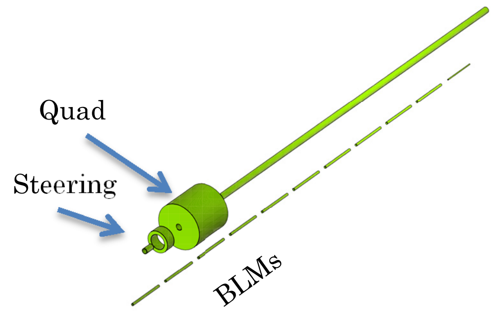


Figure 4: Dose measured with OSL dosimeters. Measurement was done Jun. 17 – Jun. 29, 2015.

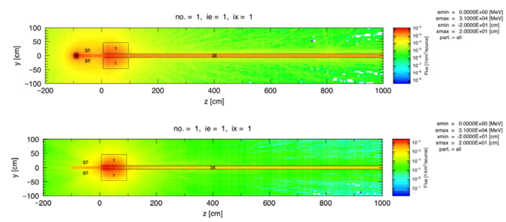


Figure 5: Dose measured with OSL dosimeters. Measurement was done Jun. 17 – Jun. 29, 2015.

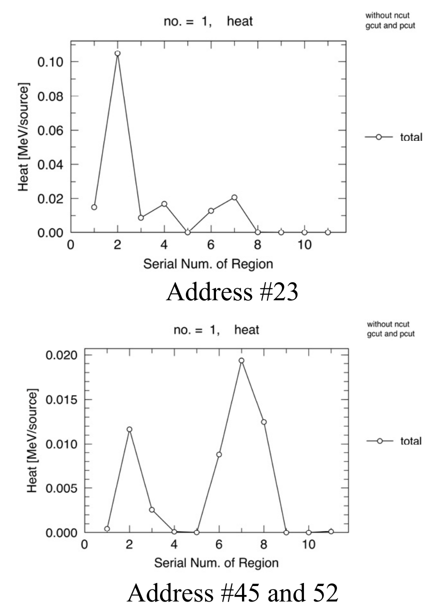
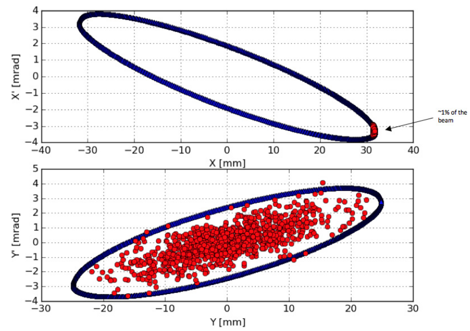
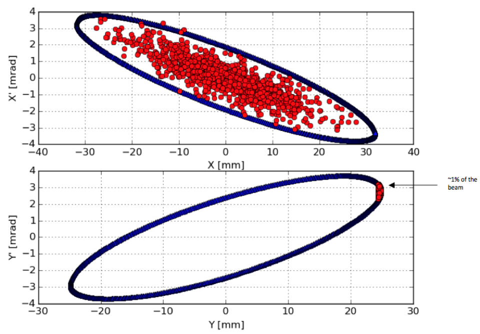


Figure 6: Deposited energy at each BLM. Num. 3 is the present BLM position. Others are the deposited energies if the BLMs are put at these positions.

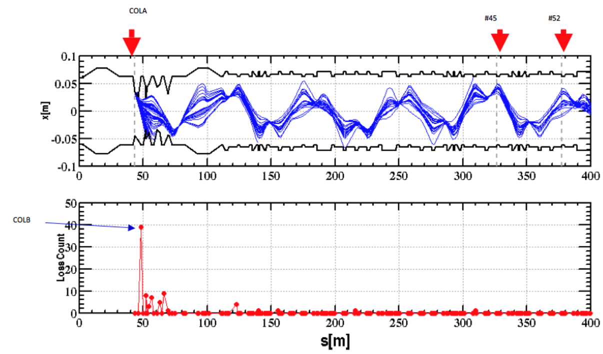


(a) Vertical: Gaussian, horizontal: hollow distribution.

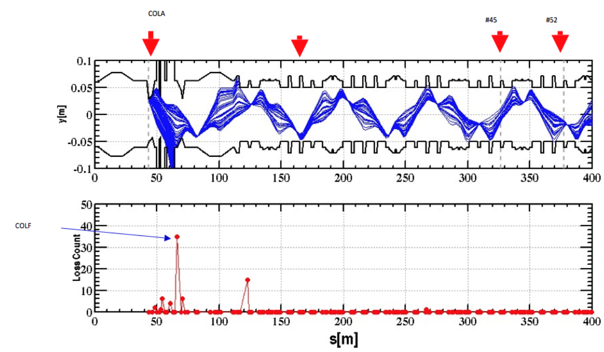


(b) Horizontal: Gaussian, vertical: hollow distribution.

Figure 7: Initial distributions for the beam particle tracking.



(a) Vertical: Gaussian, horizontal: hollow distribution.



(b) Horizontal: Gaussian, vertical: hollow distribution.

Figure 8: Trajectories of beam particles.

5. Beam particle tracking simulation

In order to clarify the source of the beam loss the beam particles are tracked with the SAD code [5]. The scattering at the jaw of the MR collimator A causes additional kick on the beam particles. Two cases:

(1) The Horizontal emittance is set at 70 π and the vertical at 80 π mm mrad, (both correspond to 3σ). The fraction of the beam, 1 %, at the horizontal fringe hits the jaw.

(2) The emittances are set as same as the above. The fraction of the beam, 1 %, at the vertical fringe hits the jaw.

A particle receives a kick after pass the Collimator A: a random kick and dispersion in energy. The random kick is around (+/- 5mrad). The dispersion in energy is between 0 to 1 %. The initial phase space distributions are shown in Figures 7. The tracked trajectories are shown in Figure 8. The results obtained so far shows no beam losses at the addresses #45 and #52.

6. Summary and prospect

Beam Loss signals by the BLMs are nearly 10 times smaller than those expected by the residual radiations at the addresses #45 and #52. Detailed measurements are underway. Using BLM #23 (QD) as a reference, BLMs #45 and #52 are examined. At #23 (QD), beam loss may have occurred at the downstream of the bending magnet, on the other hand at #45 (QF) and #52 (QF), it occurred at the Quad. Low sensitivity of the #45 and #52 BLM may due to thick Quad core made of iron and large scattering angle. These processes attenuate the secondary particles flux from the beam collision point, which is proved qualitatively with a simulation using the PHITS code. Beam loss mechanism is investigated using SAD code with 70 π mm mrad beam particles hitting the jaw of the collimator A. No beam loss is obtained so far and the simulation is in progress with additional assumptions.

To observe and to evaluate the beam loss amount, adding BLMs with scintillator etc. with small secondary particle attenuation is progressing. Calibration of present BLMs with the DCCT may be another solution.

Acknowledgements

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References

[1] J-PARC radiation safety section, Internal reports, “第 1 種管理区域　線量当量率測定記録”. Using detector is the Geiger-Müller tube survey meter.
[2] T. Toyama , in these proceedings and references therein.
[3] http://www.nagase-landauer.co.jp
[4] H.Iwase,K.Niita etal., http://phits.jaea.go.jp.
[5] Strategic Accelerator Design, http://acc-physics.kek.jp/SAD/