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OVERVIEW OF SEVEN-UNIT COLLIMATOR SYSTEM AND ITS OPERATION FOR J-PARC MAIN RING

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Abstract

The J-PARC main ring has three linear sections, and one have a beam collimator system downstream of the injection devices to localise beam losses. In September 2024, the seventh collimator unit was installed, completing an upgrade of the collimator system that has been underway since 2012. The system was changed from one that scatters and captures the beam halo to one that draws the jaw close to the beam core and directly removes its halo. This allowed a number of collimator units to be placed in a limited area. The original beam loss capacity in the collimator area was 450 W. Seven collimator units allow a beam loss of 3.5 kW. Currently, six collimator units are used to deliver 800 kW beams to neutrino experiments with losses of less than 500 W. By using seven collimator units, a beam of 1.3 MW can be delivered with a reasonable loss amount. The combination of units effectively removes the halo component of the beam and localises the beam losses. However, the direct removal method can create loss spots downstream of the collimator according to phase advance. This paper describes the operation of collimators in actual beam operation.

INTRODUCTION

The J-PARC main ring (MR) is located at the downstream end of the three accelerators that make up J-PARC. Figure 1 shows an overall view of the J-PARC MR. The MR is a three-fold symmetrical ring with three straight sections and three curved sections. The beam collimator system is located in the first straight section (called as INS-A) following the beam injection equipment. The purpose of the beam collimator is to localize the beam loss at the collimator and to protect the rest of the ring from activation due to beam loss. In particular, the apertures of INS-B and INS-C, where the beam extraction devices are installed, are narrow and prone to beam loss. The beam operation of MR started with a beam loss capacity of 450 W in the collimator area, but it was required to increase the capacity drastically in about three years [1]. Since the beam loss allowance per collimator unit is limited, this was achieved by increasing the number of units. In order to reduce the number of units, the method of capturing beam halos by scattering them was changed to a method of removing them by pulling the jaw directly into the beam core. The current beam loss capacity in the collimator area is 3.5 kW. However, this does not mean that the accelerator can be operated with beam losses in excess of 3 kW at INS-A. It is desirable to minimize the beam loss, and it is necessary to realize beam operation with minimal beam loss while achieving beam loss localization.

Even in the case of a 1.3 MW high-intensity beam operation, the beam loss should not exceed 1 kW.

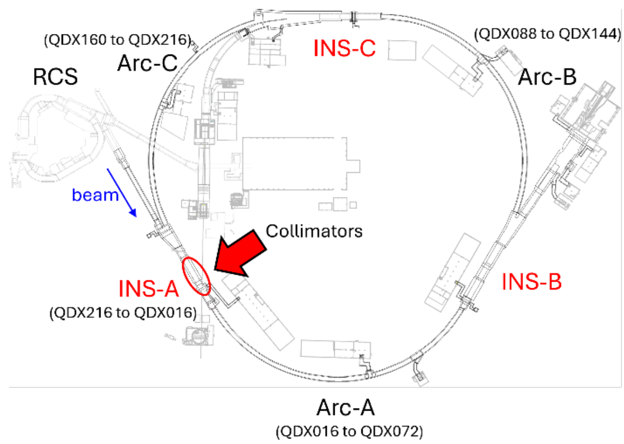

Figure 1: An overall view of J-PARC MR.

BEAM COLLIMATORS

The modification of the MR beam collimator system started in 2012, and after some twists and turns, the beam loss capacity of 3.5 kW was achieved. Figure 2 shows the first linear section of the MR. The beam loss capacity of each collimator unit is limited to 500 W by the thickness of the concrete shielding in the floor direction. This is the reason why seven collimator units are needed to obtain a beam loss capacity of 3.5 kW [2]. The current collimator units are referred to as Col-A, B, C, D, F, G, and H from upstream. Col-E is a missing number. Each collimator unit has one L-shaped jaw inside the beam pipe. The jaw is brought into contact with the beam by physically displacing the beam pipe from the outside. The jaw can change its tilt as well as up, down, left, and right independently. Since it has four degrees of freedom, it is called a four-axis collimator. However, Col-A and Col-B at the top of the beamline are the same units that were introduced on a trial basis in 2012, and only these two units do not have the jaw angle adjustment function.

The seventh unit, Col-F, was installed in September 2024. The configuration of seven collimator units with a beam loss capacity of 3.5 kW was completed.

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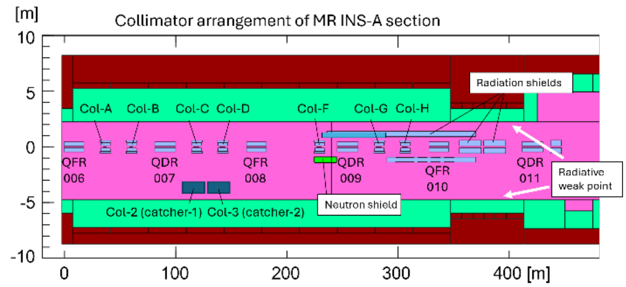

Figure 2: Arrangement of collimator units in INS-A.

BEAM RESPONSE TO COLLIMATORS

Figure 3 shows the phase of jaw for each beam collimator unit. Each collimator unit has one jaw for both horizontal and vertical planes. A collimator with a jaw to the right or above the beam is called a plus collimator, and the opposite is called a minus collimator. Col-A, B, D, and G are plus collimators, and Col-C, F, and H are minus collimators. Because A and B are close in phase, they are often treated as if they were two units in one. Col-C and Col-D, and Col-G and Col-H are in opposite phase, respectively. If there is an undesirable loss in one round of the ring, a jaw with a phase close to it is used to reduce the loss spot.

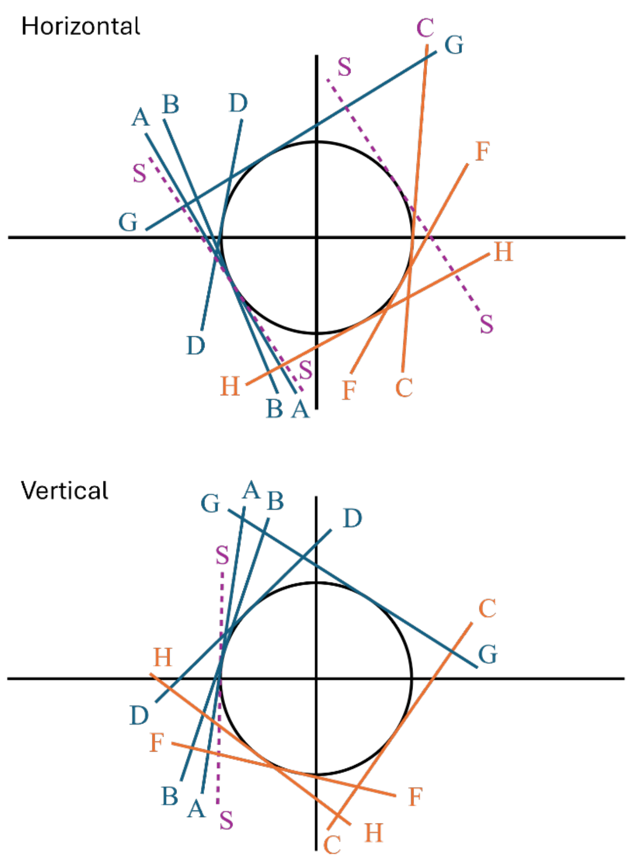

Figure 3: Position of collimator jaws relative to the beam in phase space. “S” is a scatterer set that is being installed on a trial basis, so it will not be mentioned here.

In the MR collimator system, there are two jaws with two degrees of freedom and five jaws with four degrees of freedom. If these were all variables correlated to beam loss, optimization would be nearly impossible. Fortunately, MR beams have small HV coupling, and the adjustments in the horizontal and vertical directions can be viewed as independent. The need for the jaw angle adjustment function has increased with the conversion of the collimator to a beam halo direct elimination system. If the angle between the beam envelope and the jaw plane does not match, the amount of particles scattered at the downstream end of the jaw increases, causing loss spots downstream. Once this angle is aligned, changing the jaw position has little effect. Therefore, it is known that the optimization of the jaw angle can be regarded as almost independent in actual operation. As a result, only one parameter, the jaw position, needs to be considered for all collimator units when adjusting the beam. Also, the horizontal and vertical planes can be adjusted independently. However, there are still seven variables to be optimized. In addition, in a ring accelerator, the response to jaw is complicated because the beam that passes through the collimator returns in a circular motion.

There are also beam collimators in the beam injection path to MR [3]. The beam collimator in the injection path has as many as 12 jaws, but optimization is straightforward. The jaw positions are adjusted in order from the upstream side while observing the beam loss response. Since the response is linear, superposition is possible, and the adjustment is almost completed in one iteration. Let us see the status of jaw position optimization in the MR collimators. The beam loss distributions at the time of collimator adjustment on March 7, 2025 are shown in Fig. 4 as an example. The horizontal axis indicates the address of one ring cycle. The address is assigned to each quadrupole magnet, and it makes a round from 001 to 216. The vertical axis is the BLM count value. Here, the peaks at addresses 159 to 166 are glares from the beam dump when the beam is thrown into it and should not be a concern. When the beam collimator is not working, large losses occur, especially at the location of the septum magnets for beam extraction. Losses are noticeable at the SX septum in INS-B and the FX septum in INS-C. Col-A+B+F succeed in eliminating the loss of INS-B. It is noteworthy that Col-A, B, and F cannot eliminate the loss by themselves, but only by combining them. It is difficult to predict such a response from the beam response for each jaw. It is urgent to establish a method to predict the beam loss for various combinations of jaw positions by simulation.

Figure 5 shows the loss distribution during the fast extraction operation on the neutrino beamline for the T2K experiment. The localization of the beam loss is very successful.

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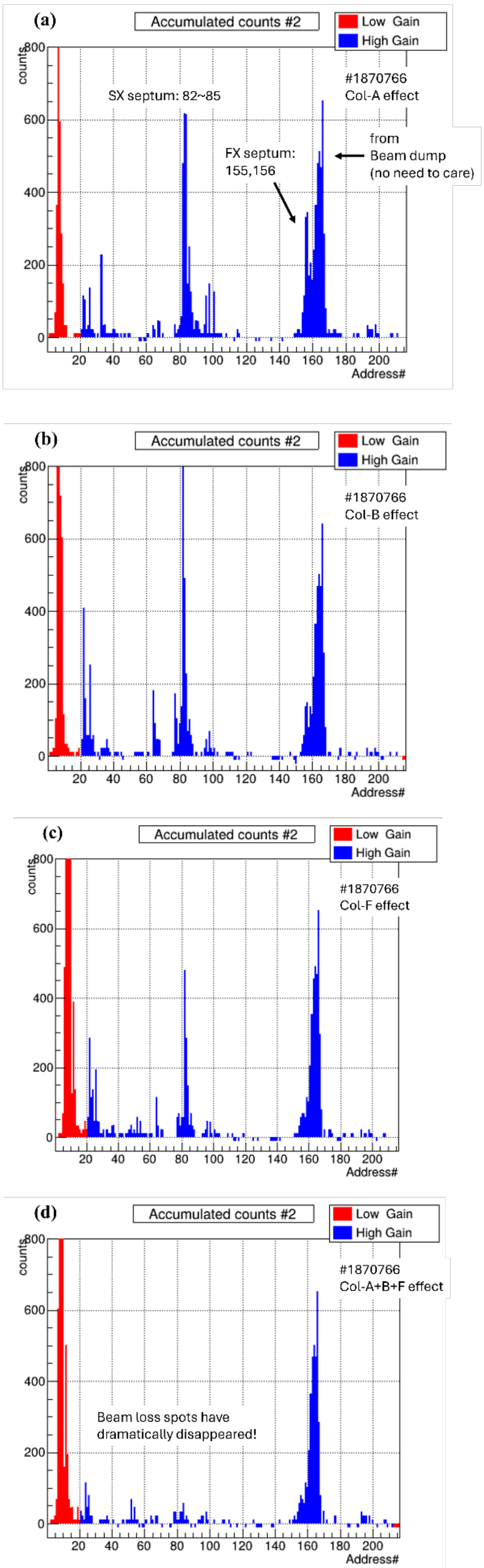

Figure 4: Examples of beam loss localization by three collimators. The low gain means 1/8 of the sensitivity of the high gain. (a) Effect by Col-A. (b) Effect by Col-B. (c) Effect by Col-F. (d) Effect by Col-A+B+F.

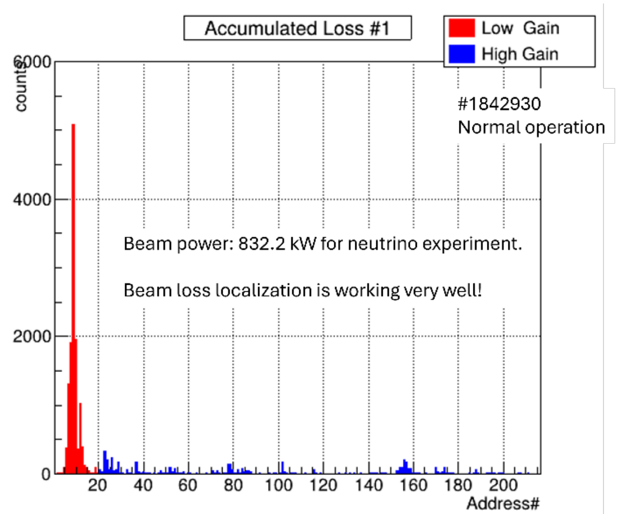

Figure 5: Beam loss distribution during normal fast extraction operation on March 3, 2025.

SUMMARY

The discussion here is summarized:

- J-PARC MR has installed its seventh collimator in the summer of 2024, establishing a beam loss capacity of 3.5 kW.
- The MR collimator has 2x2+5x4 degrees of freedom when adjusting the beam, but the jaw position and angle adjustment can be performed independently in the horizontal and vertical direction.
- The optimization of the jaw angle can also be treated as an independent parameter.
- Seven jaw positions should be optimized in both the horizontal and vertical directions, but the effects of each jaw do not add up.
- It is necessary to develop a jaw position optimization method by simulation.

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