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SIMULATION STUDY ON DOUBLE DIFFUSER FOR LOSS REDUCTION IN SLOW EXTRACTION AT J-PARC MAIN RING

R. Muto*[1], Y. Arakaki[1], T. Kimura[1], S. Murasugi[1], K. Okamura[1], Y. Shirakabe[1], M. Tomizawa[1], E. Yanaoka[1], High Energy Accelerator Research Organization (KEK), Ibaraki, Japan
A. Matsumura, Nippon Advanced Technology Co., Ltd., Ibaraki, Japan
[1]also at J-PARC Center, Ibaraki, Japan

Abstract

J-PARC (Japan Proton Accelerator Research Complex) Main Ring delivers slow-extracted 30 GeV proton beam to various nuclear and particle physics experiments. In the slow extraction the beam loss at the electrostatic septum (ESS) is inevitable, and the beam loss reduction is a key issue to realize the high intensity beam delivery. We carried out simulation studies on the effectiveness of the beam diffusers at the upstream of the ESS for the beam loss reduction with various materials and dimensions of the diffusers. We found out that putting two diffusers simultaneously on the beam was effective for the beam loss reduction, and the expected beam loss was 0.35 times as high as the operation without diffusers. According to the simulation results we installed the diffusers in the J-PARC Main Ring. We performed beam test with one diffuser and beam loss reduction of 60% was observed, which was in good agreement with the simulation results.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) [1] is located in Tokai-mura, Ibaraki, Japan, and its Main Ring (MR) delivers slow-extracted 30-GeV proton beam to Hadron Experimental Facility, where various nuclear and particle physics experiments are conducted. Figure 1 shows the schematic view of the MR and the layout of its straight section for the slow extraction. For user operation we achieved 60 kW beam power with 5.2 s repetition, which corresponds to 6.5×10^{13} protons per pulse, with high extraction efficiency of 99.5% [2, 3]. In the slow extraction the beam loss at the electrostatic septum (ESS) is inevitable, and the further beam loss reduction is necessary to achieve higher beam intensity. Thus we examined the effectiveness of beam diffusers in J-PARC MR as a method for the reduction of the beam loss at ESS in the slow extraction.

DIFFUSER FOR LOSS REDUCTION

The beam diffuser is placed at the upstream of the ESS to deflect the beam particles, which are destined to hit the septum without the diffuser, utilizing the multiple Coulomb scattering. Recently CERN SPS demonstrates its effectiveness even with their high beam momentum [4]. We carried out simulation studies with MARS [5] and FLUKA [6] codes to estimate its effectiveness in 30 GeV J-PARC MR slow extraction.

* ryotaro.muto@kek.jp

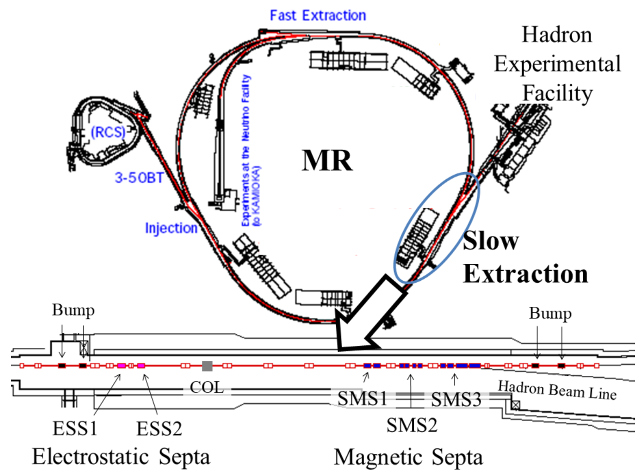

Figure 1: Schematic view of J-PARC MR and its straight section for the slow extraction.

SIMULATION STUDIES FOR DIFFUSERS

Locations of Diffusers

Because we make bump orbit during the slow extraction and the diffuser must be in the bump orbit to avoid the interference with the beam at the injection timing, there are only two possible locations for the diffusers in the ring at the upstream of the ESS. Those locations are indicated in Fig. 2 as "diff0" and "diff1". The phase differences between each location and the ESS are 5 degrees for diff0 and 0.7 degrees for diff1. We examined the effectiveness of the diffusers in these two locations.

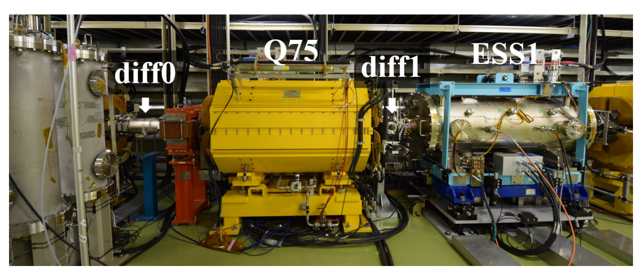

Figure 2: Photograph on the ESS1 and possible locations for the diffusers, diff0 and diff1.

Material

The material with the large atomic number (Z) is better for the diffuser because we can obtain larger angular spread from multiple Coulomb scattering with shorter diffuser, and

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it causes the smaller cross section for the large angle nuclear scattering, which causes additional beam loss.

To illustrate the superiority of the large Z nuclei for the diffuser material, simulations for angular distributions of the particles scattered on beryllium and tungsten diffusers were carried out. Figure 3 shows the results using MARS code. The angular spread by the Coulomb scattering with 50 mm long beryllium diffuser and with 0.5 mm long tungsten diffuser are almost same, but the probability of the large angle nuclear scattering with the beryllium diffuser is much larger than that with tungsten diffuser.

Among high-Z nuclei we chose tantalum (Z = 73) for the diffuser material because of its good workability.

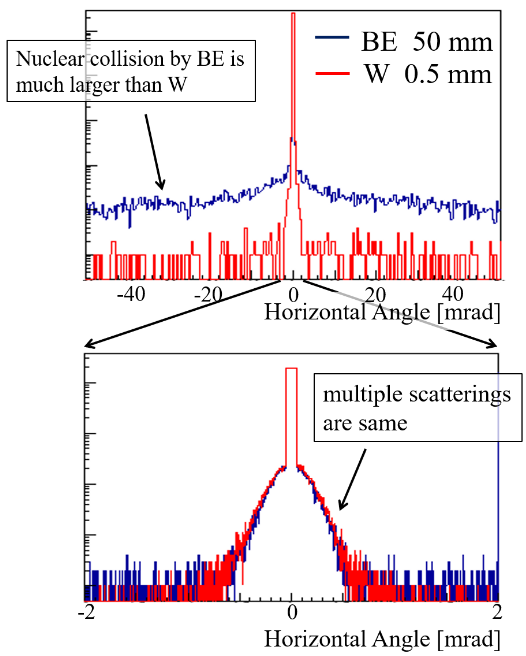

Figure 3: Simulation for angle distribution using MARS code with beryllium (blue) and tungsten (red) diffusers.

Thickness and Length Scan for Single Diffuser

We performed thickness and length scans of the diffusers to obtain the optimal dimensions. We uses FLUKA code for the estimation, and the scan was carried out with diffuser0 or diffuser1 exclusively in the beam. The momentum spread of the beam was set to be ±0.3%, and the angular distribution of the beam was Gaussian with 1-sigma of 17 μrad according to the particle tracking simulation using SAD code [7]. Figures 4 and 5 show the results for diffuser0 and diffuser1, respectively. We observed less hit rate on the ESS ribbons with thicker and longer diffuser, but the total beam loss has a minimum because the beam loss on diffuser increases with thickness and length. Table 1 shows the obtained optimal dimensions and beam losses for each diffuser.

Loss Reduction with Double Diffuser

We check the effectiveness of the diffusers with both diffuser0 and diffuser1 simultaneously in the beam. Size and

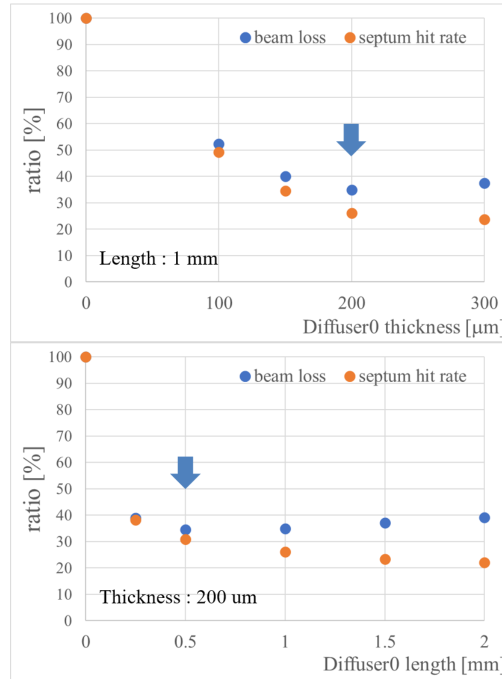

Figure 4: Results of parameter scans in FLUKA simulation for diffuser0. The upper panel shows the results of the thickness scan with the length of 1 mm. The lower panel shows the results of the length scan with the optimal thickness of 200 μm. Blue circles show the total beam loss. Orange circles show the particle hit rate on the ESS ribbons. Both are normalized to the no diffuser operation. The arrows show the optimal parameters.

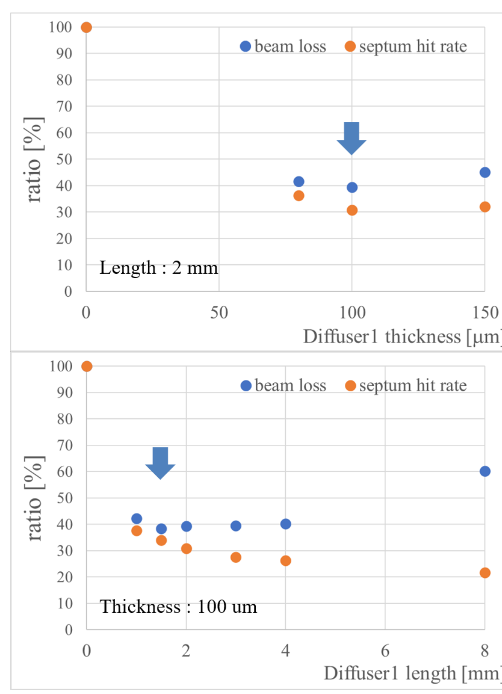

Figure 5: Results of parameter scans for diffuser1. The thickness scan with the length of 2 mm and the length scan with the optimal thickness of 100 μm are shown.

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length of each diffuser are optimized individually as described above. Table 1 shows the result. We obtained better reduction rate of the beam loss with double diffuser than single diffuser. The estimated loss reduction rate for double diffuser was about 65%.

Table 1: Summary of the simulation results for the length and thickness scan. t and L stand for thickness and length, respectively, and the values are in millimeter. Beam losses are normalized to the no diffuser operation.

	diff0		**diff1**		**Beam Loss**
	t	**L**	**t**	**L**	
No diff	-	-	-	-	1
diff0 only	0.2	0.5	-	-	0.42
diff1 only	-	-	0.1	2	0.47
diff0 and 1	0.2	0.5	0.1	2	0.35

BEAM TEST

According to the simulation results, we fabricated two diffusers and installed them in the J-PARC MR. One is diffuser0 with 200 µm in thickness and 0.5 mm in length, and the other is diffuser1 with 100 µm in thickness and 2.0 mm in length. Figure 6 shows the photographs of the diffusers before installation.

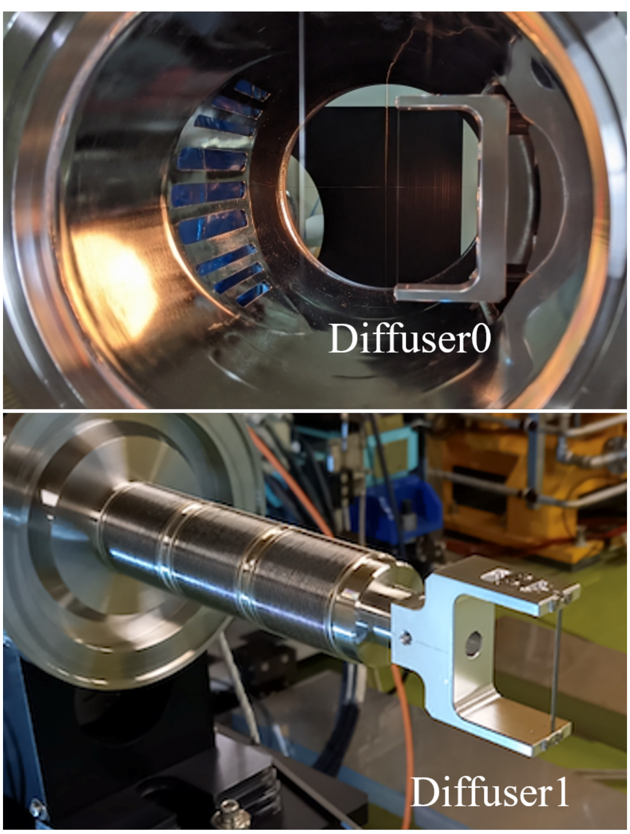

Figure 6: Photographs of the diffuser0 and diffuser1 before the installation to the J-PARC MR.

We performed beam test of those diffusers in February 2021. Because of the limited beam test time we could test only one diffuser, diffuser0. The result is shown in Fig. 7. When we set the position of the diffuser0 at −44.4 mm from the center of the circulation beam, the beam loss at the down stream of the ESS1 reduced to about 0.4 of the no diffuser operation. This beam loss reduction is in good agreement with the simulation results.

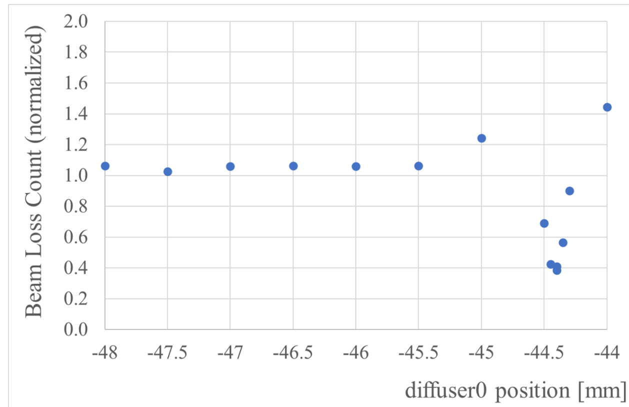

Figure 7: The result of the beam test for diffuser0. Vertical axis is the beam loss at the downstream of the ESS normalized to the no diffuser operation. Horizontal axis is the position of the diffuser0, and the origin is center of the circulation beam. The minimum beam loss was 0.4 with the diffuser0 position of −44.4 mm.

CONCLUSION

We preformed simulation studies on the beam diffuser for the loss reduction in J-PARC MR slow extraction, and found that double diffuser was more effective than the single diffuser. We optimized the sizes and lengths of the diffusers, and installed them in the J-PARC MR. We performed the beam test for one of the two diffusers, and observed beam loss reduction rate was in good agreement with the simulation result. Beam test for double diffuser is planed in June, 2021.

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