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LAYOUT OF THE NEW SEPTUM MAGNETS FOR FAST EXTRACTION IN J-PARC MAIN RING

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Abstract

At J-PARC Main Ring (MR), we are pursuing to improve the beam power from 500 kW to 1.3 MW by reducing the repetition cycle from 2.48 to 1.16 seconds (1 Hz operation). Additionally, we are considering the beam particles increasing by selecting a more optimal tune. The fast extraction (FX) equipment to the neutrino facility (NU) is needed to upgrade for the 1 Hz operation. We plan to replace most FX septum magnets with new ones in 2021. We report a layout of the FX line in confirmation of new beam optics and mention the beam loss during the fast extraction.

INTRODUCTION

J-PARC MR has contributed by supplying the high-intensity proton beam for the T2K long-baseline neutrino experiment. Currently, it is required higher beam power increase the statistics of the CP violation search. The MR group plans to meet the request by shortening the repetition cycle and increasing the number of particles per bunch. If we achieve the 1.16 seconds cycle and the operation of 3.3×10^{14} protons per pulse, the MR output power of 1.3 MW can realize [1].

To apply the 1 Hz operation, we replace most FX septum magnets in 2021. Figure 1 shows the current layout, parameters, and the new replacement. By changing the direction of the electric current flowing through the kicker coil, we can switch the extracting beam to the neutrino or the abort lines. The low field septum magnets (LF-SM), SM11-SM22 are changed to an eddy current type septum; since the Eddy is a pulse operation, it generates less heat and can be fast repetitive operations [2, 3]. The high field septum magnets (HF-SM) are conventional, and all septum magnets except SM33 are replaced [4]. We have already produced these new septum magnets, and we measured the magnetic fields and leakage magnetic fields in the recent few years.

By increasing the beam power, beam loss becomes serious. Even at present, there are some high residual points on the duct surface of the extraction equipment. The cause of the loss was investigated by performing a beam optics simulation and observing the correlation with the measured loss. In addition, since operation with different tunes from the current one is being considered for 1.3 MW output [5], the placement of the new FX septum magnets, especially the position of the septum of the Eddy, was optimized. Furthermore, we simulated the extracting beam orbit when the pulse of the eddy magnet was not output due to a failure and examined the countermeasures.

BEAM OPTICS SIMULATION

Figure 2 shows the current beam envelopes, the aperture, and residual doses. The beam envelopes are simulated using SAD (Strategic Accelerator Design) [6] with the momentum compaction factor of 0.7% and the closed orbit distortion of 3 mm. The figure shows the horizontal, the vertical circulating, and the vertical extracting orbits in order from the top. In the figures, the blue and green lines show the beam envelops of the FX tune and slow extraction (SX) tune, respectively, assuming our collimator setting of 60 π mm mrad. The purple lines are the extraction envelopes simulating the two sigma emittances of 15 π mm mrad and 19 π mm mrad; the values measured under the current FX tune [5]. The residual doses indicated in the figure were measured 6 hours later of the beam stop, on Jun. 24, 2020. The last beam operation was the beam study of the SX at 60 kW, with no beam to the NU side.

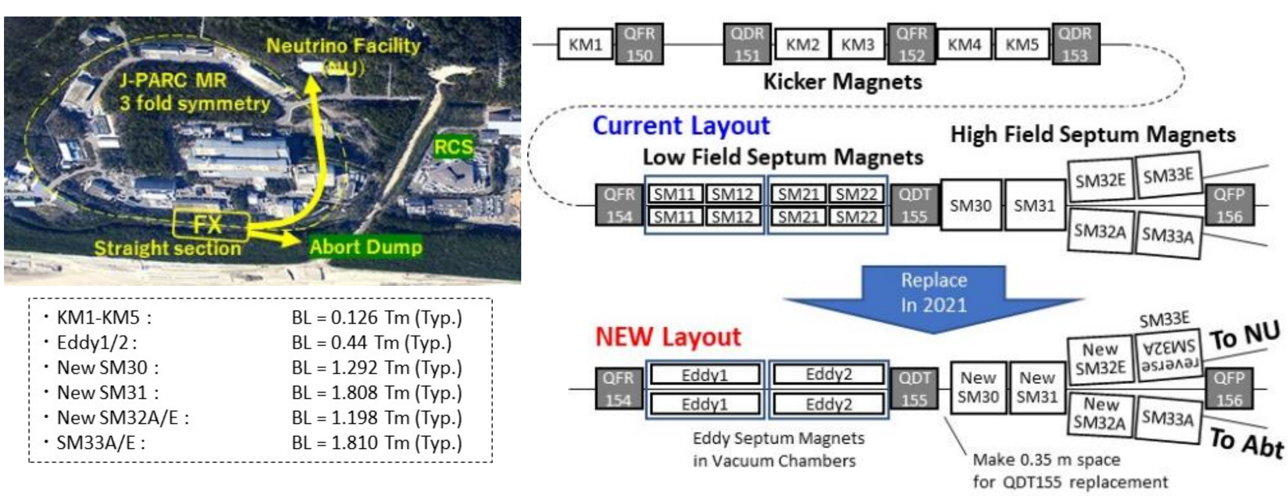

Figure 1: The outline of layout and replacement.

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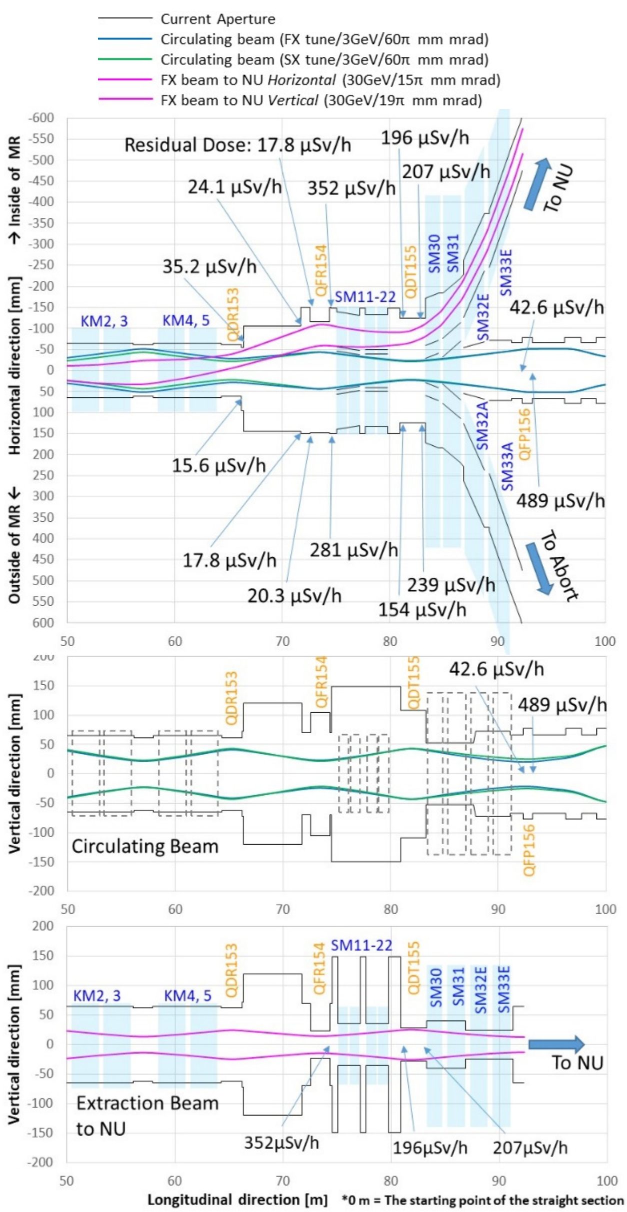

Figure 2: Beam envelopes and the current aperture with residual doses.

Despite the SX beam operation before the measurement, the residual doses at the NU side of QFR154 downstream were higher than the abort side. There is an asymmetrical shape duct of the QFR154 and its upstream with a narrow NU aperture in the horizontal direction. The design of this asymmetry comes from the abort aperture that is supposed to pass the 3 GeV injection beam of 60 π. However, the results of the residual dose suggest that the narrow aperture on the NU side causes beam loss and activates the duct. The residual doses around QDT155 were also high. The vertical envelope of the extraction beam is much close to the QDT155 duct resulting in a tail of the beam hits and causes beam loss. On the other hand, around QFP156 there are high radiation doses, though the aperture has enough margin of both horizontal and vertical. It is due to the secondary beam generated by the low magnetic field septum, which is just π / 2 phase advanced from QFP156.

LAYOUT OF SM

Two eddy septum magnets Eddy1, Eddy2 are installed in vacuum chambers. The septum plates of 9 mm thickness including the magnetic shield have to be placed in a position that does not conflict the circulating beam. Since the circulating beam passes repeatedly, the confliction causes much beam loss. We use the tune that maximizes the circulating beam envelope at the entrance of the Eddy1, and set the upstream edge of the septum plate about 1 mm outside the envelope. On the exit side of the Eddy1, the circulating beam and the extraction beam move away from each other. The Eddy1 is installed at an angle of a 3 mrad along the circulating beam envelope to have an allowance. The position and rotation of the Eddy2 are determined to follow a straight line connecting the downstream end of the Eddy1 septum plate and the upstream end of the circumference duct of SM30.

As we described later, we have a plan of replacement for the longer QDT155. The new SM31 and SM32 have shorter magnet core lengths to provide space for the new QDT. The old and new SM30s have the same length, but the new SM30 is installed 346.5 mm downstream. The SM33 on the abort side (SM33A) is utilized without any changes, and the new SM33 on the NU side (SM33E) is installed with the magnets of the old SM32A reversed up and downstream. This is due to the larger aperture of the old SM32A and SM33A, and the aperture of the new NU side is expanded to the same size as the abort aperture.

EXPANSION OF APERTURE

Figure 3 represents the current aperture and future expansion plans. The red line in the figure shows the new septum aperture. In the horizontal, around the QFR154 and the upstream, the blue line represents the symmetrical ducts that will be introduced in near future, and are expected to reduce beam loss by avoiding beam-duct conflict. The green line on the QDT155 indicates the aperture of the large aperture QDT. As the bore diameter increases, the magnetic field gradient of convergence weakens, it is necessary to increase the number of coils turns times coil currents and to extend the core length of the magnet, as to recover the magnetic field gradient length (GL). The design of the new QDT has been completed and is waiting for a budget.

Figure 3 also shows the beam envelope using the tune candidates when the number of particles is increased. The circulating beam is 81 π emittance, which is the maximum injection emittance, and the collimator corresponding to the full open. The extraction is simulated at 30 GeV with the 30 π emittance in both the horizontal and vertical directions. In some tunes, the aperture is not enough at the entrance of the SM30 circulating duct, but it is thought that there is a solution by adjusting the excitation current of quadrupole magnets. We expect the placement of the new septum has been optimized, and a sufficient aperture has been secured.

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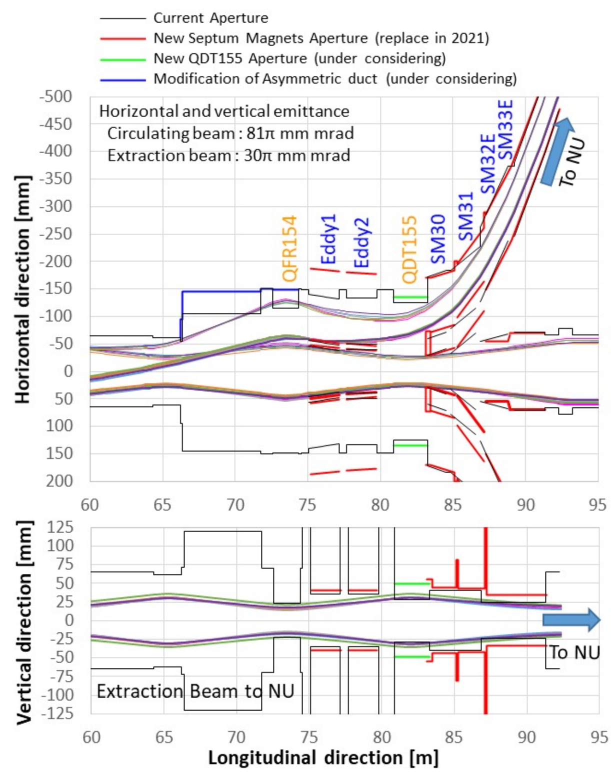

Figure 3: New Aperture plans and beam envelopes.

IN CASE OF EDDY SM FAILURE

The eddy septum magnets are operated by pulse, so they can misfire. By simulation results shown in Fig. 4, if the Eddy1 or Eddy2 misfired, a part of the extraction beam passes through to the NU line. The NU line has superconducting magnets (SC). Quenching by heat up can occur if the extraction beam hits the inner wall of the SC ducts.

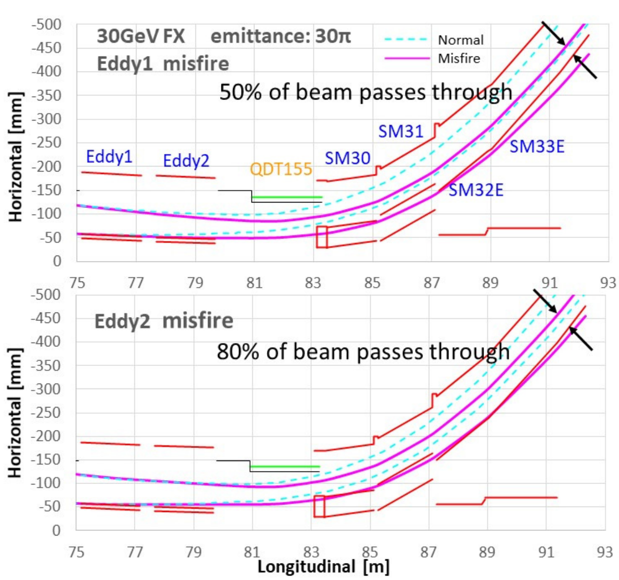

Figure 4: Simulation of the eddy SM failure.

Figure 5 shows a pulse current waveform of the Eddy septum. The pulse rise needs about 350 µs, and at 6 µs near the pulse top, it takes out all eight bunch beams in the MR at once. If the anomaly pulse waveform of the Eddy can be detected within 350 µs and kicked to the abort line using the kicker magnets, the beam will not go to the neutrino line, and the SC quenching can be avoided. Currently, we are developing a detection system and a trigger system to establish a high-speed emergency abort extraction.

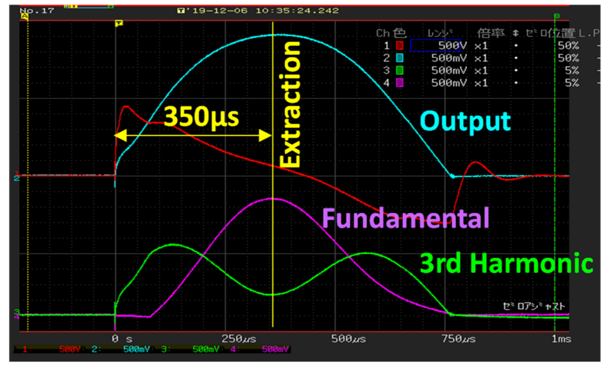

Figure 5: Pulse operation of the eddy SM.

CONCLUSION

We are introducing new FX septum magnets for 1Hz operation in 2021. As the result of the optics simulation using the tune for the high-power operation, we confirmed the new placement of the FX septum magnets with no problems. On the other hand, in the simulation and the comparison of the loss distribution, it was found some points of the aperture are not sufficient. Regarding Eddy Septum, the part of the beam is extracting to the NU line in the event of a failure. We are planning to take measures to make a high-speed emergency abort.

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