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SIMULATION STUDY OF FAST EXTRACTION IN THE ABSENCE OF ONE SEPTUM MAGNET FOR J-PARC MAIN RING

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Abstract

At J-PARC main ring (MR), the two fast extracting beamlines to the neutrino facility and to the abort dump have a symmetrical layout of 6 septum magnets each, a total of 12. Since there are many magnets, it is necessary to be careful about failure. It is important to consider how to continue beam supply even if one of the septum magnets is missing. From July 2021, upgrade works of the FX septum magnets commenced with an aim of increasing the beam power of MR to 1.3 MW from 500 kW. We simulated the beam extraction without one of the septum magnets under the conditions of the new geometry of septum magnets and the new aperture. We found that the beam can be extracted by increasing the current of the surrounding septum magnets and compensating for the output.

INTRODUCTION

J-PARC MR plays a role in supplying high-intensity proton beams in the T2K Neutrino experiment. It is planned to achieve an output of 1.3 MW by shortening the repetition cycle to 1.16 s and increasing the number of particles by up to 3.3×10^{14} [1]. Fast extraction (FX) magnets have been replaced with equipment corresponding to this early repetition cycle since 2021. Figure 1 shows the FX section magnets picture and layout. The Neutrino beamline is at the inside of the ring, the Abort is at the outside, and the circulating beamline is at the center. From the upstream, five kicker magnets, two low magnetic field septum magnets, and four high magnetic field septum magnets are aligned. Two low field magnets (FX-EDDY1 and FX-EDDY2) and three high field magnets (SM30, 31, 32) were replaced in period from July 2021 to May 2022. The most downstream high field magnet (SM33) reuses the septum magnets that have been used.

An EDDY type septum magnet is used as a low magnetic field magnet of about 0.3 T. In the 1 Hz operation, heat generation of the coil is an issue. The EDDY type magnets are pulse-excited, which eliminates the problem of heat generation. The maximum magnetic field has also improved to be about double. Owing to this higher magnetic field, even if one of the EDDY magnets is rendered inoperable, the beam operation can be continued.

Four high magnetic field septum magnets produce magnetic fields above 1 T. The 1 Hz operation also makes the heat generated by the coil severe even in the high field magnet; furthermore, the heat generated by the eddy current that loops between the circulating and extracting vacuum ducts becomes a problem. We introduced ceramic ducts to overcome this problem of loop current. We are also considering expanding the aperture of quadrupole magnets between the septum magnets to reduce beam loss. QFR154 only needs an expansion of the duct aperture; however, QDT155 needs an expansion of the magnet aperture, and the QDT155 magnet will be longer in the future. In anticipation of this, the length of the septum magnet was shortened and optimized, and SM30, SM31, and SM32 were renewed. The power supplies of the high field septum magnets are reused, with each capable of providing an output of 4.5 kA-300 V. The margins of the SM30 and SM31 are about 10% in combination with the magnets, and SM32 and SM33 are about 50%.

The orbit calculation and the aperture of the FX section are described in reference [2]. The beam envelopes are

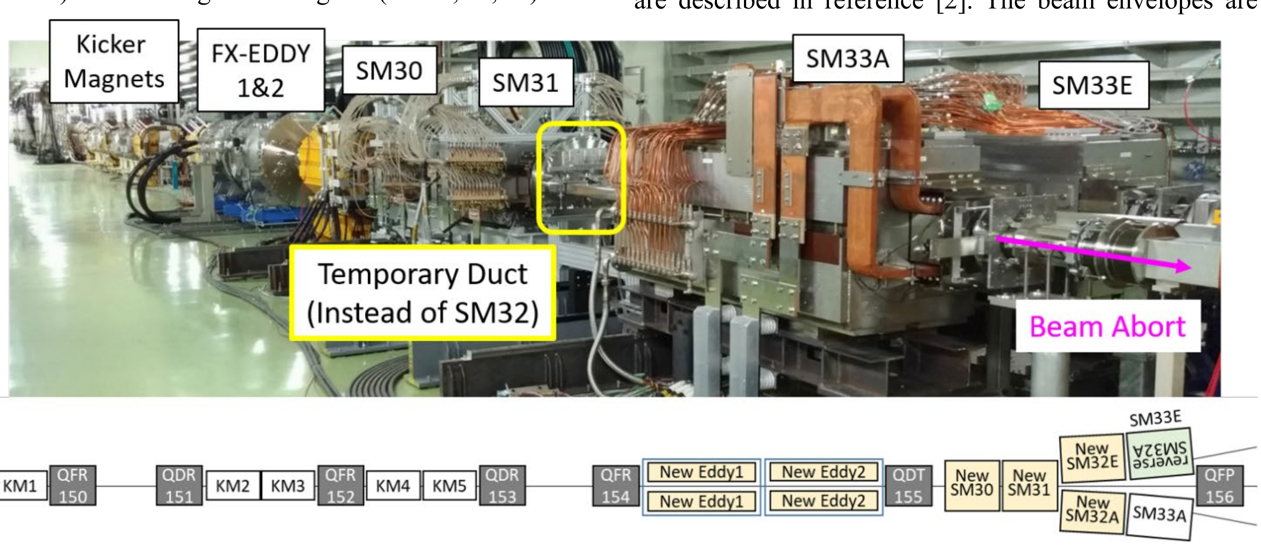

Figure 1: The layout of the FX magnets at J-PARC MR.

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simulated using SAD (Strategic Accelerator Design) [3] with the X-tune of 21.35, Y-tune of 21.43, momentum compaction factor of 0.1%, and closed orbit distortion of 1 mm. The 30 GeV extraction beam emittance assumes 15π mm mrad that has been measured in the horizontal direction [4].

Figure 2 shows the envelopes of the circulating and the extracting beam orbits. The horizontal direction is shown at the top, and the vertical direction is shown at the bottom. The black line represents the aperture of each device. The delivery point was 92.32 m in the upper figure right end, the beam position was 543 mm, and the angle was 77.22 mrad. There are five kickers; however, we use four kicker magnets because the KM1 does not work for separation at the most upstream septum. We study the condition of four kickers having a fixed kick angle. In addition, we are considering only the horizontal direction since there is no change in the vertical.

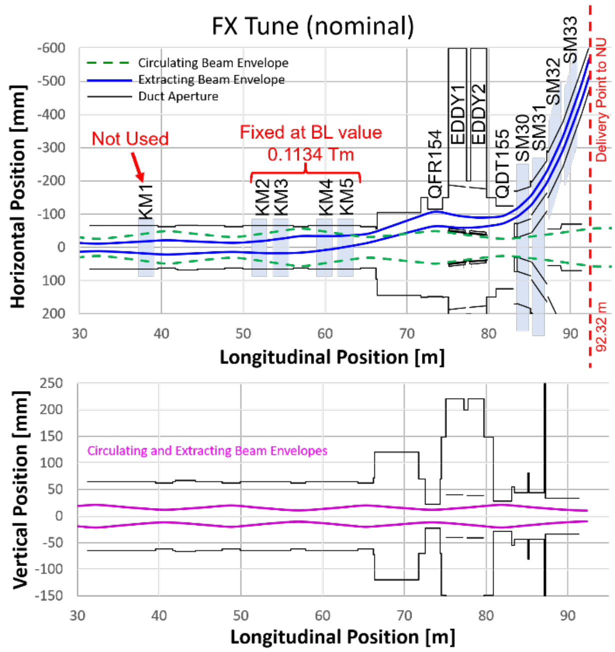

Figure 2: FX tune beam envelopes.

FAILURE STUDY OF EDDY SEPTUM

Table 1 summarizes the integrated magnetic field lengths (BL) used in this study. The design value is listed in the second column, the maximum output BL of each device is listed in the third column, and the magnetic field length required by the FX Tune is in the 4th and subsequent columns. The 5th and 6th are the cases in which EDDY1 and EDDY2 are missing, respectively. Figure 3 shows the extracted orbit when one of the FX-EDDYs is missing. The EDDY magnets are next to each other, and the unbroken magnet is excited to a higher level in order to secure the extracted orbit. This results in a change to the orbit, which is not significant. Usually, EDDY2 without EDDY1 requires more than twice the excitation, but depending on the tune, the excitation amount of FX-EDDY may be small. Currently, high-power candidate tunes have an excitation of about 60% of the design value, so the excitation of EDDY2 in the absence of the EDDY1 case is only 180% of the design value. If the power supply is broken down, it is possible to continue beam operation with only EDDY1 by swapping the cable in the tunnel. Even if the magnet is broken down, it is possible to switch the position of the magnet and operate it as EDDY1. If the magnet is replaced, it is necessary to break the vacuum, and the beam operation will stop for about 10 days.

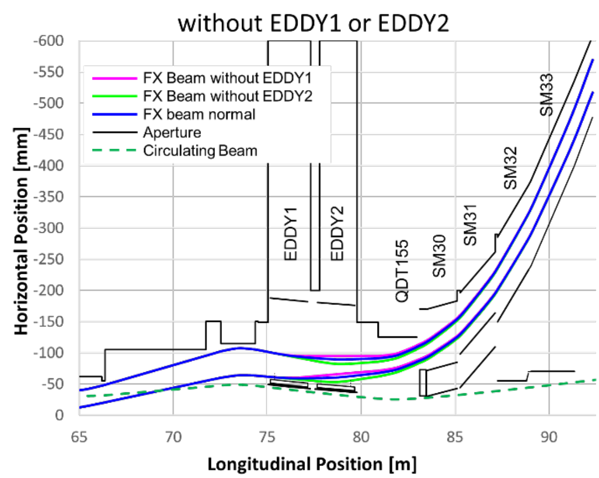

Figure 3: Failure cases of the EDDY1 or EDDY2.

FAILURE STUDY OF SM30 AND SM31

If SM30 or SM31 is missing, the excitation amount needs to be increased not only for the FX-EDDY magnets but also for the downstream septum magnets to secure the extracting angle at the delivery point. Figure 4 and the 7th and 8th columns of Table 1 show the results without SM30 or SM31. As shown in the table, if SM30 is missing,

Table 1: Summary of the Integrated Magnetic Field Length

	Design BL [Tm]	Maximum BL [Tm] (Current)	BL [Tm]						
			Normal	without EDDY1	without EDDY2	without SM30	without SM31	without SM32	without SM33
EDDY1	0.44	0.847 (18kA)	0.330	0	0.570	0.275	0.274	0.235	0.235
EDDY2	0.44	0.847 (18kA)	0.330	0.786	0	0.800	0.800	0.544	0.671
SM30	1.292	1.344 (3.9kA)	1.292	1.292	1.292	0	1.331	1.318	1.331
SM31	1.808	2.115 (4.0kA)	1.808	1.808	1.808	2.106	0	2.094	2.106
SM32	1.198	1.726 (4.2kA)	1.216	1.195	1.232	1.361	1.647	0	1.725
SM33	1.810	2.970 (4.2kA)	2.093	2.056	2.119	2.341	2.832	2.858	0

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EDDY2 and SM31 need the values of BL close to the limit. Without SM31, SM32 and SM33 require high magnetic field excitation in addition to EDDY2 and SM31. As shown in Figure 4, the beam conflicts with the vacuum duct at QDT155 without SM30, and at QDT155 and the downstream of SM30 without SM31. In the simulation, the beam aperture can be secured with only 8.7π mm mrad without SM30 and 8.8π mm mrad without SM31. In actual operation, it is necessary to be careful about beam loss, especially until the introduction of the large aperture QDT. It is also necessary to find a better solution by adjusting the kicker magnet (KM1), tune, and quadrupole magnet excitation.

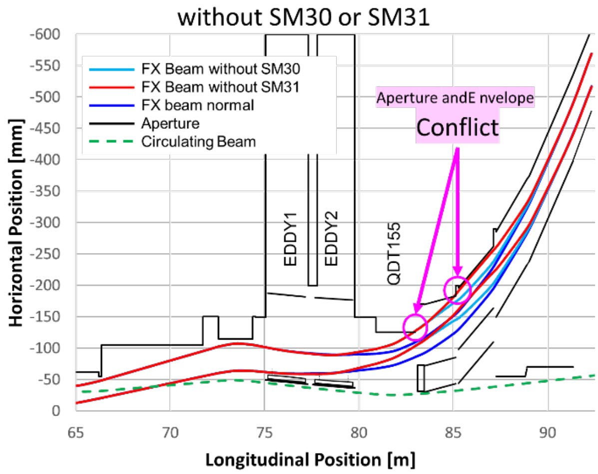

Figure 4: Failure cases of the SM30 or SM31.

FAILURE STUDY OF SM32 AND SM33

Figure 5 shows the beam envelope without SM32 or SM33. In Table 1, it is shown in the 9th and 10th columns. In the absence of SM32, the magnets SM30, SM31 and SM33 require the BL near the limit, but there is no interference, and a beam of 15π mm mrad can be extracted. Meanwhile, in the case of SM33, since it is the most downstream septum magnet, it is not possible to secure both the position and angle at the delivery point only by adjusting the septum magnet of the accelerator. If the angle at the delivery point is maintained, the extracted beam will hit the vacuum duct of SM33, and the beam is not extracted without large beam loss.

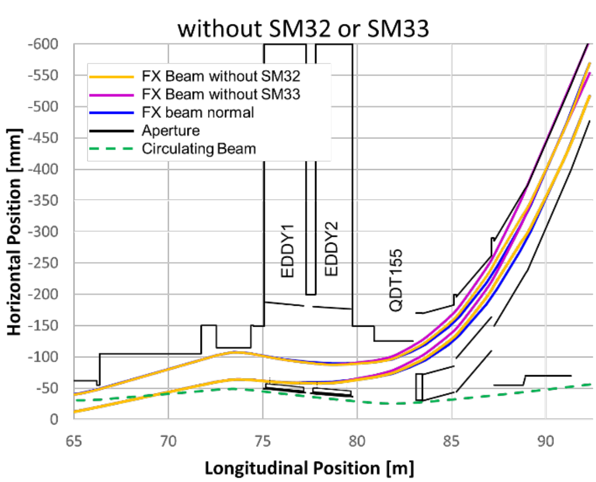

Figure 5: Failure cases of the SM32 or SM33.

Before updating, SM32 and SM33 both used similar magnets with a length of 1.9 m. The magnets on the abort side and neutrino side are completely separated, and there are a total of four septum magnets. The abort line also passes a large emittance of 3 GeV injected beam for which adiabatic damping does not work. For this reason, the vertical aperture on the abort side is wide, and after the update, these magnets are reused as two SM33 septum magnets. Therefore, there are two spare septum magnets with the same length and a narrow vertical aperture. Since the duct length was changed at the time of renewal, it is necessary to make new vacuum ducts and assemble them to be used immediately.

In August 2021, a problem occurred with the coil of the SM32 magnet. The accelerator beam commissioning in June 2022 is scheduled to operate the beam without the SM32 septum magnet. Details of this failure were reported at the same conference [5]. Because this paper reports just a simulation, but in June, we will be performing the actual work.

CONCLUSION

We examined the measures required to continue the beam operation in the absence of the FX septum magnets or their power supplies. The margin of the newly introduced septum magnets is fully utilized to prevent long-term beam stoppage with temporary measures for about 10 days. Since the FX section also plays the role of the beam abort, it is not possible to continue beam operation without the FX septum magnets. If the magnet or power supply fails, it may take more than half a year to recover, depending on the broken parts. Although the countermeasures against failures have been fragile before, we expect this study has made it possible to continue beam operation in a short stop period. There are still some things that need to be prepared such as to expand the aperture of QFR154 and QDT155, we will make efforts to improve them in the future, including securing finance.

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