LOW LEAKAGE FIELD SEPTA FOR J-PARC MAIN RING INJECTION SYSTEM UPGRADE

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Abstract

Injection into the J-PARC main ring is implemented by 4 kickers and 2 pulsed septa at 3 GeV energy. To accommodate the injection beam of 54 πmm.mrad, both septa have large physical aperture of 81 πmm.mrad. However, large aperture leads to large end fringe field, which has significant contribution to the leakage field interfering the circulating beam and causing beam loss. To provide users a proton beam with high beam power of 0.75 MW, the beam intensity will increase greatly in future. Thus, the injection system needs to be upgraded to accommodate the high intensity beam. Considering the strong space charge effects, larger physical aperture is needed to reduce the localized beam loss. This paper will discuss the problems encountered in operating the present septa, and give an optimized design for the new septa.

INTRODUCTION

The J-PARC main ring is a three fold symmetry lattice, which has three 116 m long straight sections. The injection system and the dump system share the same straight section. The injection system consists of 2 magnetic septa, 3 bump magnets and several kickers as shown in Fig. 1. The bump magnets can for a local bump orbit to release the beam cleance at the defocusing quadrupole (QDT) for high intensity injection beam. The 3 GeV incoming beam from the beam transfer line is deflected by two septa, a high-field septum-I and a low-field septum-II. To satisfy the thin septum thickness requirement, an eddy current septum is selected for the septum-II. However, the maximum peak gap field achievable is limited to about 0.32 T because of HV power supply restriction. The injection septum-I has to generate a high magnetic field of 1.5 T, which is close the material saturation leading to large leakage field. Due to the large physical aperture, the end fringe field is considerable large, which makes deleterious effects on the circulating beam also.

Beam commissioning with low beam intensity started from 2008. Without correction, the beam orbit distortion related to injection septa leakage field has been observed. Septa modification has been carried to improve their performance.

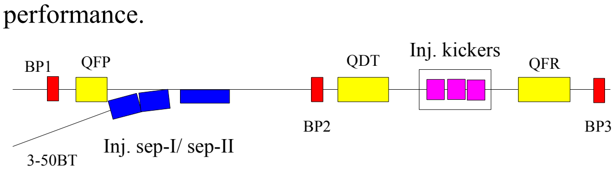

Figure 1: JPARC MR injection system layout.

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HIGH FIELD INJECTION SEPTUM-I

The high-field septum-I is divided in to parts with an angle of 5.67° to deal with the large bending angle. The circulating beam pipe is partly shielded at the downstream because of the narrow installation space. At the upstream, there is no shield surrounds the pipe because of the installation of some components (see Fig. 2). Since the magnet is required to generate high field of 1.5 T, the leakage flux at the downstream is very big. Furthermore, the magnet works in pulse model, induced eddy current affects the leakage field also.

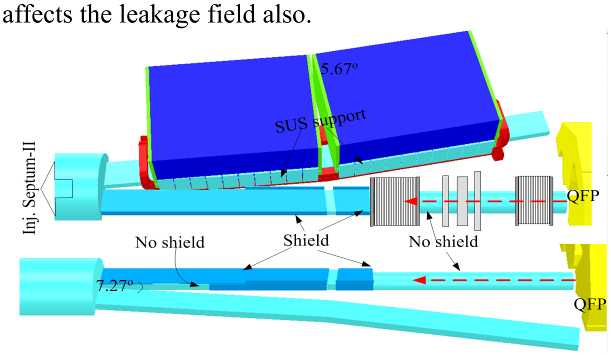

Figure 2: Injection septum-I structure and beam pipe.

Problems Encountered

The effect of the septum-I leakage field on the closed orbit was observed in the initial commissioning stage [1]. Fig. 3 shows the closed orbit distortion due to the leakage field from the septum-1. Beam injection starts after the top field become stable, which is about 40 ms delayed from the beginning of the top field. During the period of the "top" field and "fall" field the beam position changes accordingly, which means both the DC leakage field and the eddy leakage field can deteriorate the beam orbit.

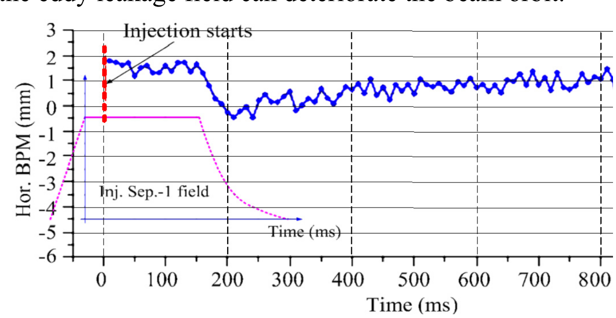

Figure 3: Close orbit distortion because of the leakage of injection septum-I.

Leakage Field Analysis

To investigate the leakage field, 3D simulation with eddy current effects had been performed. Fig. 4 shows the leakage field longitudinal distribution along the circulating beam center at 3 typical time. The entire leakage field can be divided into two parts, body leakage and end fringe leakage. The body leakage is time dependant indicating that the eddy current plays an important role.

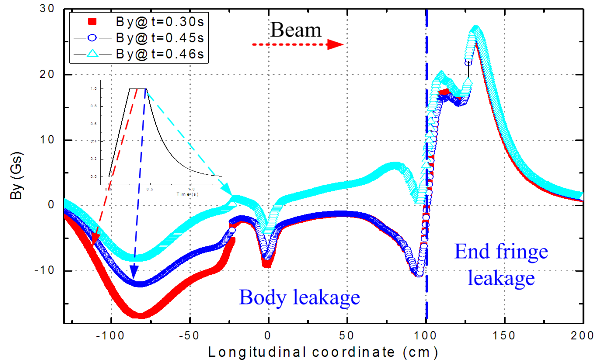

Figure 4: Leakage field longitudinal distribution along circulating beam center at 3 different, middle/end of top, beginning of fall.

The time dependant leakage field integral along the circulating beam center is calculated by opera-3D. The orbit analysis result using the technique of SVD (singular value decomposition) agrees with the field simulation well as shown in Fig. 5.

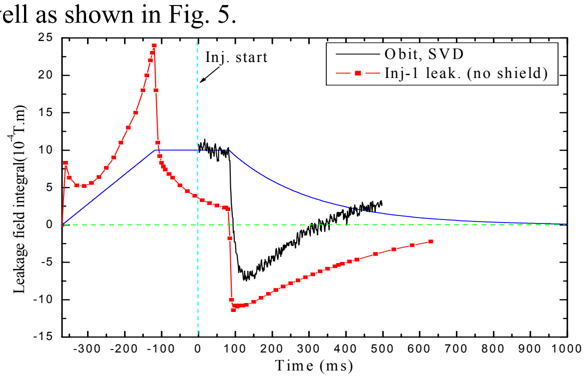

Figure 5: Leakage field integral predication and beam orbit vs. time.

To suppress the leakage, the septum-I was modified during the shutdown. The SUS coil supports were replaced by iron plates, and a shield plat is inserted in the between of end coil and the circulating beam pipe. SVD analysis shows that the maximum beam distortion will decrease to half after modification. However, the distortion is still unacceptable large for high intensity beam. So, a replacement new septum is proposed.

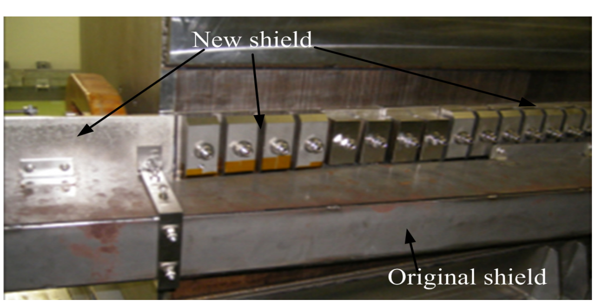

Figure 6: Septum-I modification.

MIC Septum Field Analysis

The new septum, which intends to replace the existing one, not only generate low leakage field to minimize any deleterious effects on the circulating beam but also needs to meet the requirements for high beam intensity operation, such as high radiation resistant, large aperture… thus a MIC septum is proposed.

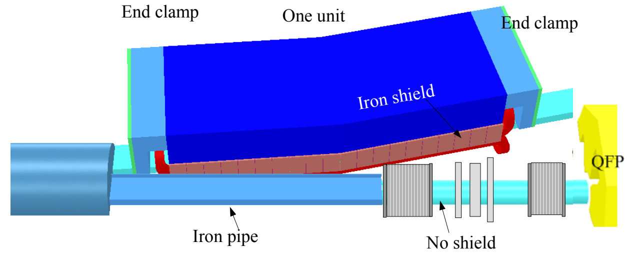

Figure 7: MIC injection septum-I.

The new septum structure cannot be changed much for the same installation place (see Fig. 7). The magnet core is designed as one unit so that gap field integral increases. There are many challenges in design this septum [2]. In view of leakage flux minimization, two crucial means, end field clamp and iron beam duct, are adopted, which can decrease the leakage to a negligible level (see Fig. 8).

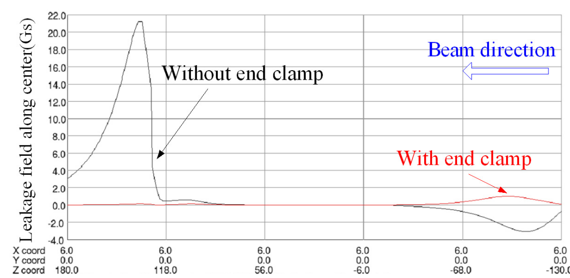

Figure 8: Leakage field of MIC injection septum-I.

LOW FIELD INJECTION SEPTUM-II

The present using septum-II is an eddy current septum because of the requirement of thin septum (see Fig. 9). The magnet is installed inside a vacuum tank. It is excited by a full sine wave with pulse width of 300 μs. The maximum gap field is about 0.32 T, which is limited by the HV discharge. Besides the copper septum screen the leakage, a very thin shield film (0.35 mm) and an aluminium beam pipe are utilized to suppress the body leakage field also.

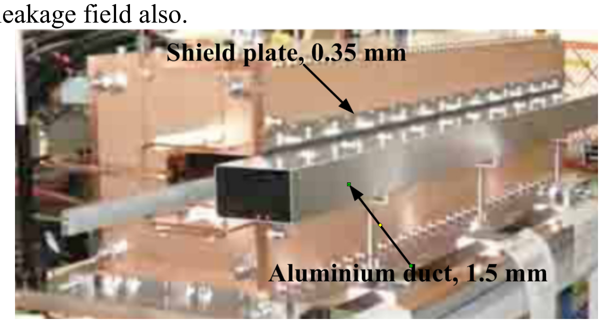

Figure 9: Eddy current septum structure. Vacuum tank is not shown.

Problems Encountered

Fig. 10 shows the beam current decrease during the operation of septum-II. Beam loss occurred every 40 ms whenever the injection septum was excited. It indicates that the leakage field of the septum-II has deleterious effects on the circulating beam and causing beam loss.

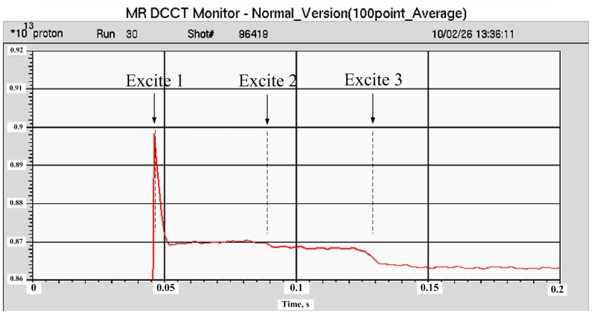

Figure 10: Beam loss due to septum-II excitation.

Field Analysis

OPERA-3D transient analysis code is used to simulate the leakage field. Fig. 11 shows the leakage at the circulating beam orbit center. It shows clearly that the end field contribution to the leakage is orders of magnitude higher than that of the body leakage field. The end fringe contribution appears at the longitudinal extremities, which can be illustrated in Fig. 12.

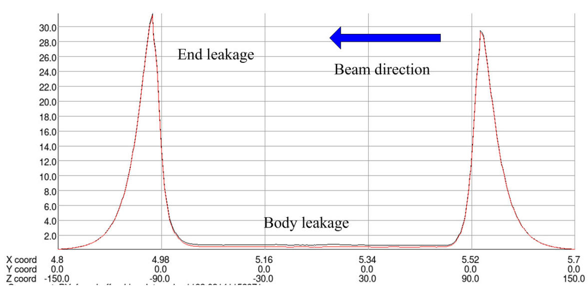

Figure 11: Leakage field longitudinal distribution at cir. Beam orbit center.

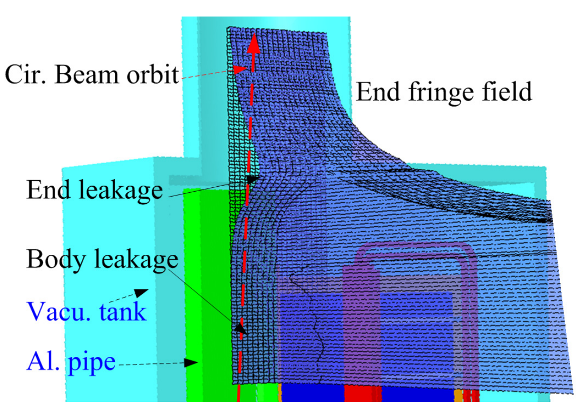

Figure 12: End fringe field shape at peak current.

End field Clamp

Fig. 12 clearly shows that the leakage field comes from the end fringe field contribution. Thus one direct way to eliminate the leakage field is suppress the end fringe field. Several end field clamps have been studied for comparison. After optimization, the end field clamp is designed as Fig. 13.

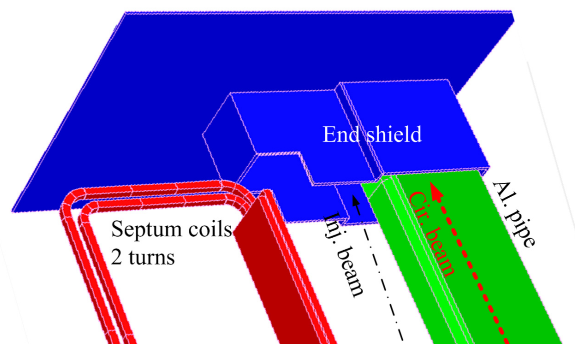

Figure 13: End field clamp structure. Vacuum tank is not shown for clarity.

Fig. 14 compares the resultant leakage field distribution in 3 different cases. The thickness of shield has effects on leakage field, but not very much. With end clamps, the total leakage field can decrease from 1.2 mT.m to 0.14 mT.m. However, the cost of using end field clamp is the degradation of gap 1.6%.

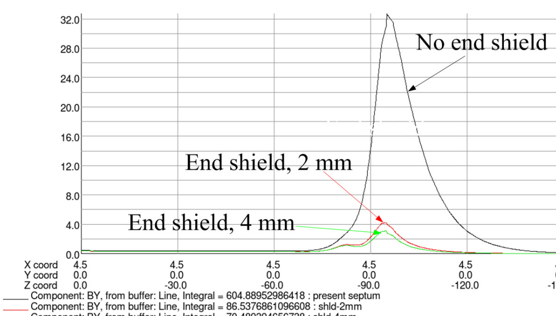

Figure 14: Leakage field distribution comparison, with/without end shield clamp (half magnet).

CONCLUSION

The deleterious effects of the injection septa leakage fields on the circulating beam have been encountered during the beam commissioning. Electromagnetic simulation indicates that the main contribution comes from end fringe field due to the large aperture. Using end field clamps can suppress the leakage field greatly.

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[2] K. Fan, K. Ishii et al, This proceeding.
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