

POSSIBILITY STUDY OF HIGH REPETITION RATE OPERATION OF JPARC MAIN RING

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Abstract

The original design of the JPARC main ring is to provide high beam power of 750 kW with a machine repetition rate of 0.3 Hz. However, the severe space charge effects at low injection energy limit the beam intensity. In order to raise the beam power to the design limit, one logical way is to increase the repetition rate. However, the resulting eddy current in the laminations and pipes may impair the field quality of all magnets. In addition, the activation of beam pipe becomes severer in high beam power operation. Titanium beam pipe is proposed to replace the stainless steel pipe to reduce the activation and to decrease the decay time. However, titanium has lower resistivity, severer eddy current effects are expected. The studies investigate the eddy current effects on field quality of the main dipole, quadrupole and sextupole magnets.

INTRODUCTION

The J-PARC facility is a world leading accelerator project, which consists of a 181 MeV linac, a rapid cycling synchrotron and a 50 GeV main ring (MR). The MR has the ambitious goal of accelerating a proton beam to a beam power of 750 kW. However, the maximum beam energy is reduced to 30 GeV due to the saturation of magnets, which requires higher beam intensity to realize the design beam power. The present beam power is only 230 kW. In order to increase the beam power to the design limit, the injection beam intensity must be increased greatly. However, beam simulations show that the beam losses increase drastically with the increase of beam intensity during the injection period due to the severe space charge effects [1]. Fig. 1 compares the beam losses at different conditions.

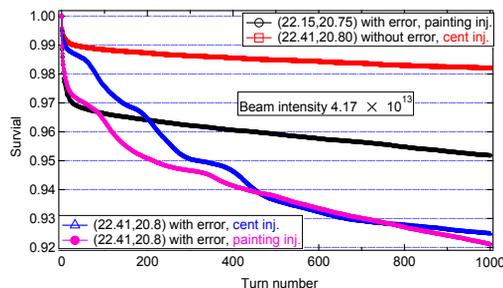


Figure1: Beam losses during injection period.

One possible way to increase the beam power without increase the beam intensity greatly is to increase the repetition rate of operation, which can mitigate the space

charge effects. However, the increase of the repetition rate leads to the increase of induced eddy currents. The eddy current in turn acts to produce "eddy fields", which contains various multipole fields that act on the beam [2]. The eddy current dissipated in the beam pipe may create thermal problems also. Detailed studies must be carried out in advance to determine how much repetition rate is feasible, and to predict the eddy current effects on the beam. The MR contains many kinds of magnets. This report studies the eddy current effects in bending magnets, the quadrupole, and the sextupole magnets as examples to explain the effects and how to correct them.

BENDING MAGNET

There are 96 bending magnets in the MR, which is about 6 meters long. The beam duct is made of stainless steel SUS-304 with a thickness of 2 mm. The eddy current distribution in the beam pipe depends on its structure. Since the bending magnet has large physical aperture, significant end fringe fields exist, which has considerable field components normal to the laminations and end plate. Thus, the eddy currents can be generated at both the beam pipe and the magnet end plates as shown in Fig. 2. The resulting eddy fields contain nonlinear fields that worsen the main field quality, particularly during the rise time, i.e. the beam acceleration period.

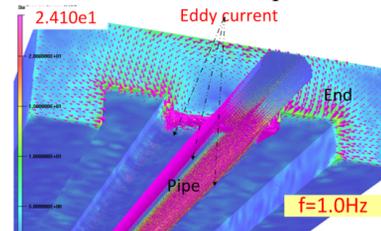


Figure 2: Eddy current distribution.

Figure 3 compares the field uniformity at the mid-plane with different repetition rate. With the increase of the ramp rate, the field uniformity becomes worse.

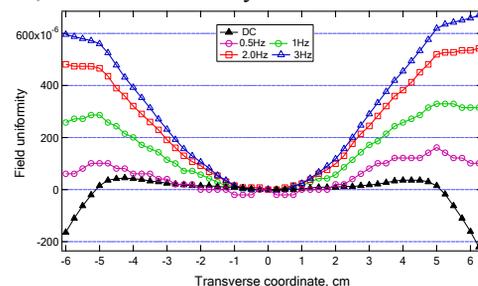


Figure 3: Coil structure of low-field septa.

Figure 4 compares the multipole field components at different repetition rate. With the increase of repetition rate the sextupole components increases, which might affect the beam quality.

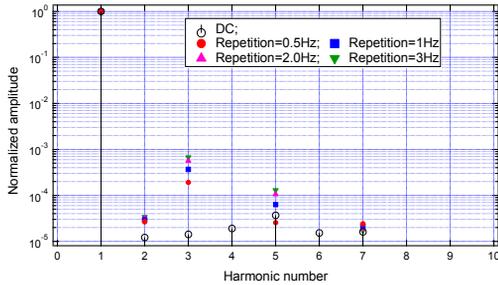


Figure 4: Higher-order field components comparison.

Thermal Generation

The eddy current flowing in the beam duct creates joule heat, and causes thermal problems also. For a bending magnet, the beam duct length is about 6 m long, which is wrapped by a kapton sheet for insulation. In addition the trim coils are jammed between the pipe and the main coils. So, the air convection inside the magnet aperture can be neglected. Thus, the heat generated at the center of the beam duct cannot be transferred to outside effectively. The thermal problems at the center can be simplified to 2D. The power losses dissipated in the beam duct are proportional to the square of eddy current density. The temperature at the center of the pipe is calculated by ANSYS as shown in Fig. 5. Considering the multipole field components and the heat generation, the repetition rate of 1 Hz is feasible.

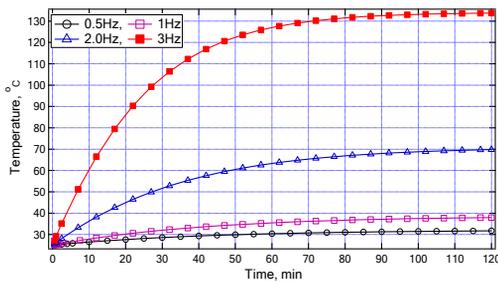


Figure 5: Temperature comparison.

Time Delay

The eddy current circuit contains inductance, which results time delay of the response field as shown in Fig. 6. Since all bending magnets have the same time delay, it can be corrected by adjusting the timing system.

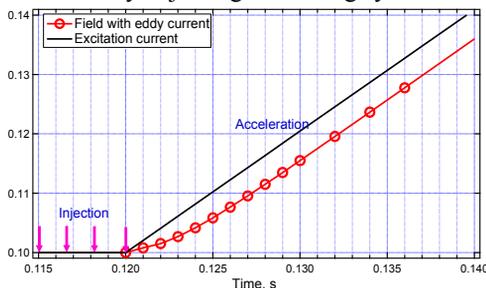


Figure 6: Time delay due to eddy current.

QUADRUPOLE

The Q magnets have 11 families with an aperture of 130 mm, 140 mm and 150 mm. The beam pipes have several shapes, which are shown in Fig. 7.

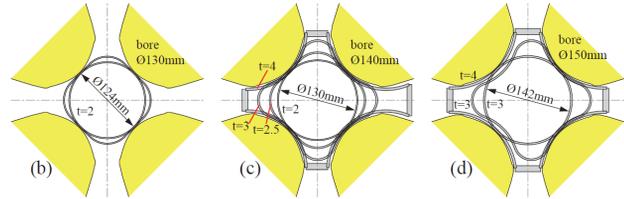


Figure 7: pipe shapes of Q magnet.

Q magnet with Different Beam Pipe

Three different pipes of the QDT are selected for studying the generation of eddy currents and their effects. The pipes are shown in Fig. 8 (half). The eddy current generation depends on the geometry and the material of the pipes.

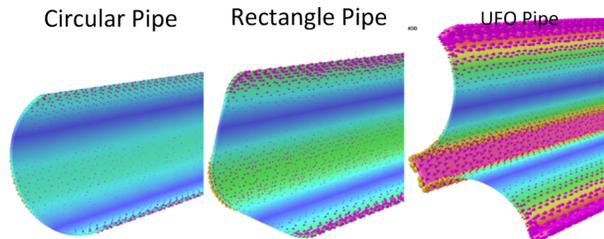


Figure 8: Eddy current distribution in different pipes.

To compare the eddy current effects of different beam pipes, which generate error fields superimposing to the main Q field, 3D beam trace is used to evaluate field quality. A laminar beam of circular cross section is launched upstream of the Q magnet and is compared with the beam parameters at the exit of the Q. This is shown in Fig. 9, which clearly show the difference of eddy current effects of different beam pipes.

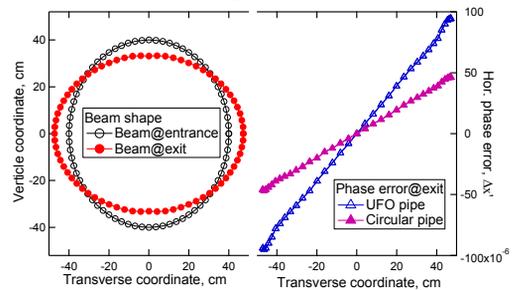


Figure 9: Comparison beam parameters of different pipes.

Q Field Delay of Different Beam Pipe

The time delay of the main magnetic field depends upon the pipe structure. Since the magnets are powered in series by the same power supply, their time delays are different, which then introduce error fields. Fig. 10 illustrates the effects of time delay. We need to compensate for these different time delays.

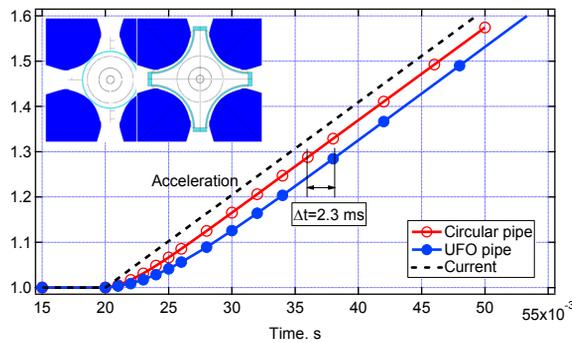
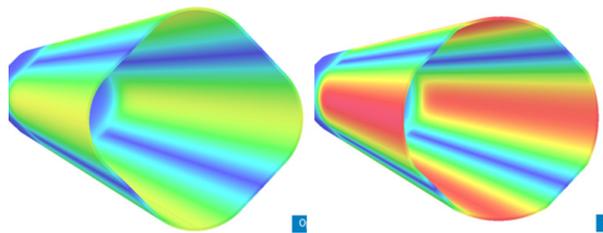


Figure 10: Time delay of different pipes.

Q Magnet Pipe Different Material

Activation of beam pipe might be a nuisance for a high intensity proton accelerator like JPARC, which prevents quick access to the accelerator after switching off. Light materials, such as titanium, have low activation level and decay more rapidly, which saves a lot of "decay time" and makes hands-on maintenance easier. The vacuum group designs a new titanium beam pipe to replace the present stainless pipe as shown in Fig. 11.



Stainless pipe (Rectangle) Titanium pipe (hexagon)
Figure 11: New material beam pipes.

The resulting field quality is compared in Fig. 12. The higher-order field components do not change greatly because the new pipe shape is symmetrical and the main eddy field is quadrupole, which is just opposite to main field.

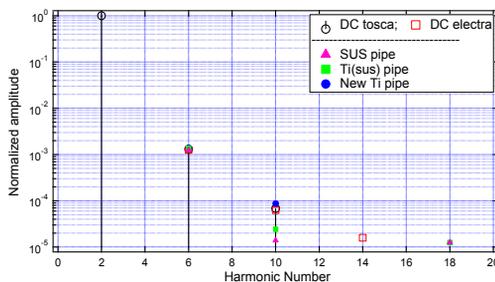


Figure 12: Harmonic comparison of different pipe.

SEXTUPOLE

The original sextupole beam pipe is circular shape. To reduce the activation of beam pipe, new pipe with Titanium material is proposed, which is shown in Fig. 13. Results of eddy current effects due to different pipes shape are compared.



Figure 13: Beam pipes of sextupole.

During the injection period, the high-order field components are evaluated based on the field Br at r= 5 cm. The 18-pole field is less than 10⁻³ as shown in Fig. 14.

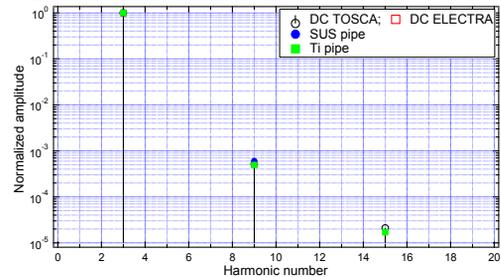


Figure 14: Higher-order field components comparison.

The time delay is shown in Fig. 15. Titanium pipe has longer time delay. Compared with Q magnet, the sextupole is much smaller and the resulting eddy current effect is smaller.

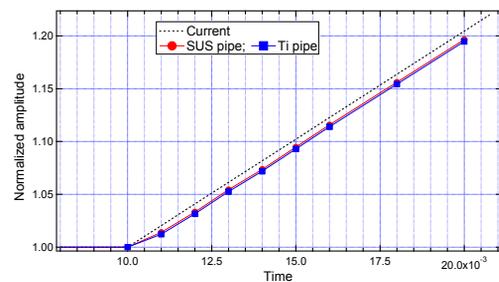


Figure 15: Time delay of sextupole of different pipe.

Summary

In order to raise the MR beam power to the design limit, the repetition rate can be increased to reduce the space charge effects. Simulations show that if the repetition rate increases from the original design of 0.3 Hz to 1 Hz, the eddy current effects on the field quality of all magnets are tolerable. However, the time delay needs to be corrected.

REFERENCES

- [1] K. Ohmi, K. Fan, et al., Simulation of spce charge effects in JPARC, IPAC10.
- [2] N. Sereno, et al., Eddy-current-Induced multipole field calculations, LS-2302.