LEAKAGE FIELD OF SEPTUM MAGNETS OF 3GEV RCS AT J-PARC

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Abstract

Septum magnets are installed in 3-GeV rapid-cycling synchrotron (RCS) at Japan Proton Accelerator Research Complex (J-PARC) for the beam injection and extraction. In order to realize MW beam in the RCS ring and to reduce the beam loss during the beam injection and extraction, the septum magnets have large physical aperture and are operated in DC. Thus the magnetic leakage fields from the injection and extraction septa are exited at the beam circulating orbits during the beam acceleration, and the leakage fields form error fields at the ring as a source of the closed orbit distortion (COD). In order to reduce the leakage fields, the silicon steel sheets are set for magnetic shield. In addition a few ring vacuum chambers, which are located near the septum magnets, are made of the erector-magnetic stainless steel.

The beam commissioning of the J-PARC 3-GeV has been started from September 2007, and the proton beam was accelerated to the final energy of 3GeV and extracted in the 3N dump, which is located at beam transport line to neutron production target, successfully on 31st October 2007. Up to now, the beam study has been carried out. As a result of the RCS beam study, it is confirmed that there are large COD cased by the extraction septum magnets (ESEPs) and the 3NBT bending magnet (3NBT-B01). The leakage field strength can be estimated from both the COD measurements and the leakage field measurements. The results of the COD measurements estimate that the leakage field from the ESEP is 22 Gm, and the one of the 3NBT-B01 is 29 Gm. On the other hand, the leakage fields from ESEP and 3NBT-B01 were estimated from the field measurements at 17 Gm and 19 Gm respectively.

INTRODUCTION

The J-PARC accelerator complex consists of a 400-MeV linear accelerator (LINAC), a 3-GeV rapid-cycling synchrotron (RCS), and a 50-GeV main ring synchrotron (MR) [1]. The RCS is designed to accelerate the H^+ beam from 400 MeV to 3 GeV, with $8.3x10^{13}$ protons per pulse at 25 Hz repetition rate. Thus it realizes a 1 MW, 40 kJ proton source. At the first stage, the beam is injected from the LINAC with 181 MeV energy. The RCS boosts up the beam power to 0.6 MW through accelerating the proton from 181 MeV to 3 GeV at a 25 Hz repetition rate.

The beam commissioning of the RCS has been started from September 2007, and the proton beam was accelerated to the final energy of 3 GeV and extracted in the 3N dump, which is located at beam transport line to neutron production target, successfully on 31st October 2007 [2]. Up to now, the beam commissioning has been carried out. The measurement and correction of the closed orbit distortion (COD) are one of the most important beam studies for the early beam commissioning. As a result of the COD measurement, it is confirmed that there are the large COD caused by the error DC fields leaked from the DC magnets at the extraction area. In this paper, the results of the COD measurements and the leakage field measurements in the RCS tunnel are reported. Then we discuss the future plan to suppress the leakage DC field at the circulating beam orbit additionally.

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COD MEASUREMENTS

Circulating beam orbits are obtained by beam position monitors (BPMs), which are installed the RCS ring. There are 54 BPMs around the ring and most of them are placed inside steering magnets [3]. The BPM is electro-static type and horizontal and vertical coherent beam oscillation can be measured at the same time. Fig. 1 shows the typical result of the COD measurement during the acceleration from 181 MeV to 3 GeV for every 1ms. As a result of the COD measurement, the amplitudes are reduced depending on an increase of the beam momentum. It means that this momentum-dependent COD is caused by the DC error fields leaked from the DC magnets.

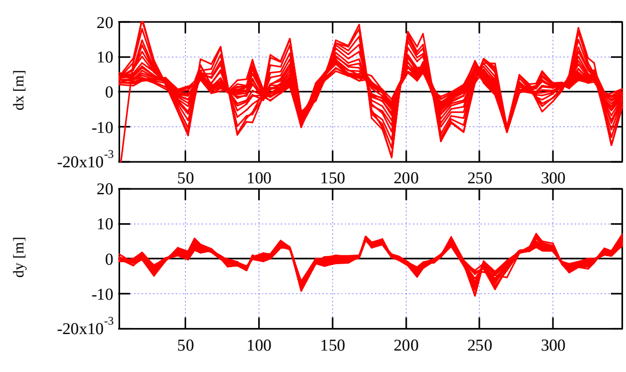

Figure 1: Measured closed orbits as a function of the longitudinal distance during the acceleration from 181 MeV to 3 GeV, in which the upper one shows horizontal closed orbits and the lower one shows vertical ones.

In order to estimate the leakage field strength from each DC magnet, the RCS was operated as a storage ring at 181 MeV, and the closed orbits were measured with the several operation patterns of the DC magnets. At first all DC magnets were off and the COD was taken. This COD was based to compare with the various measured CODs.

And next, the COD was measured by changing the exciting current of each DC magnet. Then the COD with each exciting current is compared to the COD with all DC magnets off. As a result, the large COD are caused by the extraction septum magnets (ESEPs) and the 3NBT bending magnet (3NBT-B01) mainly. Fig. 2 and Fig. 3 show the measured COD cased by the ESEPs and the 3NBT-B01 respectively. The amplitudes of the horizontal and vertical CODs with ESEPs excited at 3GeV mode is 12 mm and 0.7 mm, and the leakage fields, which is estimated with the beam simulation, is 22 Gm and 1.4 Gm (K0 ~ -0.7 mrad and skew K0 ~ -0.045 mrad) respectively. In the case of the 3NBT-B01, the amplitude is about 9mm and 1.4mm, and the leakage field is 29 Gm and 2.5 Gm (K0 ~ -0.9 mrad and skew K0 ~ -0.078 mrad).

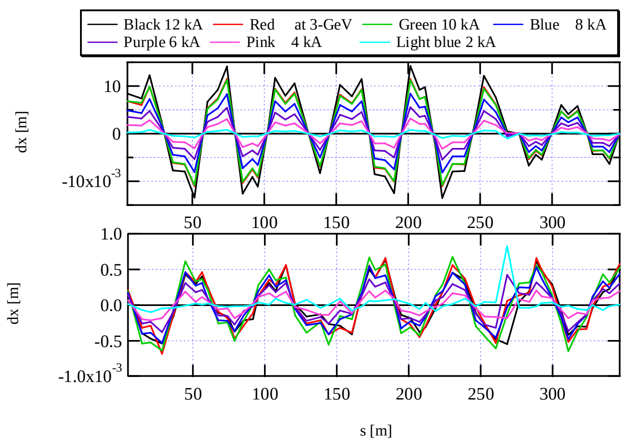

Figure 2: Measured CODs cased by the ESEPS at injection energy. The COD with each exciting current of the ESEPs is compared to COD with all DC magnet off, in which the upper one shows horizontal closed orbits and the lower one shows the vertical ones.

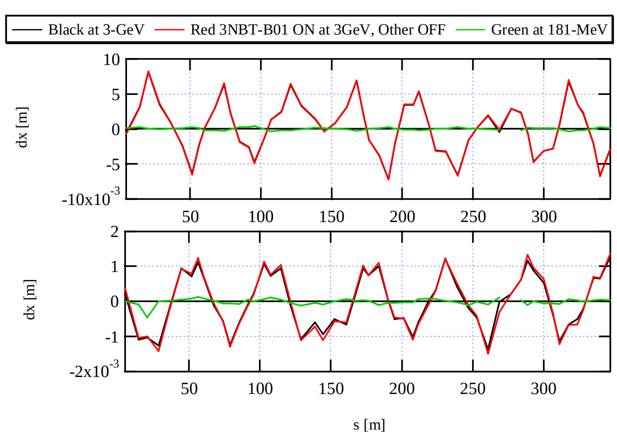

Figure 3: Measured CODs cased by the 3NBT DC magnets at injection energy. The COD with each operation pattern of the 3NBT DC magnets is compared to COD with all DC magnet off, in which the upper one shows horizontal closed orbits and the lower one shows the vertical ones.

LEAKGE FIELD MEASUREMENTS

There are 54 sets of the steering magnets (STMs) installed in the ring to correct the horizontal and vertical CODs. The exciting current patterns of the STMs were estimated from the different error sources, which were obtained the several COD measurements. After the COD correction with the STMs, both the horizontal COD and the vertical COD were reduced to the value smaller than a few mm during the beam acceleration. On the other hand, the COD correction could not reduce the DC leakage field. Thus the error DC fields affect the beam dynamics. In fact, As a result of the betatron resonance survey, the DC leakage fields enhance the half integer and liner coupling resonance. It suggests that there are significant K1 and skew K1 components in the leakage fields. Therefore, to suppress the leakage fields at the circulating orbit from the ESEP and the 3NBT-B01 additionally is one of the most important key issues in the J-PARC RCS.

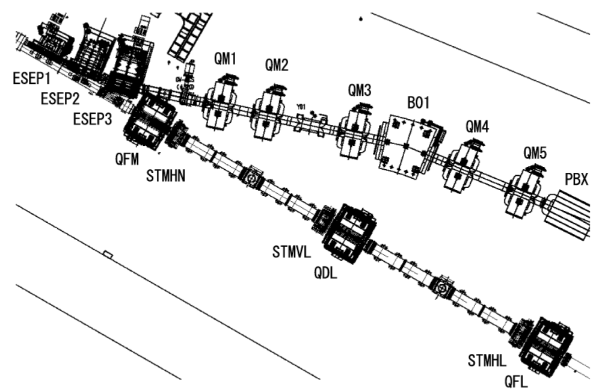

Figure 4: The schematic diagram of the RCS extraction area.

Fig. 4 shows the layout of the RCS extraction area. In order to obtain the distribution of the error DC field at the ring, the DC leakage fields were measured in the RCS tunnel. The leakage fields were measured along s-axis on the vacuum chamber. Fig. 5 and Fig. 6 show the results of measured field distributions leaked from the ESEPs and 3NBT-B01 excited at 3-GeV mode respectively.

In the case of the ESEPs, there are two types of the field distributions, as shown in Fig. 5. One is the narrow area and high peak distribution, and there are the two distributions between every ESEP. The other is the broad area and low peak distribution, and it exits at outside of the ESEP3. The septum magnets installed in the RCS have the magnetic shields made of the laminated silicon steel sheets to suppress the leakage fields. In addition a few ring vacuum chambers, which are located near the septum magnets, are made of the erector-magnetic stainless steel, and they have the capability of to diminish leakage field of the order of 100 G [4][5]. In the case of the ESEPs, every ESEP has the magnetic shield, but there are the gaps between every shield as shown Fig. 7. Thus the former type of distribution had formed from the coil leakage field pass through between each magnetic shield directly. The latter distribution had formed from the leakage field of the ESEP3 because the magnetic shield is saturated. The vacuum chambers located outside of the ESEP1, 2 were made of the electro-magnetic stainless steel. Then the chamber of the ESEP3 was made of SUS430 and it has also the field shielding capability. But the flanges were made of SUS316L and there are a few mm gaps of the magnetic chamber. Thus the leakage fields at the flange permeate into the vacuum chamber slightly. In the case of the titanium bellows, the field can permeate into the chamber thoroughly. Thus the total error DC field leaked from the ESEPs was estimated at about 17 Gm, and it was similar to the estimation from the COD measurement.

Fig. 6 shows the error DC field distribution leaked from the 3NBT-B01 excited at 3-GeV mode. The leakage fields were very weak with peak field of about 3 G, but it spreaded over the very broad area with length of about 10 m. The vacuum chambers at the ring were made of titanium and then the leakage fields can permeate into the chamber thoroughly. Therefore the total error DC field leaked from 3NBT-B01 at about 19 Gm, and it is comparable with the COD measurement.

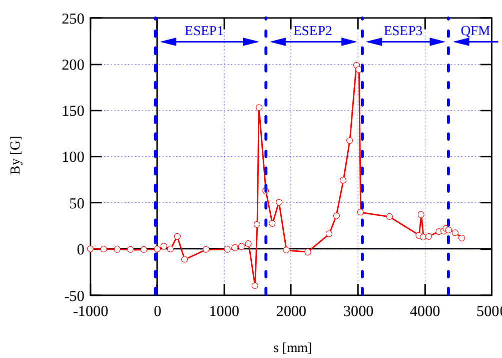

Figure 5: Measured leakage field distribution from the ESEPs along the s-axis on the top of the vacuum chamber, in which the origin of s-axis indicates the upper-stream flange of the ESEP1.

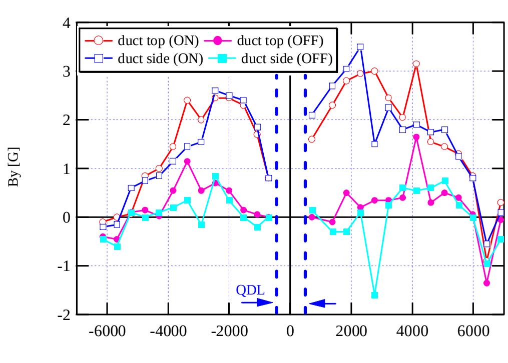

Figure 6: Measured field distribution leaked from the 3NBT-B01 along the s-axis on the top and side of the vacuum chamber, in which the origin indicates the center of the QDL.

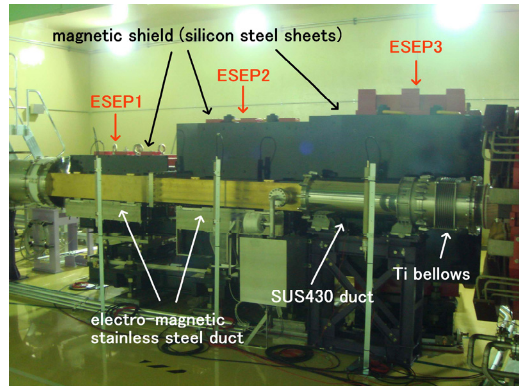

Figure 7: Three extraction septum magnets installed in the RCS tunnel.

SUMMARY

The beam commissioning of the J-PARC RCS has been started, and the proton beam was accelerated to the final energy of 3 GeV and extracted in the 3N dump successfully. From the beam studies, it is confirmed that there are the error DC fields at the circulating orbit leaked from ESEP and 3NBT-B01, and they affect the beam dynamics. The leakage field strength can be estimated from both the COD measurements and the leak field measurements. The results of the COD measurements estimate that the leakage field from the ESEP is 22 Gm, and the one of the 3NBT-B01 is 29 Gm. On the other hand, the leakage fields from ESEP and 3NBT-B01 were estimated from the field measurements at 17 Gm and 19 Gm respectively.

In order to suppress the leakage field, additional magnetic shield will be installed in this summer shutdown. In the case of the ESEPs, the additional magnetic shield plates will be attached on the gaps between the every existent shield and will be added to the existent shield of the ESEP3. In the case of the 3NBT-B01, the Ti-chambers will be wrapped with the magnetic shield sheets.

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