# MAGNET PATTERN CONTROL SYSTEM OF THE J-PARC MAIN RING

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*Abstract*

In the J-PARC Main Ring (MR), the bending, quadrupole, sextupole, and steering magnets can be controlled on the operating interfaces (OPI). The optics parameters for all magnets are calculated by using SAD, and are converted to BL tables of integrated magnetic field for each power supply. The BL tables contain the magnetic field parameters required from the optics, pattern timing, and beam energy. For MR beam studies, the BL tables are adjustable with offset and factor. For examples, this system is used for COD correction, manipulating local bump orbit, beta function measurement, aperture survey, and slow extraction. In this proceeding, the operating pattern of magnets and results of beam studies are described.

## COMPONENTS OF THE MR

The MR [1] is designed with three straight sections and arc ones. There are 96 bending magnets, 216 quadrupole magnets, 72 sextupole magnets, and 96 horizontal steering magnets, and 95 vertical magnets. The bending magnets are driven by 6 power supplies and operated as 1 family. The quadrupole magnets are operated as 7 families in straight sections and 4 families in arc ones. The sextupole magnets are installed in each arc sections as 3 families. The horizontal steering magnets are placed upstream of each focusing quadrupole magnets and the vertical ones are installed upstream of each defocusing quadrupole magnets. In the beam ducts of steering magnets, there are beam position monitors (BPMs).

Figure 1 shows the EPICS [2] network of the MR. A lot of components of MR are connected to this network. If an operator put a operating tune from the OPI of MR optics to the online model constructed by using SAD [3], the k values of quadrupole magnets are calculated. The online model is called as Virtual Main Ring (VMR). In this calculation, 4 families of quadrupole magnets in the arc sections are not changed to keep dispersion free in the straight sections.

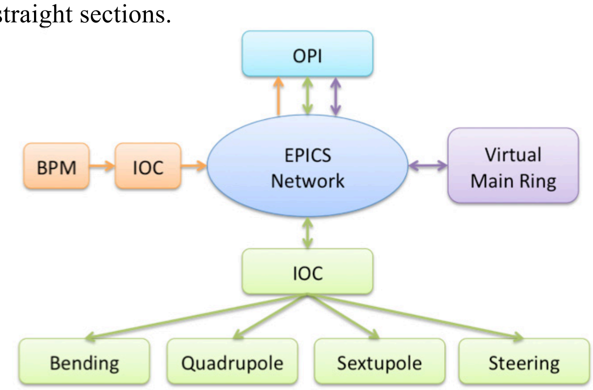


Figure 1: EPICS network of J-PARC Main Ring

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## PATTERN OF MAIN MAGNETS

The MR has two types of operating cycles for fast extraction (FX) and slow extraction (SX). The FX cycle is 3.52 sec and the SX cycle is 6 sec. Before making new BL patterns of the magnets, a momentum pattern should be produced. Figure 2 shows the pattern for FX. Between the start of cycle and 170 msec is the flat base for injecting the beam. After the beam injection, the beam is accelerated to the flat top energy, 30 GeV, for 1900 msec. The pattern is kept flat top for 150 msec. In this pattern, there are 100 msec smoothing sections of parabola curves in start and end of acceleration and deceleration to reduce the dI/dt of the magnets.

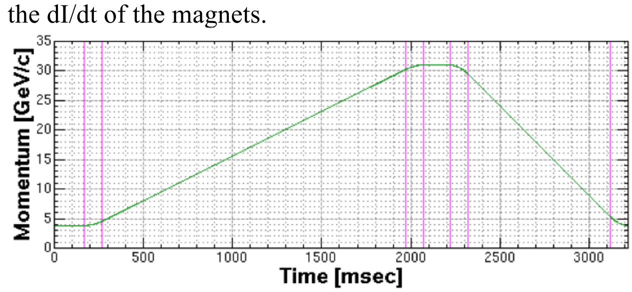


Figure 2: FX momentum pattern

With the calculated k values and momentum pattern, the new BL, GL, and G'L patterns are made on the Input Output Converter (IOC). The power supplies have two pattern memories. One is for operating the magnet, and another one is for receiving pattern from the IOC. If the pattern switch trigger is put, the pattern memories are switched, and then the new operating pattern works. However, if the flat base of new pattern is different from the one of operating pattern, the flat bases should be connected smoothly to operate the power supplies in safe. This magnet control system can connect the previous and new flat bases automatically, but in practically, this step is done manually with stopping the cycle trigger for more safe operation.

## COD CORRECTION

The bare COD of the MR is about +/-10mm in horizontal plane, and +/-5mm in vertical plane. To correct the COD, next 3 steps are necessary.

1. Taking all BPM data in the ring
2. Calculation of the COD correction by the VMR
3. Setting new k values for the steering magnets

If these steps are iterated 3-5 times, the COD will be +/-2mm. Figure 3 and 4 show the horizontal and vertical COD plots at flat base energy before and after correction.

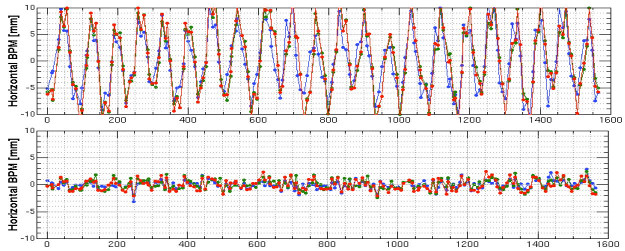

Figure 3: Horizontal COD correction

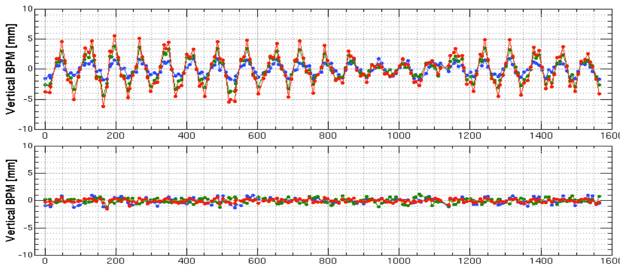

Figure 4: Vertical COD correction

The flow of COD correction works well with using the BPM data taking system [4, 5], the VMR, and the steering control system on the EPICS network. However, the RMS of COD is blown up if the beam was accelerated with the COD correction setting at flat base only as shown in Figure 6 (magenta plots). In the other way, if the COD correction setting at flat top was used, the RMS at flat base comes larger as blue plots in Figure 5.

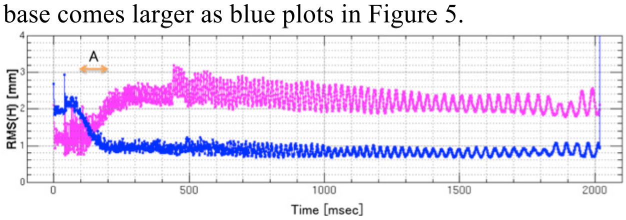

Figure 5: RMS of horizontal COD

To keep small COD from flat base to flat top, the two operating pattern of all steering magnets are connected at A in Figure 5. As an example, the pattern of horizontal steering magnet at address #001 in the MR is shown in Figure 6. The main pattern is based on the flat top COD correction, and the BL offset, which puts flat base COD correction into practice, is added to the timing before the RMS crossing. With these connected steering patterns, the RMS of horizontal COD is kept small as shown in Figure 7.

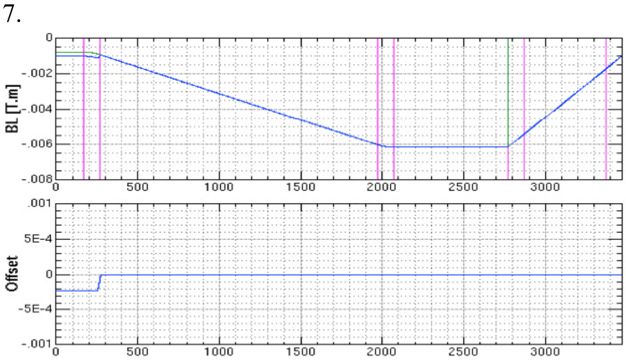

Figure 6: Horizontal steering pattern at address #001

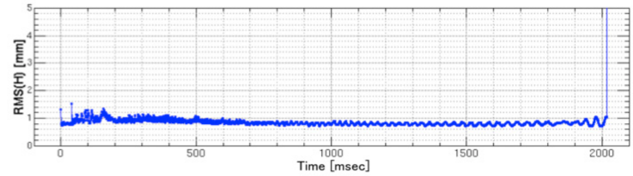

Figure 7: RMS of horizontal COD with connected steering patterns

## LINEAR COUPLING RESONANCE CORRECTION

To have high power beam, the linear coupling resonance should be corrected for opening tune-spread space. Installing skew quadrupole magnets is a solution to reduce the resonance, but the MR has not skew quadrupole magnets yet. As the other solution, vertical local bumps at sextupole magnets, by using vertical steering magnets can produce the skew quadrupole magnetic field to the beam. For this study, the heights of local bumps are calculated on the VMR, and the corrected patterns are set to the steering magnets. With optimizing the heights of local bumps in two sextupole magnets, 94% beam is survived on the linear coupling resonance. Figure 8 shows the beam lifetime before (red) and after (green) the correction.

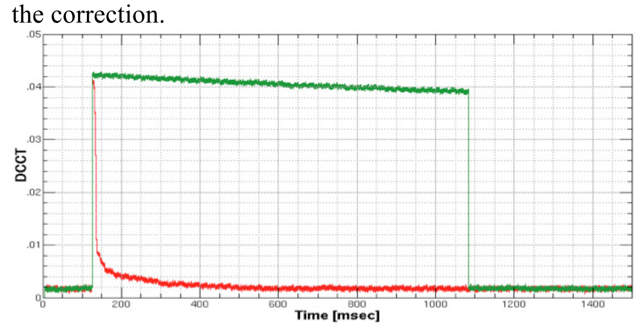

Figure 8: Beam lifetime before and after the coupling resonance correction

## APERTURE SURVEY

The aperture survey at injection septa, injection kickers, injection dump kickers, injection dump septa, collimators, electro static septum (ESS), SX septum magnets, FX kickers, FX septum magnets and dispersion peaks in the arc sections had been done with setting local bumps until all protons are lost. For this study, the MR operation mode had been set as 3GeV DC. The bump height is increased gradually during 1000 msec, and the maximum height is set as +/- 80mm. Figure 9 shows an example of steering BL offset pattern. The measured beam current during the aperture survey is shown in Figure 10.

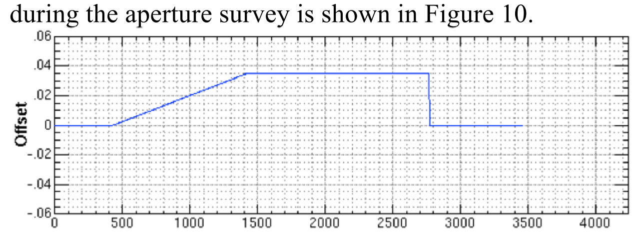

Figure 9: Steering pattern for aperture survey

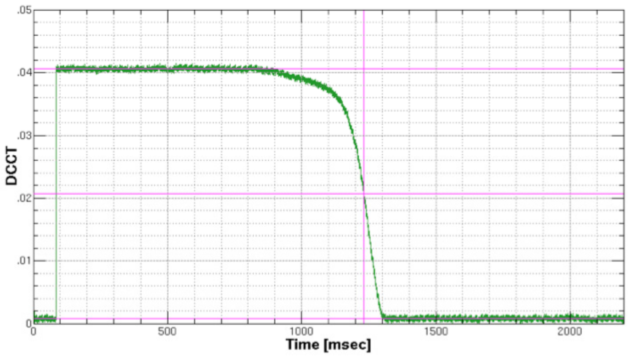


Figure 10: Beam current during aperture survey

## BETA FUNCTION MEASUREMENT

To measure the beta function, single kicks by steering magnets are used. With considering no beam loss in the MR, the single kicks are set as +/- 0.2mrad. If only one single kick was given in a MR cycle, 383 shots are required to measure the beta functions at all BPMs. To have the study time shorter, each BL offset of steering magnets is set with time shift as shown in Figure 11. With this method of pattern setting, only 12 shots are required to measure all beta functions in the MR. The measured beta functions in the first straight section and arc section are shown in Figure 12. The blue and red curves are calculated beta function in horizontal and vertical, and the plots are the measured beta functions.

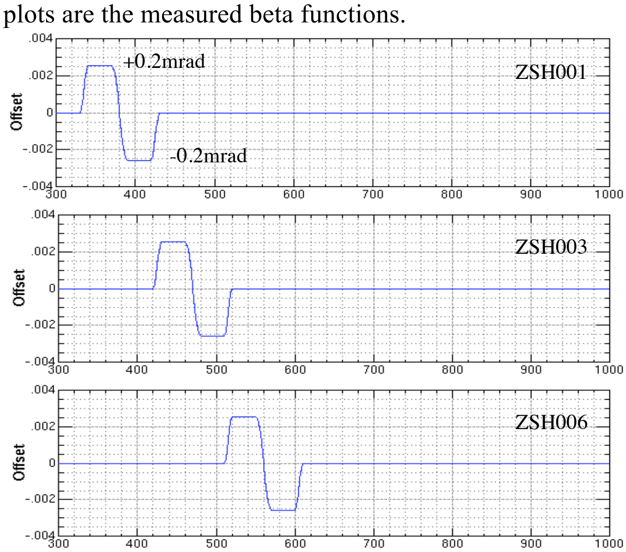


Figure 11: Steering patterns for beta function measurement

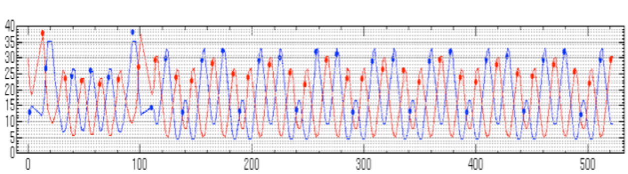

Figure 12: Calculated and measured beta function

## TUNE RAMPING IN SLOW EXTRACTION

To extract the beam to the hadron experimental hall, the horizontal tune is pushed to the third order resonance. To vary the horizontal tune, the QFN family placed in the arc sections is used. Figure 13 shows the operating pattern of the QFN. At the flat top energy, the GL offset is added to the base pattern. The measured beam current of the slow extraction is shown in Figure 14.

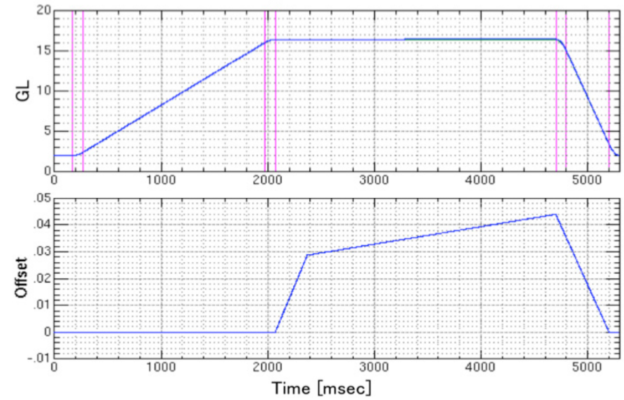


Figure 13: QFN pattern for slow extraction

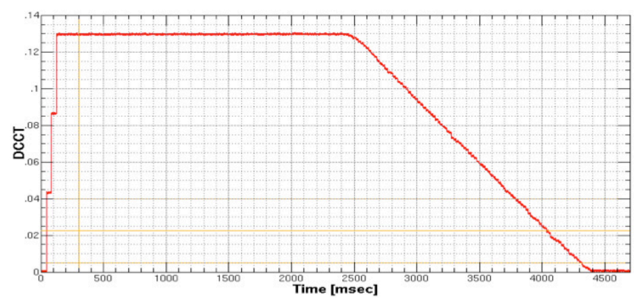


Figure 14: Beam current of the slow extraction

## CONCLUSION

The magnet pattern control system of the MR is useful for beam operation and studies as described on this proceeding. In near future, automatic beam based alignment (BBA) system will be produced. For the BBA study, it is required to set local bumps at each quadrupole magnets automatically. This magnet control system will be upgraded for any beam studies.

## REFERENCES

[1] T. Koseki, "Challenges and Solutions for J-PARC Commissioning and Early Operation", IPAC'10, Kyoto, May 2010, TUYRA02, (2010); http://www.JACoW.org.

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