ORBIT CORRECTION SYSTEM FOR S-LSR DISPERSION-FREE MODE*

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Abstract

Closed orbit correction will be applied to S-LSR for dispersion-free mode. Gradual transfer from normal mode to dispersion free one is needed and addition of electric field and correction of closed orbit distortion(COD) is shifted step by step to guide the ions through 30×26mm aperture in bending sections. Maximum COD is reduced from 2.5mm to 0.8mm using a proton beam. Based on this result, possible process to realize the dispersion-free mode is simulated. During the process, COD will be kept below 9mm, smaller than vertical aperture of ±13mm.

INTRODUCTION

Commissioning of $^{24}Mg^{+}$ beam at S-LSR[1] has been started with preparing for the dispersion-free mode using both magnetic and electric field. The relation among dispersion $\Delta r/r$,magnetic field B, electric field E is written[2] as

$$\frac{\Delta r}{r} = \frac{qr}{mv^2}\frac{\Delta v}{v}(vB - 2E) \quad (1)$$

where r is the bending radius; q, m, v are charge, mass and velocity of the particle. These fields must satisfy the equation about centrifugal force:

$$m\frac{v^2}{r} = q(vB - E) \quad (2)$$

Eq. (1) shows that increase of electric field decreases dispersion. When electric field reaches

$$E = vB/2 \quad (3)$$

the linear dispersion is completely suppressed.

The electric field is generated by electrostatic deflectors. Gaps of the deflectors are 30mm in width and 26mm in height; this is much smaller than the original aperture. To guide ions through such small gaps, COD correction is necessary.

APERTURE AND COD SOURCES

S-LSR has been operated using a proton beam and a magnesium beam without the electrostatic deflectors. This operation is called “Normal mode”, which has large aperture and small COD. The horizontal aperture is limited to ±60mm by the middle electrodes of a micro channel plate(MCP) beam profile monitor. The vertical aperture is limited to ±20mm by the electrodes of electrostatic beam position monitors. In normal mode, dominant COD source are toroidal magnetic field in an electron cooler, vertical electric field in the MCP and individual differences of BL products of the bending magnets.

On the contrary, operation using the deflectors called “Dispersion-free mode” has small aperture and large COD. The aperture is limited by the deflectors; ±15mm and ±13mm in the horizontal and vertical directions respectively. COD will be increased to a few centimeters by errors of gap lengths and rotation of electrodes. The increased COD is not measured yet; however the foreseen COD is calculated using MAD[3]. The result of calculation is shown in Fig.1.

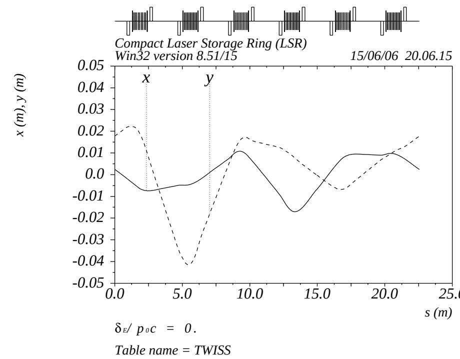

Figure 1: Calculated COD with electrode errors

Here, table 1 shows aperture and COD at the normal mode and the dispersion-free mode. It shows increased COD exceeds the decreased aperture in the dispersion-free mode. This means that some closed orbit correction is necessary for dispersion-free circulation.

Table 1: Aperture and COD at the normal mode and the dispersion-free mode

	Normal	D-Free
Horizontal Aperture	±60mm	±15mm
Vertical Aperture	±20mm	±13mm
Horizontal COD	±5mm	±12mm
Vertical COD	±3mm	±40mm

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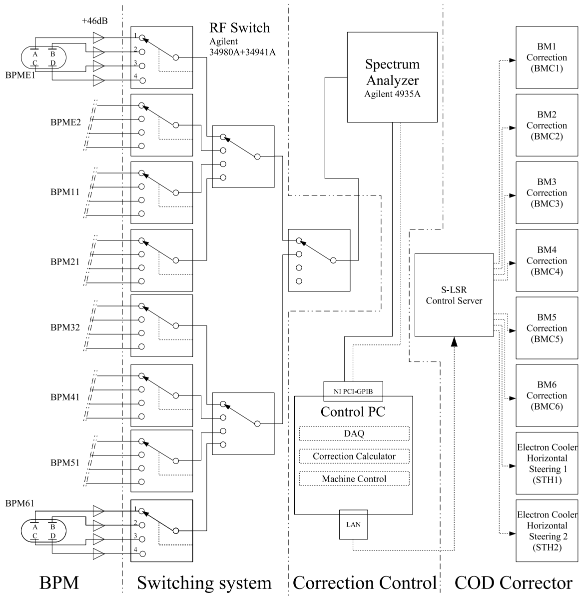

Figure 2: Block diagram of the COD correction system

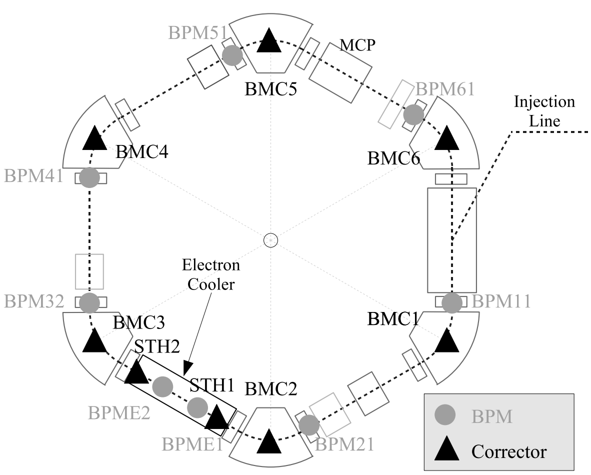

Figure 3: The layout of BPMs and correctors. BPMs are indicated as circles and correctors are triangles.

CORRECTION WITH PROTON BEAMS

Before storage of $^{24}Mg^{+}$ ions, COD correction is tested with proton beams. Experimental setup is shown in Fig.2. Horizontal COD correction is performed with use of correction current at each dipole magnet and steering magnets at electron cooling section. Vertical correction is performed by 6 kickers converted from beam position monitors as described later. The correction system consists of eight electrostatic BPMs, BPM switching system, correction control system and eight COD correctors. The layout of monitors and correctors are shown in Fig.3.

Signals from four plates are led into a spectrum analyzer and acquired by a computer one after another. The horizontal and vertical positions are calculated from the four signal amplitudes. With measured beam positions, the best correction is calculated using simplex method. The evaluation function is RMS value of the BPMs. The response matrix of BPMs and correctors are actually measured in advance. The computer accesses the control server of S-LSR and corrects the closed orbit.

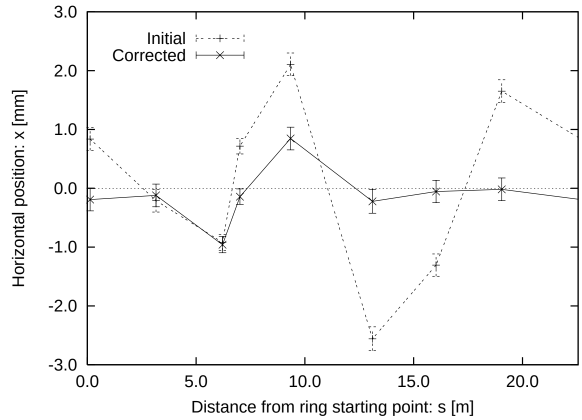

Figure 4: Result of Horizontal COD correction

The results are shown in Fig.4. Maximum COD is reduced from 2.5mm to 0.8mm. This residual COD comes from small adjustable range of steering magnets of the electron cooler.

CORRECTION SCHEME OF THE DISPERSION-FREE MODE

To realize the Mg^{+} dispersion-free mode, step-by-step increase of the electric field is necessary. At first, S-LSR is operated with electrodes on the orbit, although no voltage is applied($E = 0$),where beam circulates in small aperture with small COD.

Next, low electric field is applied and increase magnetic field to satisfy Eq. (2). When the electric field increases, COD also increases because of the errors of electrostatic deflectors. If electric field is low enough, increase of COD is still small and the beam continues circulating. Then COD can be put back to the same level as normal mode by correction. Next some more electric field and magnetic field is applied, and then COD is corrected in the same way. Therefore, steps of adding fields and correcting COD is repeated little by little until dispersion-free condition ($E = vB/2$) is achieved.

The limit of field increase per step is quantitatively estimated using MAD. Assuming non-cooled beam size is about 10mm, maximum COD must be kept within ±10mm. The betatron tune is $(\nu_x, \nu_y) = (2.07, 2.07)$, which is used for dispersion-free laser cooling.

Some parts of experimental setup are different from that in the case of proton. At first, the lifetime of $^{24}Mg^{+}$

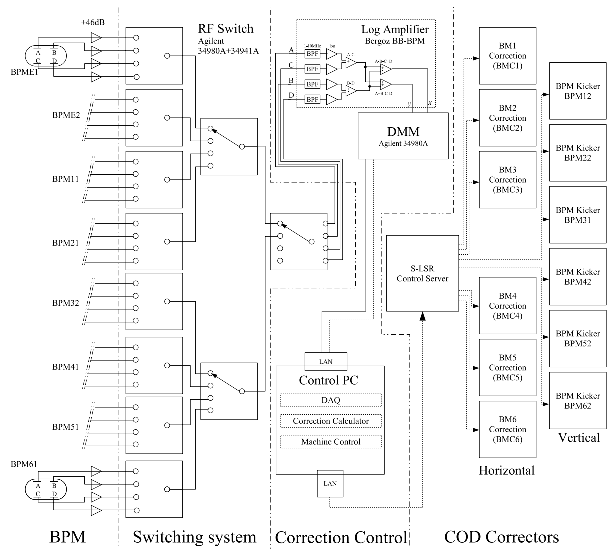

Figure 5: Block diagram of Mg^+ COD correction

beam (∼10sec) is much shorter than that of proton beam (∼several hours). Therefore fast position measurement using log amplifier is necessary.

Horizontal correction is realized by bending magnet correctors(BMC). In contrast to the case of proton beam, the electron cooler is shut down when the magnesium beam is circulating. Therefore the number of horizontal correctors is just six.

Vertical correction is realized by “BPM kickers”. S-LSR has twelve BPMs and only six of them is connected to amplifier and used for position measurement. Six unused BPMs will be connected to DC power sources and behave as vertical kickers. Hence there are six vertical kickers too. Overall setup is shown in Fig.5.

SIMULATION RESULT

The COD and the corrector values are calculated by MAD under these conditions. The result is shown in Fig.6. Magnetic field changes from B_0 =1.26T to B_{df} =2.52T, electric field from E_0 =0V/m to $E_{\mathrm{df}} = 7 \times 10^4$V/m. The final value B_{df} and E_{df} satisfies the dispersion-free condition $E_{\mathrm{df}} = vB_{\mathrm{df}}/2$.

It needs five correction steps to achieve the dispersion-free condition. Each step takes about two minutes, thus it takes about twenty minutes to complete the transition. Vertical COD is kept under 9mm during the process and horizontal COD is much smaller.

It shows that corrected vertical COD grows larger. BPMs are inserted to quadrupole magnets, which are on the side of bending magnets. Therefore if COD at BPMs are completely corrected, there are some residual COD in the center of bending magnets. This residual COD grows larger proportional to the strength of the electric field; this is acceptable if electric field stays lower than $1.2E_{df} = 8.4 \times 10^7$V/m. If more electric field is applied, we may need another vertical correctors.

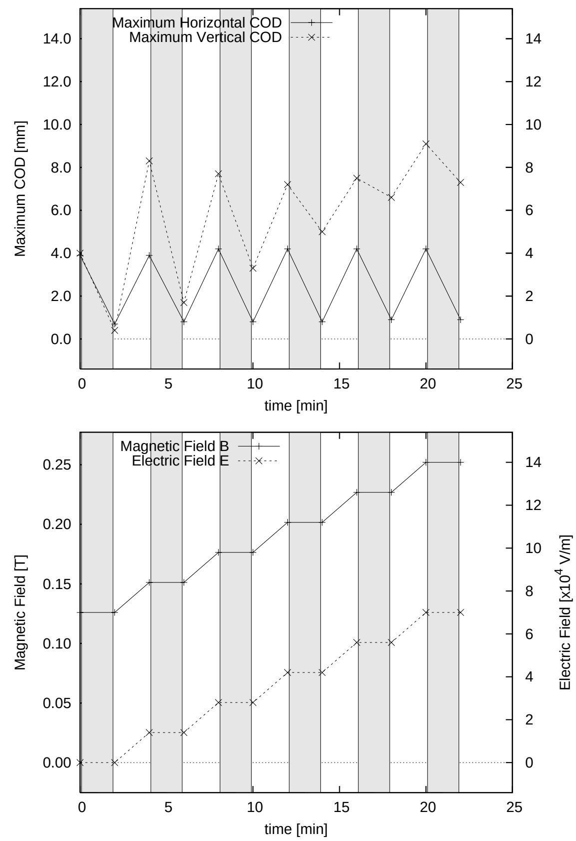

Figure 6: Gradual transition to the dispersion free mode. The upper figure shows the change of COD. The lower figure shows the change of electric field and magnetic field. Gray regions indicate periods of COD correction.

Horizontal COD is kept smaller than vertical one, the corrected value 0.8mm is comparable with that of proton beam. Final maximum correction angle is 4.0mrad in horizontal and 12.5mrad in vertical.

SUMMARY

Dispersion-free circulation of $^{24}Mg^+$ is being prepared. The procedure to realize dispersion-free circulation is constructed; it is verified quantitatively by using MAD. Adding field with step-by step correction will keep the COD within the small aperture and will enable the transition to the dispersion-free mode.

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