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Horizontal COD measurement and correction system in HIMAC synchrotron

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Abstract

A horizontal COD measurement system has been made which has twelve electrostatic pick-up monitors beside focusing quadrupole magnets. The measured horizontal COD has maximum value of 14mm, and is corrected down to 2mm with simple way by use of twelve steering magnets which have been set at same places of the monitors.

I. Introduction

HIMAC synchrotron[1] has been designed to accelerate heavy ions from He to Ar. Injection energy is 6MeV/u and maximum energy is 800MeV/u for ions of e/m=0.5. The maximum required beam intensities for each ion species are determined to have dose rate of 5Gy/min. In the carbon case which is being used for cancer treatments now, required beam intensity is 4×10^9ppp. To obtain this value in the synchrotron, the multiturn beam injection scheme is adopted. Hence, horizontal and vertical acceptances of the ring are 260π and 26π mm mrad, respectively. Slow beam extraction with third order resonance is used, and this process requires extra horizontal space for last three turn. To determine the sizes of vacuum chambers and good field regions of magnets, additional spaces for residual COD after the correction are added. Hence the maximum apertures are ±122 and ±28mm in horizontal and vertical directions, respectively. Non uniform contraction and deformation of base concrete after final alignment deteriorate its accuracy, and increase the COD. To correct these horizontal CODs and maintain the machine acceptance large, the horizontal beam position monitor and the steering magnet systems have been constructed.

II. Electrostatic pick-up monitors

To measure the horizontal COD, electrostatic pick-up monitors with triangular right and left electrodes have been made. The electrodes that are 260mm long are made of stainless steel SUS316L. The aperture is 238 mm wide and 32mm height, which is defined with window frames to prevent the noise due to lost beam hitting. The capacitance is 110pF and its balances between the right and left electrodes in each monitors are adjusted within 2 pF with a movable ground plate (see Fig.1).

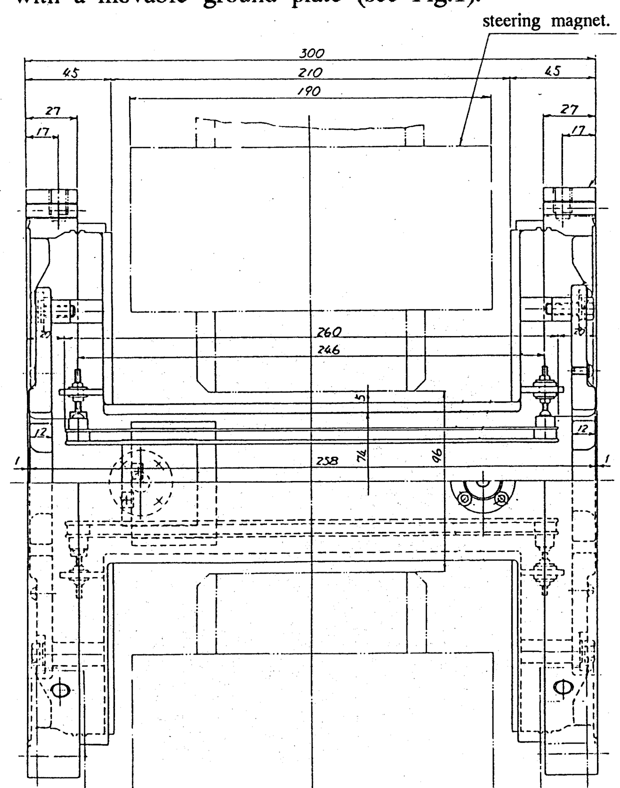

Fig.1 Electrostatic pick-up monitor together with steering magnet.

To check the output, test signal with a rod in the monitor chamber has been used. Amplitudes of output signals from right and left electrodes (V_R and V_L) have been measured as a function of the rod position. With simple assumption the position (x) is given as follows;

$$X = (W/2)(V_R-V_L)/(V_R+V_L), \quad (1)$$

where W is electrode width. In Fig.2 the measured values of $(V_R-V_L)/(V_R+V_L)$ are plotted versus the horizontal rod position, and show linear dependence on X in the full aperture with 24% larger value of the coefficient W (294mm) than the geometrical electrode width (238mm). If there are unbalanced capacitances or setting errors of right and left electrodes, measured beam position has offset error. If this error was larger than 0.5mm, we adjusted the capacitance valance to reduce the measured position at the center.

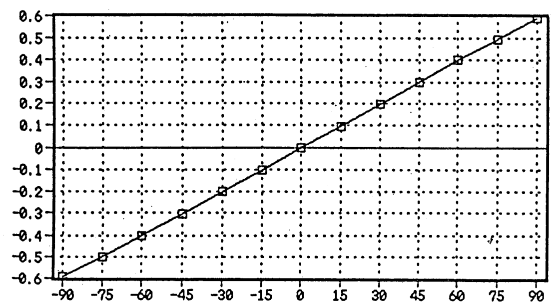

Fig.2 Output values of $(V_R-V_L)/(V_R+V_L)$ versus rod positions.

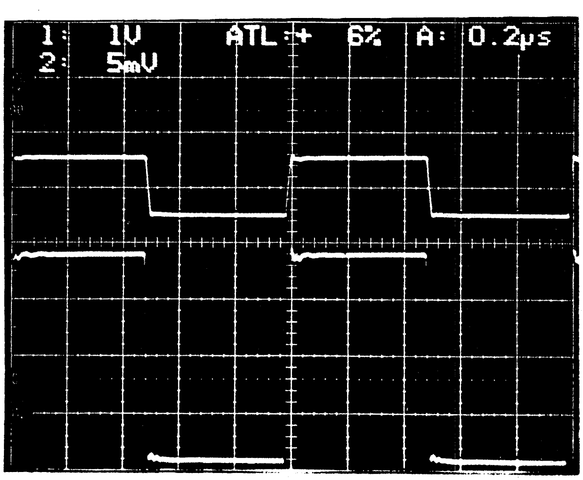

Fig.3 The upper is the input signal from signal generator and the lower signal is the measured output of the monitor electrode.

III. Monitor electronics

Monitor electronics is similar to the one[2],[3] in an acceleration system except for following points.

1) Between pick-up electrode and first FET amplifier, there is semi-rigid cable of 40cm which has resister of 100Ω in the middle. As shown in Fig.3 this attached resister permit to amplify the beam signal without distortion by the signal reflection. And this cable permit to attach the first amplifier away from the vacuum chamber and to decrease radiation damage of the FET amplifier.

2) There is only one beam signal processor for position detection, and the beam signals from twelve monitors are selected with diode switches. Isolation between input channels are better than 62dB, which value is good enough for our purpose. Switching speed is 200ns and this fast speed make it possible to measure twelve horizontal beam positions in a short time as flat base period.

At the end of signal processor a low pass filter of 1kHz is used to reduce the white noise. The measured output values are shown in Fig.4. In this monitor system, frequency range of input signal is from 1 to 8MHz, and gain range from 0 to 60 dB (range used in daily operation). With difficulty of the fine adjustment in the wide range of frequency and gain, monitor electronics have offset errors of ±2mm. Owing to the wide horizontal aperture of ±122mm, this error is acceptable.

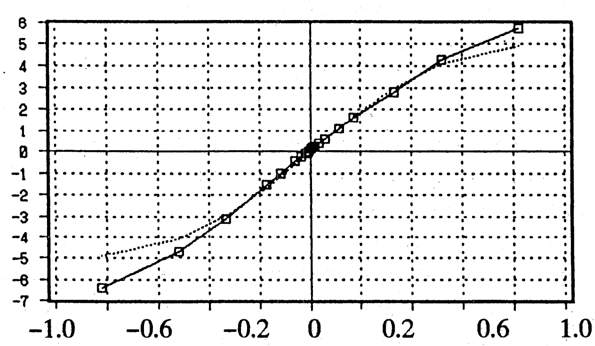

Fig.4 Output of the monitor processor versus input value of (Vr-Vl)/(Vr+Vl) with the monitor gain of 20dB and the frequency of 8MHz.

IV. Steering magnets

Twelve steering magnets have been installed at the same place as monitors to correct the horizontal COD. The magnets have been made with laminated core to make possible the pattern operation for COD correction at flat top. Maximum field strength is determined to correct the expected CODs at the flat top field which are 16mm. The value is 800 Gauss with the magnet length of 10cm. The magnet power supplies are controlled with pattern data of 12 bits.

V. COD measurement and correction

To check the monitor, beam positions were measured for different RF capture frequencies (see Fig.5). Changing RF frequency (δf), the beam position (δx) varies as follows;

$$\delta x = \eta \gamma^2 \gamma_{tr}^2 (\gamma_{tr}^2 - \gamma^2)^{-1} \delta f/f, \quad (2)$$

where η is dispersion at the monitor, γ is the energy in units of the particle rest energy, and γ_{tr} is the value at the transition energy. In the HIMAC synchrotron γ_{tr} =3.67, η =2.5m, and γ =1.0 at injection. By use of these parameters,

$$x = 2.7 \times \delta f/f \text{ (m)}, \quad (3)$$

and this coefficient is consistent with the measured value of 2.8m.

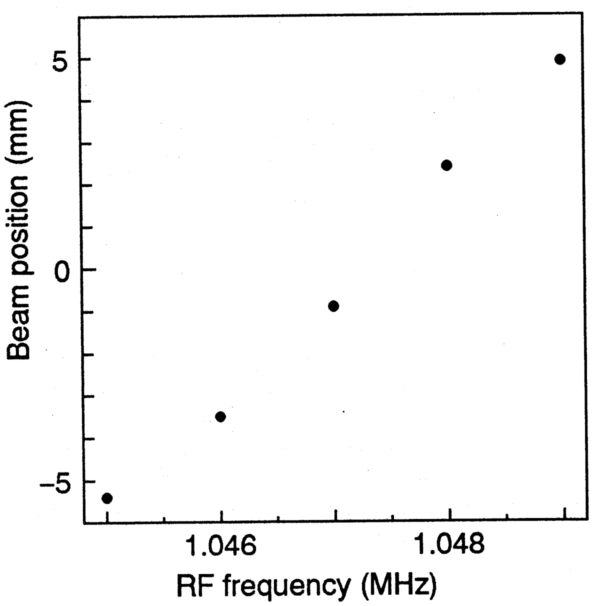

Fig.5 Measured beam positions with different RF capture frequencies.

Assuming linear lattice for COD correction, displacements of beam positions can be expressed as follows,

$$X = A\theta \quad (4)$$

where Xi is displacement of beam at the i-th position monitor, and θi is deflection angle with i-th steering magnet. The deflection angles (θ) to correct the COD (X_{COD}) is given with the inverse matrix of A as follows;

$$\theta = A^{-1} X_{COD}. \quad (5)$$

Measuring the displacement of beam position at the monitor with excitation of one steering magnet, this matrix elements of A can be determined experimentally.

At the flat base the COD could be reduced to the value smaller than 2mm (see Fig.6) with steering magnets, whose field strengths were calculated with a equation-(5).

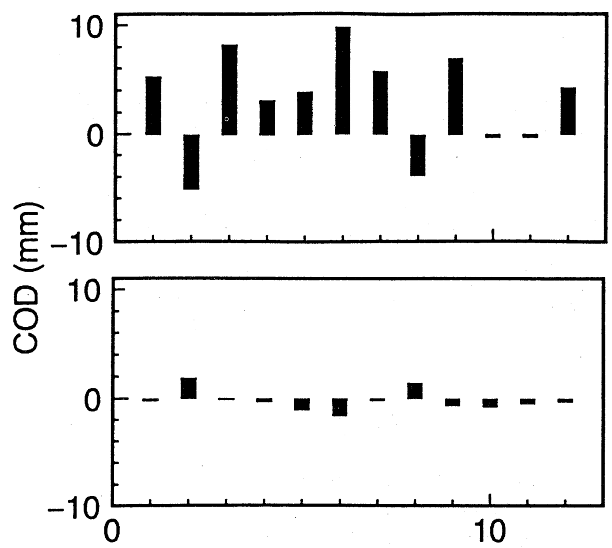

Fig.6 Measured COD before correction (Top), after correction (Bottom).

VI. Acknowledgements

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VII. References

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