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EXPERIMENTAL MEASUREMNET OF QUADRUPOLE BEAM OSCILLATING FREQUENCY AT CSNS RCS

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Abstract

In high intensity proton synchrotrons, space charges effects will cause tune shift of the beam. When the betatron tune spreads over a resonance line, the betatron oscillation amplitude will get larger, causing large beam loss. Through the quadrupolar beam transfer function, the coherent space-charge tune shift of quadrupolar beam oscillations can be derived with quadrupole oscillating frequency.
China Spallation Neutron Source (CSNS) is a high intensity accelerator based facility consists of linear accelerator and the Rapid Cycle Synchrotron (RCS). A quadrupolar BPM is already installed at RCS for obtaining quadrupolar beam oscillating information this year. This paper will present the offline calibration method of the quadrupole BPM and the preliminary results obtained from the beam experiments on CSNS/RCS

INTRODUCTION

The RCS is a crucial component of CSNS [1][2], and non-controllable beam loss is one of the primary factors that limits the ability of CSNS to further improve beam power. As a high-intensity RCS, CSNS/RCS is susceptible to space charge forces that can cause tune shifts. These tune shifts can lead to increased emittance and even beam loss when the tune is close to certain resonance lines. Therefore, measuring the space-charge induced tune shift is highly significant.

In 1966, W. Hardt derived the oscillation frequencies obtained in the presence of space charge forces and gradients errors for elliptical beams [3]. There is a theoretical relation between the coherent tune shift $Q_{coh,1}$ (obtained from the quadrupolar pick-up) and the incoherent tune shift ΔQ_{inc}, which can be written approximately as

$$Q_{coh,1} - 2Q_{0,x} = -\frac{1}{2}\left(3 - \frac{a_x}{a_x+a_y}\right)\Delta Q_{inc,x}, \quad (1)$$

with $Q_{0,x}$ the horizontal machine tune. $Q_{0,x}$ is measured in the low-current situation, while a_x and a_y are separately represent horizontal beam rms size and vertical beam rms size.

To obtain the incoherent frequency shift of the beam, it is necessary to first measure the coherent quadrupole oscillation frequency of the beam.

GENERAL MEASUREMENT PLATFORM

Internationally, many high-current synchrotrons are equipped with measurement devices for space-charge induced tune shift. By measuring the coherent oscillation frequency and transverse dimension of beam, according to the Eq. (1), the space-charge induced incoherent tune shift can be obtained.

Many high-current synchrotrons around the world are equipped with measurement devices to detect space-charge induced tune shift. This can be achieved by measuring the coherent oscillation frequency and transverse dimension of the beam, as described in Eq. (1). To measure the incoherent tune shift generated by space-charge forces, a quadrupole kicker is first needed to excite the coherent oscillation of the beam. A quadrupole pick-up is then used to obtain information about the beam's quadrupole coherent oscillation. Finally, a gas ionization beam profile monitor (IPM) is used to measure the transverse radius of the beam. Different high-intensity synchrotrons around the world have built different measurement platforms based on their own hardware conditions [4].

At the CSNS, currently only one newly designed asymmetric quadrupolar BPM is installed specifically for measuring the quadrupole oscillation frequency of the beam. This BPM is an essential beam measurement component, while measuring the beam envelope and exciting quadrupole oscillations can be achieved through other methods.

OFFLINE CALIBRATION OF QUADRUPOLAR BPM

For the designed quadrupole BPM, offline calibration of the position signal is performed first. Then, the obtained data is processed using the Gaussian two-dimensional weighting method to obtain the calibration formula for the quadrupole signal of the beam [5]. Fig. 1 shows a schematic diagram of the two-dimensional grid structure Gaussian weighting method.

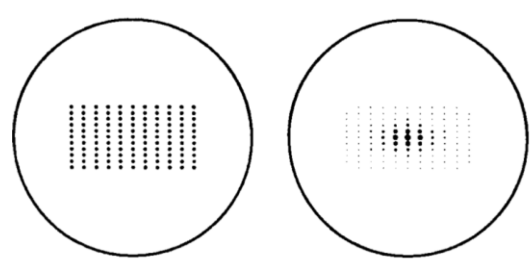

Figure 1: Gaussian weighted schematic diagram of two-dimensional grid structure

To simulate a diffuse beam, the principle of superposition is used. A rectangular grid, as shown on the left side of Fig. 1, is defined, with each grid point representing a wire position for which the lobe responses

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can be determined. A distribution function, such as a Gaussian, can be superimposed on top of this grid. By summing the lobe signals, multiplied by their appropriate weighting factor determined by the distribution function, the response of each lobe for the total beam can be obtained.

For a quadrupole-type BPM, a formula can be derived and approximated through calculations. σ_x and σ_y represent the transverse rms radius of the beam, while x and y represent the center position. The transverse quadrupole signal is represented by $Q_{\Delta/\Sigma}$, which is calculated using the formula $Q_{\Delta/\Sigma} = \frac{V_R+V_L-V_T-V_B}{V_R+V_L+V_T+V_B}$, where R, L, T, and B represent the right, left, top, and bottom electrodes, respectively. V_R represents the amplitude of the voltage signal on the right electrode. Fig. 2 is the schematic of asymmetric quadrupolar BPM.

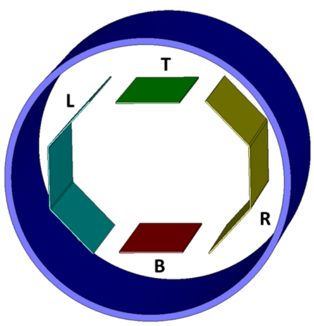

Figure 2: Schematic of asymmetric quadrupolar BPM

Through analysis of a typical stripline BPM, the following formula can be obtained.

$$Q_{\Delta/\Sigma} = c_1(\sigma_x^2 - \sigma_y^2) + c_2(x^2 - y^2) + c_3 x + c_4 y + c_5 \quad (2)$$

In the formula, c_i represents the constant term that needs to be obtained through offline calibration.

First, consider the case where the beam center position is 0, and perform offline calibration on the quadrupole component. By using the least squares method for fitting, the following fitting curve can be obtained. Fig. 3 shows the variation of the quadrupole component signal $Q_{\Delta/\Sigma}$ with respect to $(\sigma_x^2 - \sigma_y^2)$.

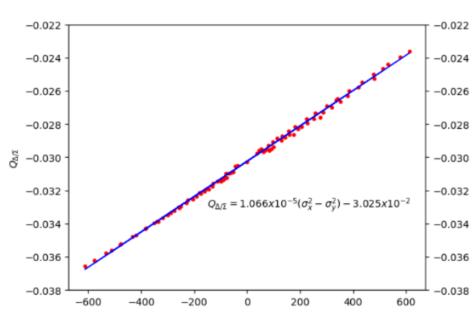

Figure 3: Variation of $Q_{\Delta/\Sigma}$ with respect to $(\sigma_x^2 - \sigma_y^2)$

By comprehensively changing σ_x , σ_y , x, and y, the relationship between $Q_{\Delta/\Sigma}$ and (σ_x , σ_y , x, y) can be obtained. Equation 1 will be expressed in the following form.

$$Q_{\Delta/\Sigma} = 1.066 \times 10^{-5}(\sigma_x^2 - \sigma_y^2) + 3.349 \times 10^{-5}(x^2 - y^2) + 1.489 \times 10^{-5}x + 1.442 \times 10^{-5}y - 3.040 \times 10^{-2} \quad (2)$$

EXPERIMENTAL MEASUREMNET

In the single bunch DC mode, beam experiments were conducted with the following beam parameters. Using an oscilloscope, measurements were taken and data was stored at the beam measurement local station. The saved data was then subjected to fast Fourier transform to find the frequency of interest. Table 1 shows the parameters used in the beam experiment.

Table 1: Parameters Used in The Beam Experiment

Parameters	Values
Kinetic Energy (MeV)	80
Particle number	1.6E12, 3.2E12, 8.0E13
Beam pulse length (ns)	981
Chopper duty	75%
Nominal tune	4.80/4.86

The Fig. 4 shows coherent quadrupole oscillation frequency of the beam at x-direction. By combining with theoretical simulations, the frequency corresponding to the beam quadrupole oscillation was identified.

Similarly, Fig. 5 and Fig. 6 show the quadrupole coherent oscillation frequency and the beta oscillation frequency of the beam in the x-direction were obtained for particle numbers of 3.2E12 and 8.0E12. Error analysis was not performed in the calculation process, and further theoretical simulations and more detailed analysis of experimental data are needed in future work. However, the above research demonstrates that the overall research method and approach are feasible. Additionally, when performing FFT analysis on the transverse quadrupole component signal, the influence of the beam centroid was not excluded, resulting in various peaks in the frequency spectrum. In future research, the formula (2) will be used to directly extract the quadrupole oscillation signal $(\sigma_x^2 - \sigma_y^2)$ for FFT analysis, which will be more accurate in identifying the quadrupole oscillation peak

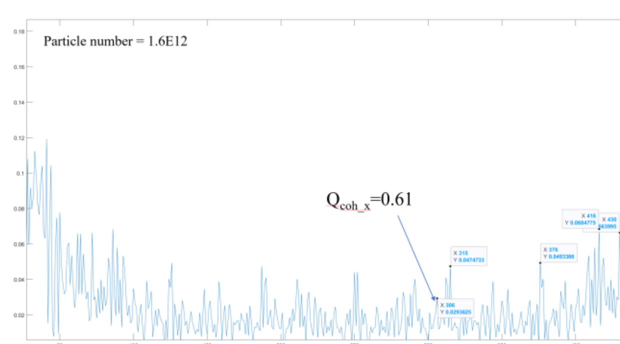

Figure 4: Coherent quadrupole oscillation frequency of the beam at x-direction with particle number of 1.6E12

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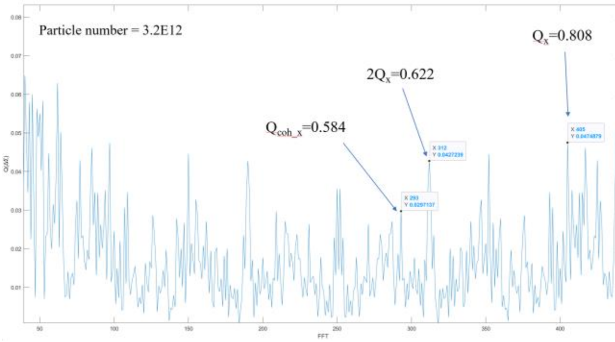

Figure 5: Coherent quadrupole oscillation frequency of the beam at x-direction with particle number of 3.2E12

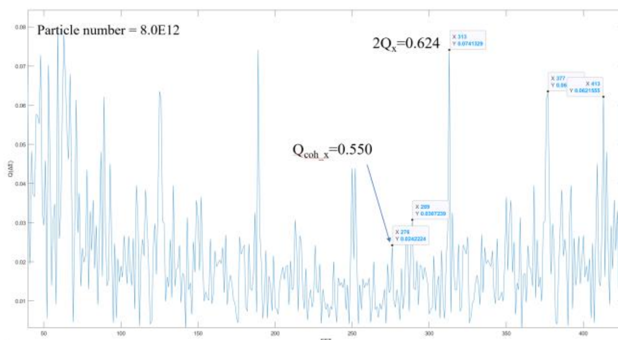

Figure 6: Coherent quadrupole oscillation frequency of the beam at x-direction with particle number of 8.5E12

CONCLUSION

A asymmetric BPM has been designed specifically for measuring the quadrupole oscillation frequency of the beam. The offline calibration of the quadrupole component has been performed. Beam experiments were conducted at different beam intensities, and preliminary results were obtained. In the future, more detailed theoretical work and simulation studies will be necessary.

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REFERENCES

[1] S. Wang, S. X. Fang, S. N. Fu, et al, Introduction to the overall physics design of CSNS accelerators, Chinese Physics C, 33(S2), (2019): 1-3. doi: 10.1088/1674-1137/33/S2/001

[2] S. Wang, S. Fu, H. Qu, et. al, Design, Development and Commissioning for High-intensity Proton Accelerator of China Spallation Neutron Source, Atomic energy science and technology, 56(9), (2022): 1747-1759. doi: 10.7538/yzk.2022.youxian.0591

[3] W. Hardt, On the incoherent space charge limit for elliptic beams, CERN internal report, ISR/Int 300 GS/66.2, 1966.

[4] Y. Yuan, et al. A Preliminary Feasibility Study of Measurement of Quadrupolar Beam Oscillations at CSNS RCS. IPAC2019. doi: 10.18429/JACoW-IPAC2019-WEPGW059

[5] Russell S J , Gilpatrick J D , Power J F , et al. Characterization of Beam Position Monitors for Measurement of Second Moment[C]. IEEE Particle Accelerator Conference. IEEE, 1995.