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A PRELIMINARY FEASIBILITY STUDY OF MEASUREMENT OF QUADRUPOLAR BEAM OSCILLATIONS AT CSNS RCS

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Abstract

In high intensity proton synchrotrons, linear and nonlinear betatron resonances cause beam loss. When the betatron tune spreads over a resonance line, the betatron oscillation amplitude will get larger, causing large beam loss. In the quadrupolar beam transfer function, the coherent space-charge tune shift of quadrupolar beam oscillations is used to determine the incoherent tune shift. China Spallation Neutron Source (CSNS) is a high intensity accelerator based facility consists of linear accelerator and the Rapid Cycle Synchrotron (RCS). A system of quadrupolar pick-up and kicker can be used for evaluating tune shifts and spreads. This paper will present already existing beam diagnostic instrumentation on CSNS/RCS, and discuss a preliminary feasibility study of measurement of quadrupolar beam oscillations through adding a quadrupolar-type beam pick-up.

INTRODUCTION

The RCS is an important component of the CSNS, and the non-controllable beam loss of CSNS/RCS is also one of the most important factors that limiting the CSNS to further improve the beam power. CSNS/RCS, as a high intensity RCS, the space charge force will cause tune shift. When the tune is close to some resonance lines, it will lead to the increase of the emittance and even the beam loss. Therefore, it is very meaningful to measure the space-charge induced tune shift. And, it is very important to develop a device for measurement of tune shift in the process of optimizing CSNS/RCS machine parameters and improving beam power.

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

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

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 size and vertical beam size.

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 tothe Eq. (1), the space-charge induced incoherent tune shift can be obtained.

In order to measure the incoherent tune shift generated by space-charge forces, firstly, we need a quadrupole kicker to excite the coherent oscillation of beam. And then using a quadrupole pick-up to obtain the information of beam's quadrupole coherent oscillation. At last, we need a gas ionization beam profile monitor (IPM) to measure the transverse radius of beam. Different high-intensity synchrotrons in the world have built different measurement platforms according to their own hardware conditions.

In 1996, the device for measuring the incoherent tune shift was first applied to CERN's LEAR [2]. The device takes the quadruple kicker to excite beam, and then uses the stripline BPM as the quadrupole pick-up to obtain the information of beam coherent oscillation [3]. At last, the IPM has been taken to measure the transverse dimension of beam. In 1998, GSI built a dual purpose device for measuring space-charge induced tune shift using its existing beam diagnostic instrumentation on SIS and conducted preliminary research [4]. In 2014, GSI redesigned and installed an asymmetric dedicated quadrupole pick-up on SIS18 to obtain the frequency shift due to space charge effects [5]. This type of pick-up is optimized to strongly suppress the dipole component of beam, and is only sensitive to the quadrupole component of beam bunch [6]. In 2016, J-PARC used a stripline pick-up to perform experiment of beam's response to quadrupole kicker in order to measure space-charge induced tune shift on MR [7]. In China, HLS II also built an experimental platform for excitation and measurement of beam quadrupole oscillation on its storage ring [8], including a stripline transverse quadrupole exciter and a set of stripline BPM.

POSSIBLE SOLUTIONS ON CSNS/RCS

Based on CSNS/RCS, we will develop a space-charge tune shift measurement system. It includes a quadrupole kicker for exciting beam quadrupole coherent oscillation, a quadrupole pick-up for acquiring information of beam coherent oscillation, beam dimension measuring device and related electronic system.

There are two exciters on CSNS/RCS for exciting beam to measure machine tune. We intend to properly modify the existing two exciters to achieve the function of a quadrupole kicker. By connecting two exciters as shown in Fig. 1, and inputting the same power to the four planes in the horizontal and vertical directions, while both planes have a phase difference of 180 degree [4].

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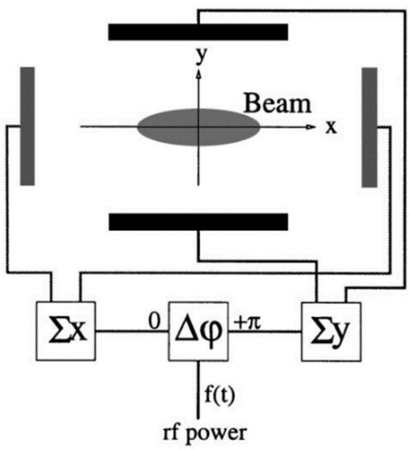

Figure 1: Quadrupolar connection scheme of the RF exciter plates.

There are 32 shoe-box BPMs at CSNS/RCS, which are insensitive to beam quadrupole oscillation and cannot be used to measure space-charge frequency shift. In order to achieve beam quadrupole oscillation information, we need to develop an asymmetric quadrupole pick-up. We intend to implement simulation and design optimization on the asymmetric pick-up with CST software and make the pick-up sensitive to beam quadrupole component, also has a high transfer impedance.

There is no IPM on CSNS/RCS for measuring beam dimension, but we can still approximatively measure beam radius through extracting beam to Ring to Target Beam Transport (RTBT) with four wire scanners on RTBT at any time during beam acceleration process. In the future, we will develop and install an IPM device on RCS to measure beam transverse dimensions of beam bunch as well as longitudinal parameters. By then, we will get more accurate information of beam size.

CONCLUSION

The article presents the international experimental device for measuring beam quadrupole oscillation, and conducts a preliminary feasibility study based on the existing beam-measuring equipment of CSNS. Without adding other hardware, it is only necessary to develop an asymmetric pick-up to obtain the beam quadrupole oscillation signal and modify corresponding electronic system.

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