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THE CHARACTERISTIC OF THE BEAM POSITION GROWTH IN CSNS/RCS*

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Abstract

An instability of the beam position growth is observed in the beam commissioning of the Rapid Cycling Synchrotron of the China Spallation Neutron Source. To simplify the study, a series of measurements have been performed to characterize the instability in the DC mode with consistent energy of 80 MeV. The measurement campaign is introduced in the paper and it conforms to the characteristics of the coupled bunch instability.

INTRODUCTION

The China Spallation Neutron Source [1, 2] (CSNS) is a high intensity proton accelerator-based facility. The accelerator complex includes a negative hydrogen (H-) linac and a rapid cycling synchrotron (RCS). The H- beam is injected into the RCS through a multi-turn charge-exchange process. The beam is extracted to the target with the beam power of 100 kW. The CSNS beam commissioning started in 2016 and it reached the designed beam power in February, 2020. The RCS is the core of the CSNS. Figure 1 shows the layout of the RCS [3] and the main parameters are listed in Table 1. The RCS lattice adopts a triplet cell based 4-fold structure with nominal tune of (4.86, 4.78) and natural chromaticity of (-4.1, -8.6). The RCS accumulates and accelerates proton beam from 80 MeV to 1.6 GeV with the repetition rate of 25 Hz. The maximum voltage offered by eight cavities is 165 kV with a maximum synchronous phase of 45 degrees.

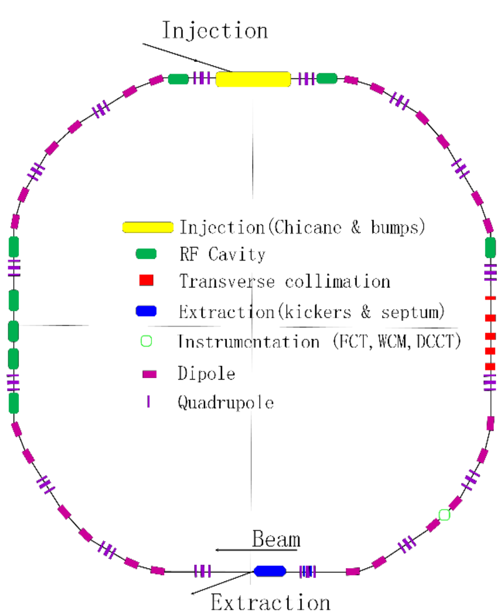

Figure 1: The layout of the RCS.

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Table 1: The RCS Main Parameters

Parameters	Values	Unit
Circumference	227.92	m
Injection energy	80	MeV
Extraction energy	1.6	GeV
Horizontal average beta	9	m
Vertical average beta	10	m
Horizontal nominal tune	4.86	
Vertical nominal tune	4.78	
Horizontal natural chromaticity	-4.1	
Vertical natural chromaticity	-8.6	
Transition γ	4.9	
Harmonic number	2	
Bunch number	2	
Proton per bunch	1.56	E13
Acceptance	540	π mm·mrad
Maximum voltage	165	kV
Maximum synchronous phase	45	degree
Space charge tune shift	0.27	

Due to the high beam intensity and high repetition rate, the beam loss must be controlled to a very low level. The impedance and instability were estimated [4]. The kicker impedance [5] was carefully measured and the kicker matches well with the pulse form network. The vacuum pipe consists of 100 meters stainless-steel chamber and about 128 meters ceramic chamber. The resistive wall impedance and its instability [6] were studied which implies that the growth rate depend on the chromaticity and the instability is not be excited with the natural chromaticity. A growth of the turn-by-turn (TbT) beam position of the AC mode in Fig. 2 was unfortunately observed and its characteristic and mitigation studies were the main task in the beam commissioning [7]. To simplify the study, a series of measurements have been performed to characterize the instability in the DC mode with consistent energy of 80 MeV and the measurement campaign is introduced in the paper.

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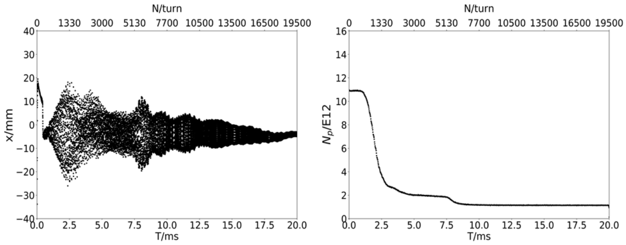

Figure 2: The TbT beam position (left) in horizontal plane and the living protons (right) in the AC mode with the beam power of 100 kW. The tune is the nominal tune with natural chromaticity in the measurement.

BEAM-BASED MEASUREMENT

A measurement campaign in the DC mode with energy of 80 MeV is undertaken to confirm and mitigate the instability in order to accumulate high beam intensity. The painting at injection, the energy spread of injected beam, the beam intensity, the tune, and the chromaticity are varied. The feature of the single bunch is also measured. The TbT beam position, the accumulated protons and the head-tail mode are the observables of interest. The instability does not relate to the initial emittance in horizontal plane. The instability highly depends on the beam intensity, the machine tune and the chromaticity. The instability is also observed when only one bucket is filled as the single bunch.

Dependence on Beam Intensity

Sets of measurements were taken for different beam intensities with the nominal tune and the natural chromaticity and double bunches are perfectly filled. The TbT beam position in Fig. 3 is related to the number of the protons. The threshold of the instability is the proton number of two bunches of about $N_p = 7 \times 10^{12}$. The growth time with the beam power of 100 kW is about 1 ms. The growth of the position in Fig. 4 is also observed for the single bunch and the threshold is about $N_p = 7.5 \times 10^{12}$. The instability is not only a coupled bunch instability but also a single bunch instability. With same beam power, the position for two bunches with different bunch protons in Fig. 5 is also compared and the growth is slower than that of the same bunch intensity. For the tune of (4.78, 4.83), the TbT beam position with different beam intensity is investigated in Fig. 6. Same with the position in horizontal plane, the growth in vertical plane is also observed as the beam intensity increasing.

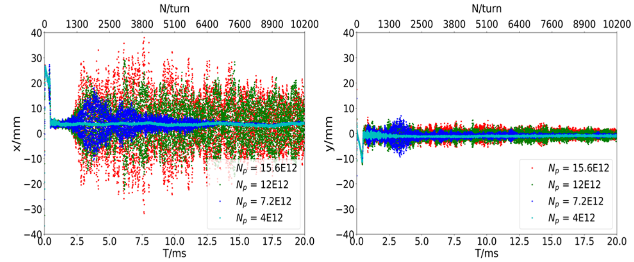

Figure 3: The TbT beam position in the RCS is a function of the beam intensity. The tune is the nominal tune with natural chromaticity and two buckets are filled in the measurement.

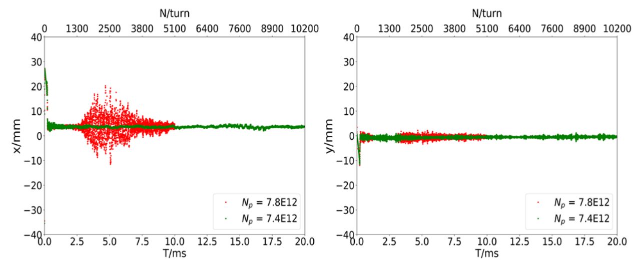

Figure 4: Measured the TbT beam position for the single bunch. The tune is the nominal tune with natural chromaticity in the measurement.

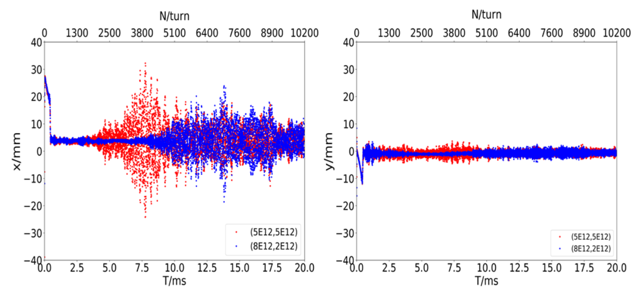

Figure 5: Measured the TbT beam position for the double bunches with same beam intensity and different bunch intensity. The tune is the nominal tune with the natural chromaticity in the measurement.

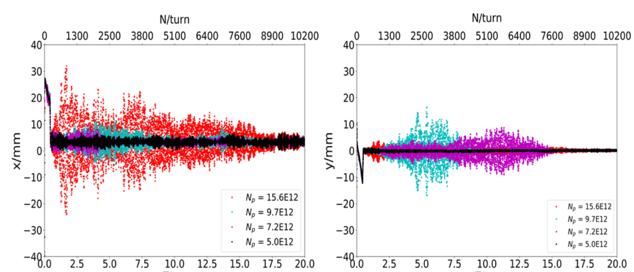

Figure 6: Measured the TbT beam position for the double bunches with different bunch protons. The tune is (4.78, 4.83) with the natural chromaticity.

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Dependence on the Tune

Sets of measurements were taken for different horizontal tunes and the TbT beam position as a function of the tune is shown in Fig. 7. The beam position growth is only observed when the horizontal tune is below the integer and it is also observed with the tune of 5.78. With the tune is closed to the integer of five, the growth of the beam position in horizontal plane is easily excited.

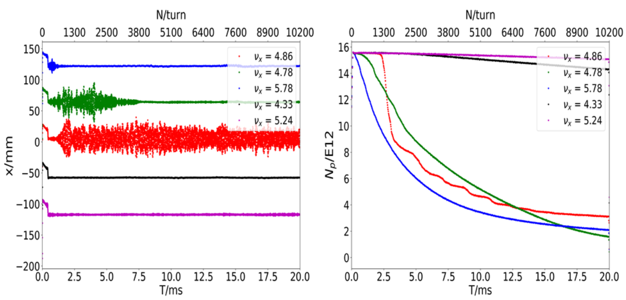

Figure 7: Measured the TbT beam position (left) and the living protons (right) for the double bunches: scan the horizontal tune with the natural chromaticity. The position in the left is shifted on the vertical axis for clarity.

Dependence on the Chromaticity

The instability as a function of the chromaticity is also measured. Two buckets are perfectly filled with the equivalent power of 100 kW and sets of measurements were taken for different chromaticity for the nominal tune. Data are collected for a range of horizontal chromaticity between -4.1 and -8.4. The TbT beam position in horizontal plane as a function of the chromaticity is given in Fig. 8 and the head-tail mode in Fig. 9 is changed with the variation of the chromaticity.

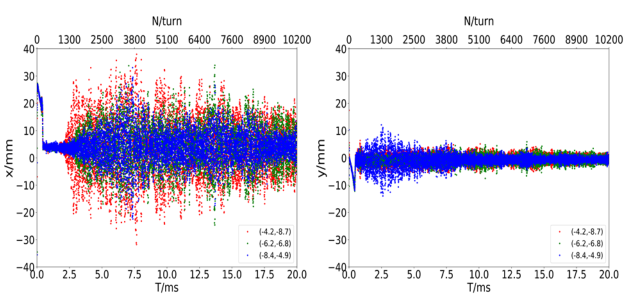

Figure 8: Measured the TbT beam position for the double bunches with nominal tune: scan the chromaticity.

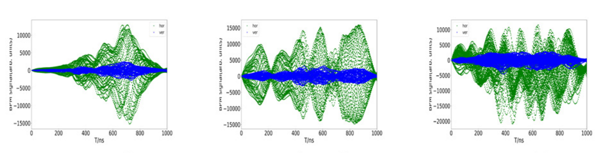

Figure 9: Measured the head-tail mode in terms of the TbT beam position in Fig. 8 for the double bunches with nominal tune: scan the chromaticity. The horizontal axis in the subplot is the sampling time and the vertical axis is the WCM signal difference in horizontal (green) and vertical (blue) plane.

CONCLUSION

The growth of the beam position is observed and it is the main work in the beam commissioning. The growth is more and more serious with the beam power increasing. The growth is observed for the double bunches and the single bunch and the threshold is about 7×10^{12}. The growth mainly happens in horizontal plane and it may be also excited when the vertical tune is closed to the integer of 5. The head-tail mode is also observed when the beam position growth happens. Based on the measurement, it is similar with the characteristics of the coupled bunch instability. Unfortunately, the source of the instability has not found based on the impedance mode in the RCS. The instability was mitigated by the tune adjusting and the chromaticity correction [7], but the beam power will be upgraded to 500 kW (3.9×10^{13} protons per bunch) and the instability will be the limit of the beam power.

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