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THE FERRITE LOADED CAVITY IMPEDANCE SIMULATION*

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Abstract

The Rapid Cycling Synchrotron of the China Spallation Neutron Source is a high intensity proton accelerator, it accumulates the 80 MeV proton beam and accelerates it to 1.6 GeV in 20 ms. The transverse coupling bunch instability is observed in beam commissioning. The source has been investigating from the commissioning. The RF acceleration system consists of eight ferrite loaded cavities. The impedance is simulated and there is a narrow-band impedance of the ferrite cavity at about 17 MHz.

INTRODUCTION

China Spallation Neutron Source (CSNS) is a high intensity proton accelerator-based facility, which consists of an H- Linac, a Rapid Cycling Synchrotron (RCS) and two beam transport lines [1, 2]. It accumulates and accelerates proton beam from 80 MeV to 1.6 GeV with repetition rate of 25 Hz. The RF acceleration system consists of eight ferrite loaded cavities [3]. The layout of the RCS is shown in Fig. 1 and the RF cavity is located along the ring. The maximum voltage offered by eight cavities is 165 kV with a maximum synchronous phase of 45 degrees. With a classical and conservative NiZn load-ferrite [4], the coaxial resonant cavity has two accelerating gaps with single ended. The ferrite loaded material is Ferroxcube 4 M2. There are 56 ferrite cores installed in a cavity. The gap inductance can be shifted from 8.1 μH to 1.4 μH as a bias current varies from 200 A to 3000 A. The capacitance is 3 nF. The resonant frequency of the cavity can sweep within 1.02~2.44 MHz to meet the need of the energy ramping. A nominal peak RF gap voltage of 12 kV is offered.

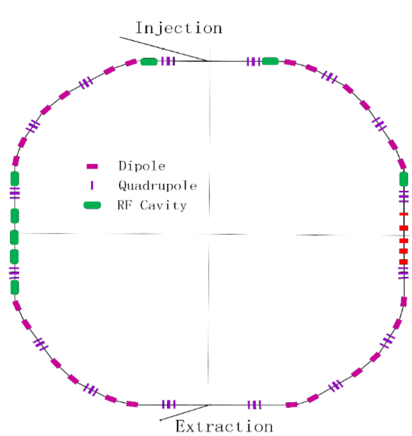

Figure 1: The layout of the cavity in the RCS.

The transverse coupling bunch instability is observed as the beam power increasing in beam commissioning. Characterization, simulation, mitigation and the source were carried out in the beam commissioning. The instability was mitigated by the tune adjusting and the chromaticity correction [5], but the beam power will be upgraded to 500 kW with protons per bunch of 3.9×10^{13} and the instability will be observed and limit the beam power. The source of the instability is not be determined based on the impedance budget [6] and the source was also investigated. The longitudinal impedance is simulated in the cavity design and the third high-order-mode (HOM) of the ferrite cavity is the main HOM [7]. The frequency of the third HOM is about 8 MHz, the busbar between two gaps was optimized and the HOM frequency is moved to about 12 MHz. The transverse impedance of the cavity was ignored in the simulation, so it is simulated recently based on CST Studio Suite [8] and introduced in the paper. According to the beam-based simulation, it may be the source of the instability.

THE CAVITY IMEPDANCE SIMULATION

The CST simulation mode of the cavity protype is developed and shown in Fig. 2. It is a coaxial-resonant cavity consisted of internal and external conductors and the inner conductor is also the beam pipe with thickness of 2 mm copper. The acceleration gap is sealed by the ceramic ring, and the induced current from the beam will penetrate into the gap. The distributed capacitance is connected at the both ends of the acceleration gap. The resonance frequency of 1.02 MHz at injection energy is firstly considered in the simulation. To resonance the cavity, the permeability of the ferrite ring is 77 and the capacitance is replaced by the cylinder with radius of 20 mm and the dielectric constant of 14400. The frequency at extraction energy is also compared with the permeability of 17. The black ferrite ring and the cooling plate are placed between the inner and outer conductors. The two gaps are connected by the busbar. The circular busbar also moves the frequency of the HOM to about 12 MHz, but the runway busbar is adopted for the real cavity in Fig. 3 and the impedance frequency is changed, so the protype and the real cavity are simulated.

Based on the simulated mode, the hexahedral meshes of 20 million is used. The speed of the wake dissipation is very slow and the wake-field length of 500 m is calculated. Figure 4 gives the simulated impedance result. The impedance of the prototype in horizontal plane has two peaks at about 21 MHz and 23 MHz, but the only one peak about 17 MHz appears in the real cavity. The vertical impedance is also simulated and it is same with the horizontal impedance. The peak frequency at extraction energy is mostly same with that at injection energy. Based on the cavity impedance estimation, the RCS transverse impedance mode is updated in Fig. 5.

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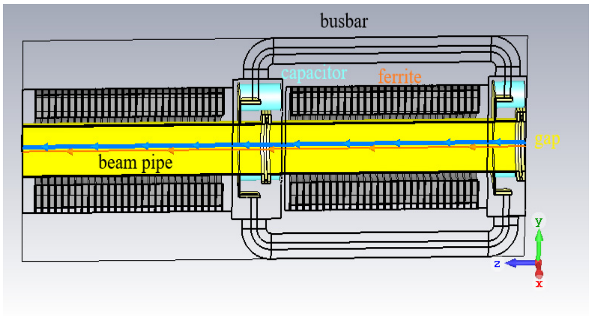

Figure 2: The CST simulation mode of the cavity protype.

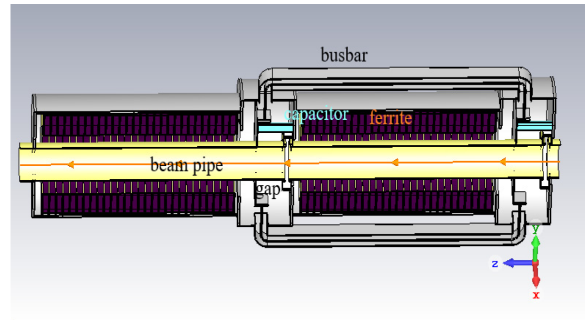

Figure 3: The CST simulation mode of the cavity.

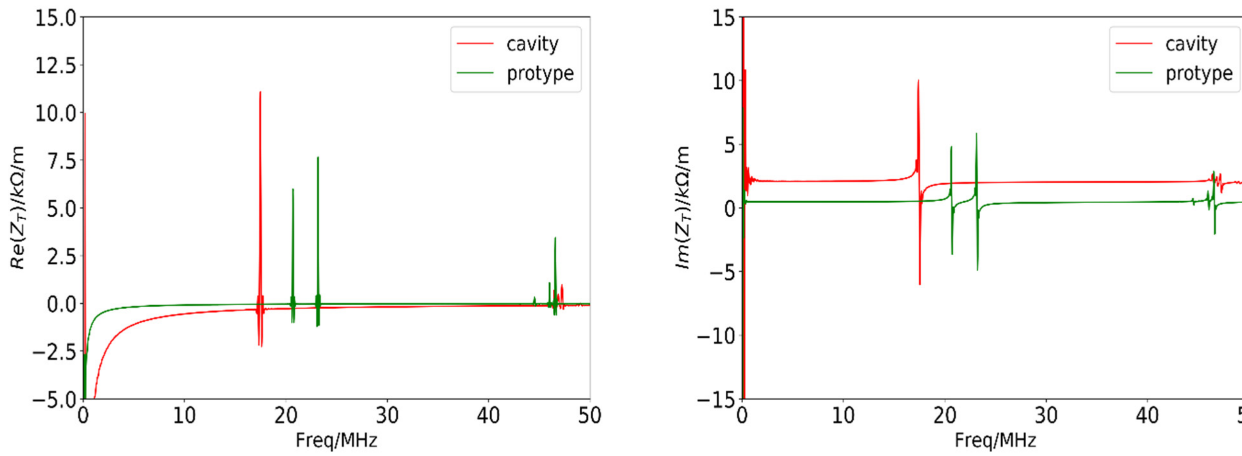

Figure 4: The transverse impedance of the ferrite cavity.

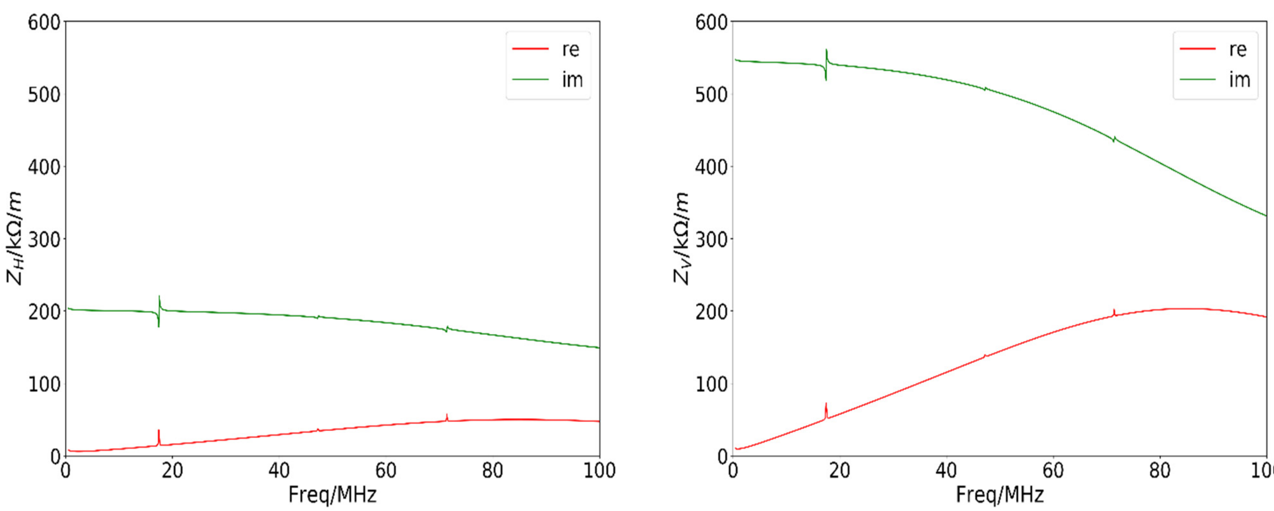

Figure 5: The RCS transverse impedance mode.

BEAM-BASED SIMULATION

The beam dynamic simulation code has been developed [9] and updated to re-appear the instability. The beam dynamic effect with the cavity wake is simulated based on the code. The simplified physical model on interaction between beam and wake field is to accumulate the wake force into a kick momentum at one position of the ring. Beam dynamic equation including the effect of the cavity wake is described by the turn-by-turn transfer matrix. The synchrotron motion with acceleration is considered in the model to track the particle dynamics with energy ramping and the longitudinal wake is ignored. Distribution of synchrotron in phase space is given by the initial three dimensions condition and the long bunch with about 80 m is sliced into many slices to study on instability of intra-beam. The nominal tune of (4.86, 4.78) with natural chromaticity of (-4.64, -8.27) in the RCS is simulated and the impedance of eight-cavity of 20 kohm/m is adopted. The two buckets are perfectly filled with two bunches and the beam position and the mode in longitudinal plane is observed. The turn-by-turn beam position with different

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beam intensity in horizontal plane is given in Fig. 6, which roughly agree with the measurement [10].

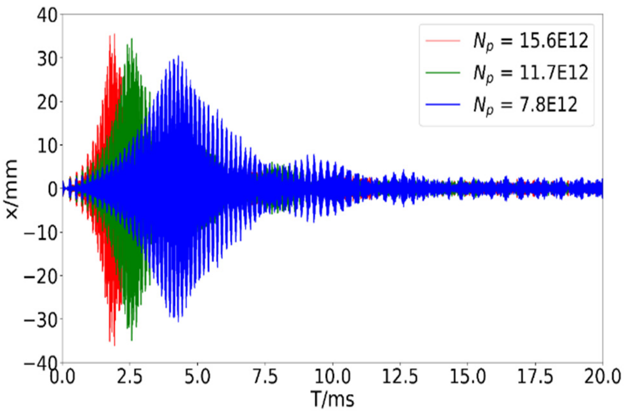

Figure 6: The cavity horizontal impedance drives the beam position with different beam intensity. The two buckets are perfectly filled with two bunches and the number of the legend is protons of two bunches.

CONCLUSION

The transverse coupling bunch instability is observed and the source is investigated in beam commissioning. The impedance of the ferrite cavity at about 17 MHz may be the source of the instability. The impedance measurement by a bench method is planning to check it.

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