IMPEDANCE COMPUTATION OF MAIN COMPONENTS IN CSNS/RCS

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Abstract

The Rapid Cycling Synchrotron (RCS) of the China Spallation Neutron Source (CSNS) is a high intensity proton accelerator. The study on the coupling impedance in the ring plays an important role in the stability of the beams. The impedance of some main components in the RCS ring, such as RF cavities and collimator were calculated by using numerical simulation. The impact of bus-bar's configuration on RF cavities and beams was estimated by impedance calculation. Furthermore, RF shield of collimators were considered.

INTRODUCTION

China Spallation Neutron Source (CSNS) consists of an 80MeV linear accelerator, a 1.6GeV RCS ring and a wolfram target [1]. There are 1.56×10^{13} protons corresponding to a ~8A peak current in the RCS ring during extraction time at the 100kW design level. The study on the coupling impedance and the collective effects in the ring plays an important role in the stability of the machine performance and in achieving the final beam power. A thorough evaluation of the coupling impedance is necessary in controlling the total impedance of the ring, which can accordingly prevent the occurrence of the beam instability and reduce the beam loss. For simple vacuum components, such as bellows, steps, ports and vacuum valves can be calculated from some classical theoretical formulas. Other complicated components, in particular the RF cavities and the collimator require verification by simulation and measurement. Our measurement platform is under building, the simulation needs to be first considered. In this paper, the impedance of RF cavities and collimator were calculated by CST software.

IMPEDANCE SIMULATION

We use 3D time-domain simulations with CST code package [2] which contains Wakefield module that can directly give the wake potential and impedance.

RF Cavities

RF system implement beam capturing and accelerating with a low beam loss. In order to provide total 165kV RF peak voltage, 8 ferrite loaded RF cavities (h=2) with sweeping range of 1.02~2.44MHz will be adopted in the phase I. Plan to add additional 4 cavities (h=4) for the phase II to increase the beam bunching factor. Each cavity has double RF gaps, at 10KV per gap and is driven by the power amplifier in parallel by means of side bus-bars. The inductance is provided by coaxial stacks of Philips 4M2 ferrite rings like as SNS [3]. Figure1 is the schematic diagram of RF cavity that the total length is about 2.71 m and inner radius of beam pipe is 170mm.

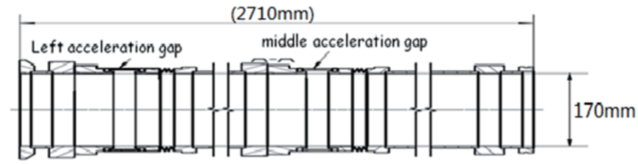

Figure1: Schematic diagram of RF cavity.

For the fundamental mode of the RF cavities, the impedance can be expressed as [4]:

$$Z_{//}=\frac{R_{sh}}{1+jQ(\omega/\omega_R-\omega_R/\omega)} \qquad (1)$$

Where ω_R is the resonant frequency, R_{sh} and Q are the shunt resistance and quality factor of the loaded cavity, respectively.

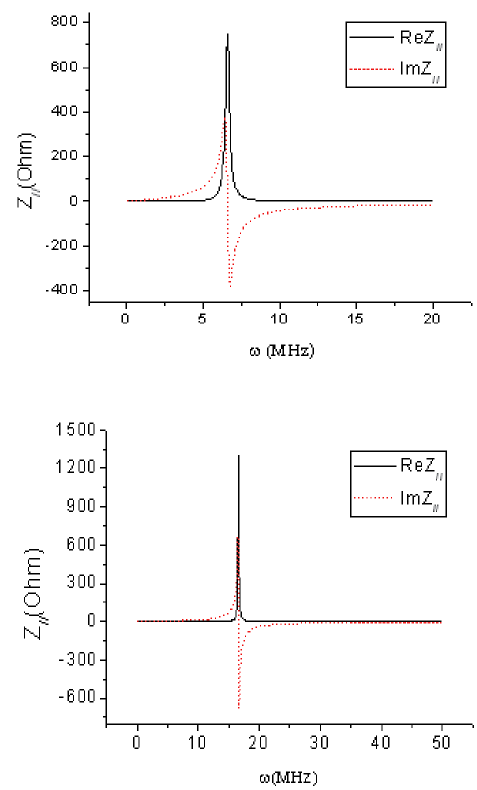

Figure 2: The longitudinal impedance of single gap for injection (up) and for extraction (down).

The total inductance of one gap can be expressed as

$$L=\frac{\mu_r\mu_0 l}{2\pi}\ln\frac{r_{out}}{r_{in}} \qquad (2)$$

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Where μ_0 and μ_r is vacuum permeability and relative permeability, respectively. Taking the ferrite length l=70cm, the inner radius r_{in}=15cm, the out radius r_{out}=25cm, the relative permeability μ_r=78 for injection and μ_r=12.2 for extraction, the inductance of the gap is 5.578μH and 0.87μH respectively. The inherent capacitance is C=4.15nF and the shunt resistance of a gap is 762Ω and 1369Ω for injection and extraction. The loaded cavity quality factor is 20.8 and 94.4 calculated from shunt resistance and inherent capacitance. So the distribution of longitudinal impedance with single accelerator gap can be drawn as figure 2, from which the frequency of fundamental mode is 1.046MHz and 2.645MHz for injection and extraction, respectively.

Simulation is needed for longitudinal high order modes of RF cavity. The RF cavity model is illustrated in figure 3. During simulation, the wakes have to be long enough to provide a good resolution at low frequencies. Due to practical limitations, we compute wakes up to a certain length, typically 10 m. The mesh inside the ferrite should be dense.

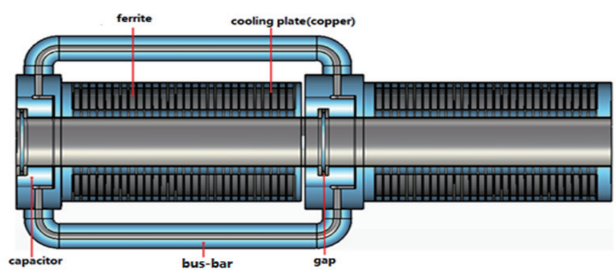

Figure 3: CST model of CSNS ring RF cavity.

It is well known that relative permeability of ferrites changes as sweeping frequency during acceleration. However the result of longitudinal impedance is almost close except the fundamental mode. Taking the injection for example, i.e. μ_r=78. The figure 4 gives the longitudinal impedance distribution of RF cavity. The lower figure is the enlargement with frequency is less than 20MHz.

From the simulation, we can see that the frequency of fundamental mode is 1.021MHz that is close to the theoretical result (1.046MHz) and the cavity can arise high order modes at the frequency of 7.11MHz, 12.75MHz and 17.67 MHz, etc. Although the amplitude is quite small than the fundamental mode, the mode of frequency at 7.11MHz is need to consider carefully. In fact, when the sweeping frequency reaches near 2.37MHz, the resonance would happen for the transmitter's third harmonic frequency is equal to 7.11MHz that is the inherent frequency of RF cavity. So the inherent frequency should move to more than 10MHz by designing bus-bar's structure can solve this problem thoroughly, and the design work is in progress.

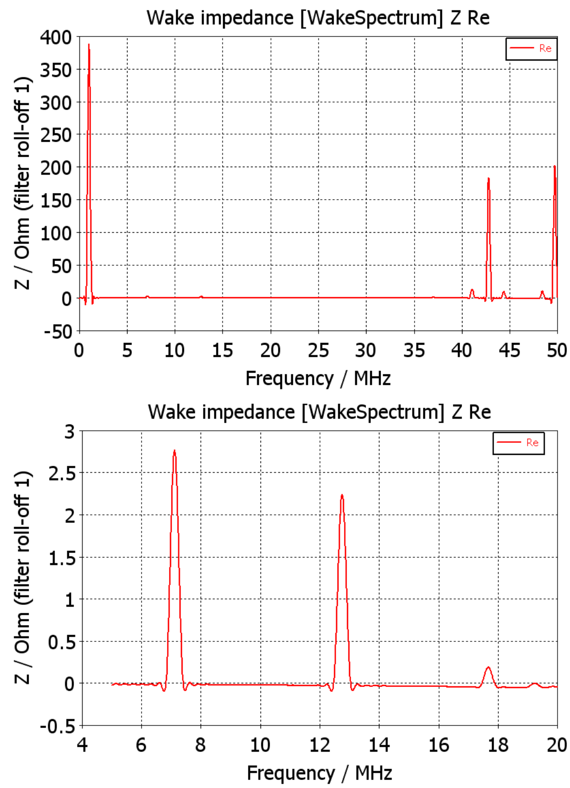

Figure 4: longitudinal impedance of RF cavity.

Collimator

Beam loss and control are of primary concern for the high intensity RCS of CSNS. A two-stage collimation system [5] is applied to restrict the beam losses in a specified area and keep the uncontrolled losses less than 1 W/m at the other part of RCS. The system is composed of one primary collimator and four secondary collimators as absorbers. The primary collimator consists of four movable scrappers made of 0.17 mm tungsten plates for increasing the divergence of the incident halo protons. The collimator is set to around 350πmm.mrad for the primary jaws.

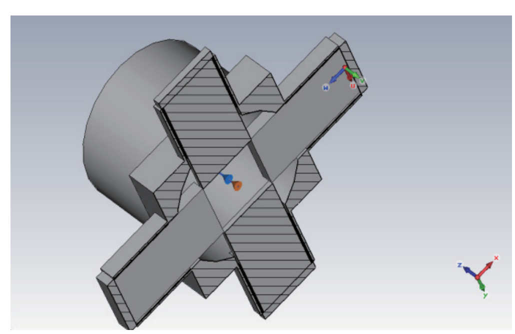

Figure5: CST model of CSNS primary collimator.

There is a slit of 5mm width between the scrappers and the outside vacuum box for moving the scrappers inside and outside easily. The RF shield must be concerned for preventing the wakefield leak from the gap, which would produce the beam instability or electromagnetic interference. The primary collimator model is illustrated in figure 5 with the total length of 625mm and inner diameter of beam pipe of 345mm. Figure 6 is the result of the longitudinal impedance of collimator. The amplitude is below 1 ohm less than 100MHz and the loss power can be estimated with the order of 4×10^{-2}W.

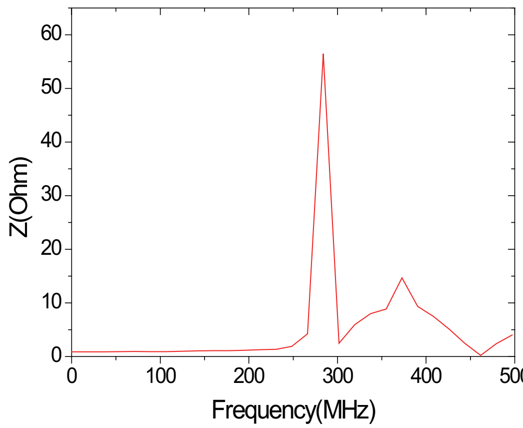

Figure 6: longitudinal impedance distribution of primary collimator with no RF shield.

Figure 7 are the spring fingers made of 0.2mm copper plates for RF shield installed in the gap for the concern of safety, which were used on the bellows of BEPCII with abundant experience [6]. Figure 8 is the result of the longitudinal impedance with RF shield. The amplitude is much smaller than no RF shield and the loss power is the order of 4×10^{-4}W. It's apparent that the RF shield is benefit to impedance and power loss.

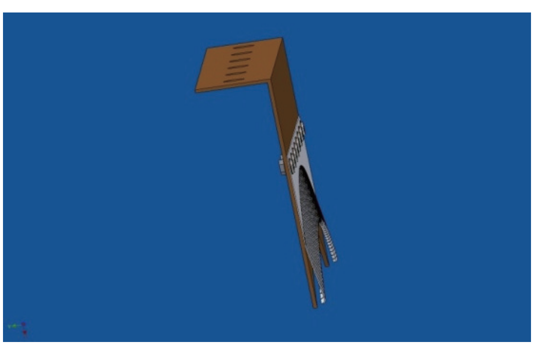

Figure7: Spring fingers for RF shield.

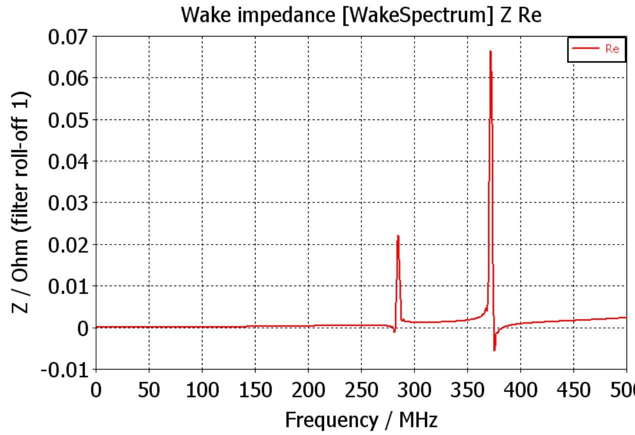

Figure 8: longitudinal impedance distribution of primary collimator with RF Shield.

CONCLUSION

The impedance of the CSNS RF cavity was calculated by CST software and the frequency of fundamental mode is close to the theoretical result. The cavity can excite many high order modes, one of which with the frequency at 7.11MHz must be considered carefully. The inherent frequency should move to more than 10MHz by designing bus-bar's structure again can solve resonance thoroughly. The RF shield of primary collimator was introduced, which shows a significant reduction of both the longitudinal coupling impedances and the loss power with small installation cost. The impedance measurement of RF cavity, collimator and extraction kicker are necessary before operation and the platform of our measurement is under preparation now.

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