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DESIGN AND TEST OF A PROTOTYPE 324 MHz RF DEFLECTOR IN THE BUNCH SHAPE MONITOR FOR CSNS-II LINAC UPGRADE*

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Abstract

During the upgrade of linac in CSNS-II, the beam injection energy will increase from 80.1 MeV to 300 MeV and the beam power from 100 kW to 500 kW. A combined layout of superconducting spoke cavities and elliptical cavities is adopted to accelerate H- beam to 300 MeV. Due to a ~10 ps short bunch width at the exit of the spoke SC section, the longitudinal beam density distribution will be measured by bunch shape monitors using low energy secondary emission electrons. As the most important part of a bunch shape monitor, a prototype 324 MHz RF deflector is designed and tuned on the basis of a quasi-symmetric lambda/2 325 MHz coaxial resonator, which was fabricated for the C-ADS proton accelerator project. Preliminary parameters of the bunch shape monitor are presented. Simulation of the RF deflector and test results in the laboratory are described and analysed.

INTRODUCTION

China Spallation Neutron Source (CSNS) is the first pulsed neutron source built in China [1]. It consists of an 80 MeV H- linac, a 1.6 GeV proton rapid cycling synchrotron (RCS), two beam transport lines and a target station. We achieved the design goal of phase I with protons bombarding the target at a beam power of 100 kW in Feb. 2022, and now begins the upgrade project to 500 kW. During the linac upgrade, the DTL section will be followed by a section of 324 MHz double-spoke superconducting cavities and a section of 648 MHz elliptical superconducting cavities [2], as shown in Fig. 1. The proton beam will be accelerated to 300 MeV at the exit of the 8th cryomodule in the second SC section.

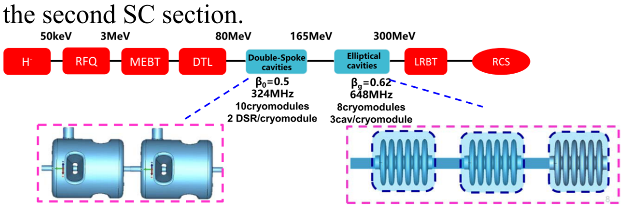

Figure 1: Superconducting cavities in CSNS-II [2].

Longitudinal bunch density distribution in ion linac is one of the main characteristics of accelerated beam. Bunch shape information is extremely important for medium energy accelerators consisting as a rule of two main parts with different rf frequencies. Results of bunch shape measurement after accelerating tank may be used to set rf phase and amplitude. What's more, longitudinal bunch density may be used to calculate energy spectrum and longitudinal beam emittance [3-6]. In the CSNS-II linac upgrade plan, two bunch shape monitors will be installed. The transverse and longitudinal beam parameters at the BSM installation point are listed in Table 1.

Table 1: Micro Bunch Parameters in the Linac of CSNS-II

Micro Bunch	Spoke 1	ELL7
Energy (MeV)	86.97	300.1
RF Freq. (MHz)	324	648
Φrms(°)	2.77	1.05
X_{rms}(mm)	2.27	2.38
Y_{rms}(mm)	4.1	2.28
Z_{rms}(mm)	2.86	1.75

Due to the ultrahigh bandwidth requirement and long cable attenuation, the normal phase detectors, such as fast current transformers and wall current monitors, are not suitable to measure the bunch shape in ion linacs. The technique of a coherent transformation of a temporal bunch structure into a spatial charge distribution of secondary electrons through RF-modulation was initially implemented by R. Witkover for BNL linac [7]. An energy (longitudinal) RF-modulation of low energy secondary electrons was used. In the Feschenko type Bunch Shape Monitor (BSM), developed in INR RAS, a transverse RF-scanning is used [8]. Thus a similar BSM is adopted in the linac upgrade project of CSNS-II, as shown in Fig. 2.

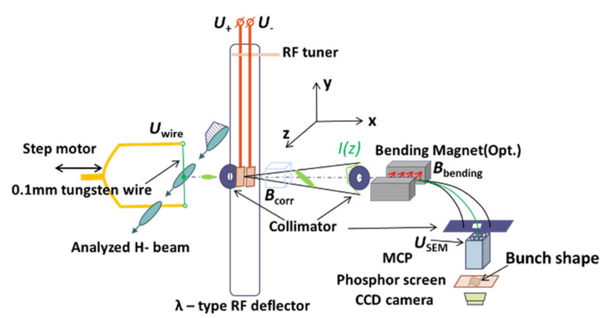

Figure 2: Configuration of bunch shape monitors in CSNS-II.

As the most important part of a bunch shape monitor, a prototype 325 MHz RF deflector was fabricated for the longitudinal bunch shape measurement in C-ADS. Due to the limitation of installing space, it was assumed to be tested at the CSNS linac. This paper will illustrate its design parameters and test results in the laboratory.

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RF DEFLECTOR DESIGN

The prototype 325 MHz RF deflector is a quasi-symmetric coaxial λ/2 standing wave resonator. It is mainly composed of a resonating cavity, two deflecting plates, two RF ports, two HV ends, two bellows and ceramic supports, as shown in Fig. 3.

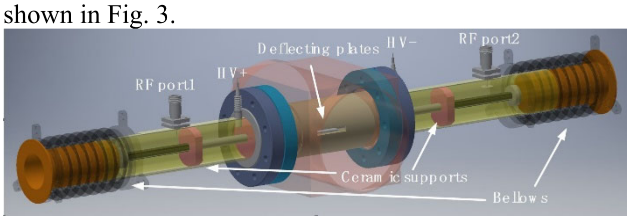

Figure 3: Structure of the C-ADS 325 MHz RF deflector.

CST Simulations

The prototype RF deflector was simulated in MW studio of CST to get a proper resonant frequency f_0 and to optimize the s-parameters. The geometry parameters are listed in Fig. 4. By changing the gaps between the tuner ends of the inner core and the cavity ends moved via bellows, that is, (L_tune_in, L_tune_out) within (5~20 mm), the resonant frequency was calculated in the CST eigenmode solver.

Finally, the combination of (L_tune_in, L_tune_out) were swept and verified to get the f_0 of the RF deflector and a tuning range of ±5 MHz, as shown in Fig. 5 a) and b). The S21 is lower than -30 dB at 325 MHz.

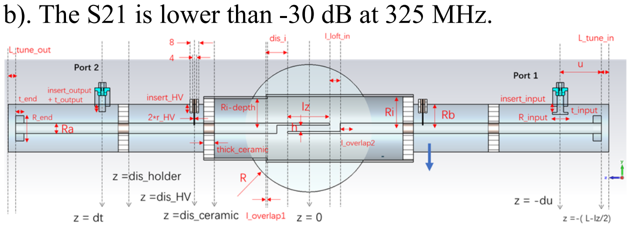

Figure 4: Geometry parameters of the prototype RF deflector.

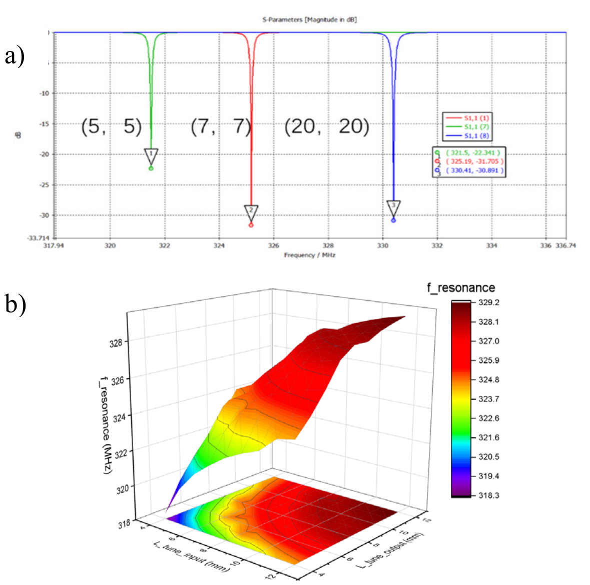

Figure 5: S21 calculation in CST by changing the combination of (L_tune_in, L_tune_out) to get the tuning range.

According to Fig. 5 b), we modified the (L_tune_in, L_tune_out) as (6.2, 6.2) for the RF deflector, and had a resonant frequency of 324 MHz, the same as the RF frequency of DTLs in CSNS. Fig. 6 a) and b) show the electric field distribution in the RF deflector at the resonant frequency of 324 MHz and the calculation of S-parameters. It indicated that this prototype RF deflector could be used to deflect the secondary emission electrons from a wire scanner bombarded by ion beam, and works at 324 MHz, synchronizing to the RF frequency of DTL and SC sections.

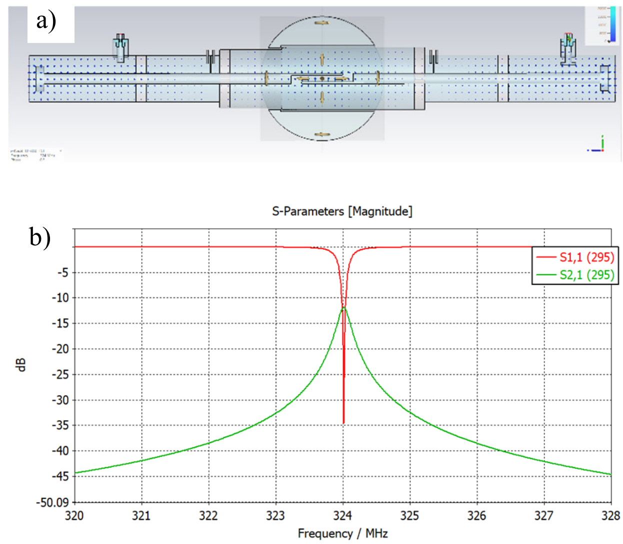

Figure 6: E-field distribution in the prototype RF deflector at 324 MHz and the S-parameters.

MEASUREMENTS IN LAB

The prototype RF deflector was fabricated at a domestic manufacturer. Figure 7 gives the two parts before assembly. It's a pity that there was no locating pin in the initial design, which brought the difficult of alignment during assembly.

The s-parameters were measured via a Keysight E5061B network analyser, shown in Fig. 8. The S11@324 MHz is only -8 dB, which is much bigger than the simulation result and means more power should be fed in to establish an RF field for deflecting the secondary electrons. A mechanical optimization in the second version of RF deflector design is undergoing.

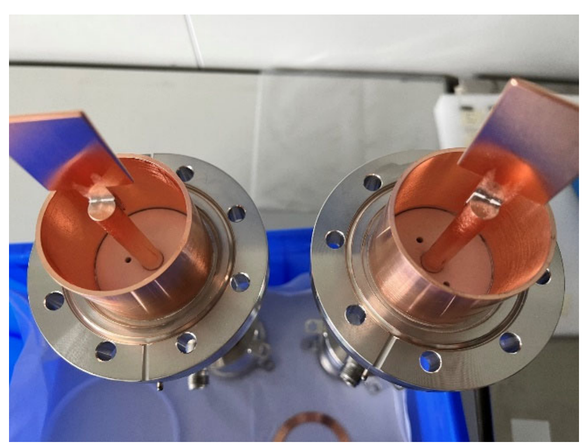

Figure 7: Two parts of the prototype RF deflector.

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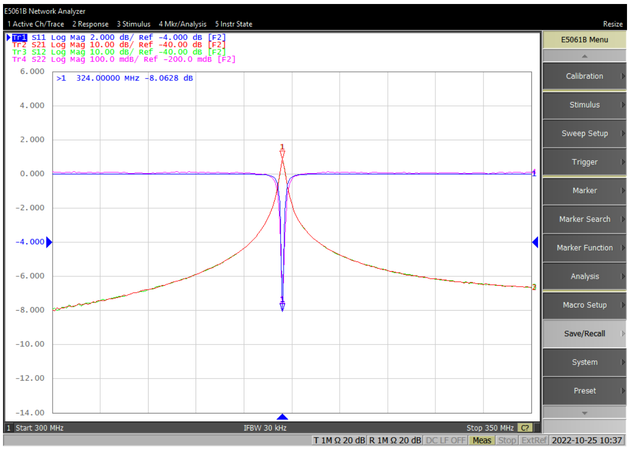

Figure 8: S-parameters of the prototype RF deflector measured by Keysight E5061B.

Figure 9 shows the high power test to the deflector with a 1 kW power amplifier, which is excited by an R&S SMA100B RF signal source. The resonator worked well and there is no waveform distortion observed.

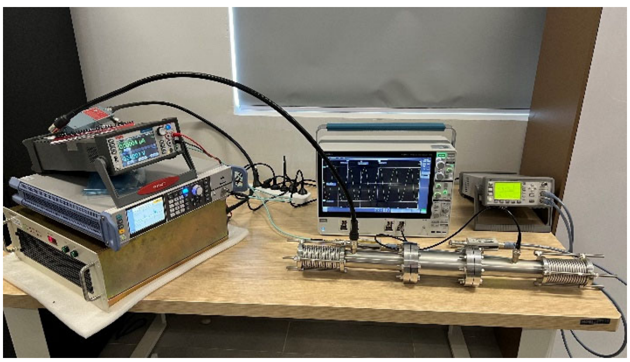
Figure 9: Tested by a 324 MHz power amplifier (Pmax=1 kW).

A test bench with a Kimball electron gun will be established at the end of this year. Then the secondary electron beam path in the deflector could be verified by tuning the amplitude and the phase of the RF field, and the high voltages on the plates.

CONCLUSION

A prototype of RF deflector was design as a 325 MHz λ/2 quasi-symmetric resonator for C-ADS project. It is also suitable to work at 324 MHz by adjusting the gap between the bellow end and the core end. The S21 parameter got unsatisfactory due to the difficulty of alignment.

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