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OPTIMIZATION OF SC CAVITY TYPE FOR CSNS LINAC UPGRADE*

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Abstract

In order to increase CSNS beam power from 100kW to 500kW, the Linac injection energy need to be increased from 80.1MeV to 300MeV. The combined layout of superconducting spoke cavities and elliptical cavities will be adopted to accelerate H- beam to 300MeV. Two operation frequency of spoke cavities were compared with single and double spoke structure, a compact 648MHz βg=0.4 single spoke cavity was proposed, and the RF performance was presented, as well as the MP behavior.

INTRODUCTION

The CSNS (China Spallation Neutron Source) is an inter-discipline complex of producing scattering neutron for scientific research and applications by national institutions, universities, and industries. It consists of three main parts, a 80MeV Linac injector, a 1.6GeV RCS (Rapid Cycling Synchrotron) and a target station, as showed in Figure 1[1].

Beam was successfully accelerated to 1.6GeV by RCS in 2017.7, and first 10kW beam power achieved at target station in 2017.11. The facility passed through the validation of government in 2018.8. The main parameters are listed in Table 1.

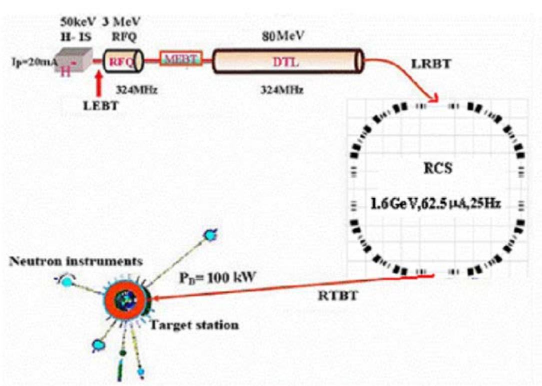

Figure 1: Schematic layout of the CSNS.

Table 1: Primary Parameters of the CSNS

Parameters	CSNS-I	CSNS-II
Beam power (kW)	100	500
Repetition rate (Hz)	25	25
Average current (mA)	62.5	312.5
Proton energy (GeV)	1.6	1.6
Linac energy (MeV)	80.1	300

SC CAVITY OR NORMAL CONDUCT CAVITY

CSNS has two stages plan for the beam power upgrading. In phase I, 100kW beam power is delivered to the target, and in phase II, the power will be upgraded to 500kW by increasing injector beam energy from 80.1MeV to 300MeV. The Linac part is composed of a penning H- source, a RFQ (Radio Frequency Quadrupole) accelerator and a DTL (Alvarez type Drift Tube Linac). The CSNS Linac parameters are showed in Table 2.

Table 2: CSNS Linac Parameters

Parameters	Value
DTL output energy(MeV)	80.1
Peak beam current (Phase I) (mA)	15
Peak beam current (Phase II) (mA)	40
Upgrading space (m)	~85
Normal conducting linac Operation frequency	324MHz

The operation frequency and cavity type need to be considered comprehensively during cavity design. The superconducting cavity are known of multiple advantages of large accelerating gradient, large beam acceptance, negligible ohmic loss compared with normal conduct cavity, short Linac length, etc. After trade-off between the normal conduct cavity and the superconducting one, the combined

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layout of superconducting spoke cavities and elliptical cavities is selected for Linac upgrading.

The spoke cavity is a TEM-class resonator suitable for medium and high β particle acceleration [2], and is widely adopted in other projects like CiADS, ESS, Raon. Several 325MHz spoke cavities with different β have been developed at IHEP and successfully used for beam acceleration [3]. This provides valuable experience of design, fabrication, surface-processing, test and beam commissioning for the development of superconducting cavities of CSNS-II Linac.

OPERATION FREQUENCY AND CAVITY TYPE CHOICES OF SPOKE CAVITY

There are two types of operation frequency choices of spoke cavity design for CSNS-II Linac, 324MHz and 648MHz. Both the 325MHz single and double spoke cavity had been fabricated and tested at IHEP. The main parameters of this two cavities are showed in Table 3 [4][5].

Table 3: Parameters of 325 Single Spoke and Double Spoke Cavities

Parameters	325MHz single spoke cavity	325MHz double spoke cavity
β	0.4 (βg)	0.5 (β_0)
Beam aperture(mm)	Φ50	Φ50
R/Q	250.4	413
G	107.3	125.8
Ep/Eacc	3.68	3.4
Bp/Eacc (mT/(MV/m))	8.31	8.67
Lcav (mm)	386.6	N/A
Rcav (mm)	278	N/A

As Table 3 illustrated, the dimension of 325MHz is about 560mm×400mm, the net weight of 3.5mm thickness niobium bare cavity is about 43kg measured by Solidworks measurement tool. The dimension of 325MHz double spoke cavity is even larger than the single spoke cavity. The weight of double spoke cavity is about 70kg, both two cavities are not easily handled during machining and post-processing.

Assuming Eacc=7MV/m, I=40mA for H- beam, then Vacc=Eacc*βgλ≈2.58MV, beam load P1=Vacc*I=103.2kW. Compared with two accelerating gaps of 325MHz single spoke cavity, the double spoke cavity have three accelerating gaps, it can shorter the total Linac length as we know, but it have a narrower acceptance of β than the single spoke cavity [2], and we can calculate that the beam load is larger than the single spoke cavity, P2≈1.5P1=154.8kW if Eacc is the same as single spoke cavity, it will increase the solid state amplifier power load and budget. The maximum design RF power of coupler is twice the beam power, so the greater the beam power is, the harder the coupler design.

RF DESIGN OF A COMPACT 648MHZ SINGLE SPOKE CAVITY

A compact 648MHz βg=0.4 single spoke cavity is proposed to upgrade the Linac output energy. The RF performance is simulated by CST with all geometric parameters of the cavity (Figure 2). The final RF result is showed in Table 4, compared with RF performance of the 325MHz single spoke cavity.

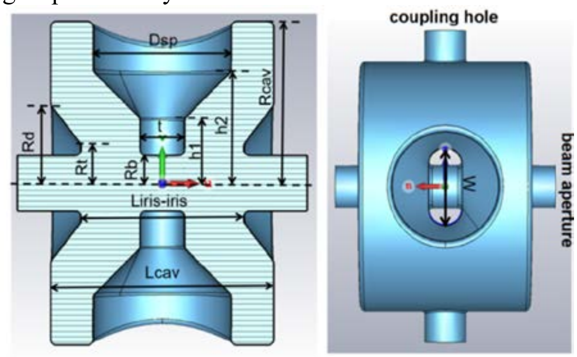

Figure 2: Geometrical parameters of 648MHz single spoke cavity.

Table 4: Parameters of 648MHz Spoke Cavity vs. 325MHz Spoke Cavity

Parameters	325MHz spoke cavity	648MHz spoke cavity
βg	0.4	0.4
Beam aperture (mm)	Φ50	Φ50
R/Q	250.4	174.3
G	107.3	99.5
Ep/Eacc	3.68	4.97
Bp/Eacc (mT/(MV/m))	8.31	8.42
Lcav (mm)	386.6	200
Rcav (mm)	278	147.3

As Table 4 illustrates, the radius of 648MHz spoke cavity is only half of that of the 325MHz spoke cavity and the volume is about 1/8, the net weight of 648MHz spoke cavity is only 12.5kg, which is much lighter than the previous two cavities. Nevertheless, the RF performances of these two cavities are almost the same, except the parameter of R/Q. Since the acceleration length of the 648MHz cavity is only half of that of the 325MHz single spoke cavity, it is easy to be understood that the R/Q of 648MHz is smaller.

The accelerating voltage Vacc=Eacc*βgλ≈1.3MV if Eacc=7MV/m, then the beam load of each cavity P=Vacc*I=52kW of 40mA H- beam for CSNS phase II. Compared with beam load of the 325MHz single spoke cavity and double spoke cavity, the solid state amplifier is much cheaper and easier to do the maintenance. And the single spoke cavity has a more wider acceptance than the double spoke cavity. Another merit of the 648MHz spoke cavity is the coupler design, the max RF power of the 648MHz spoke cavity is only 104kW, which is much

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smaller than the other two cavities, 206.4kW of the 325MHz single spoke cavity and 309.6kW of the 325MHz double spoke cavity.

MULTIPACTING SIMULATION

The multipacting behavior of the 648MHz spoke cavity is done by CST TRK solver [6]. 300°C baked processing of niobium cavity is used for background material, the initial electron source energy is set to 2eV. The electric field magnitude is swept to get SEY results with different accelerate gradient.

With a deliberating shape modification by partial resection at end plate and spoke bar to destroy resonance of secondary electron motion, marked in dashed red frame [7](showed in Figure 3), a better MP behavior was achieved(Figure 4).

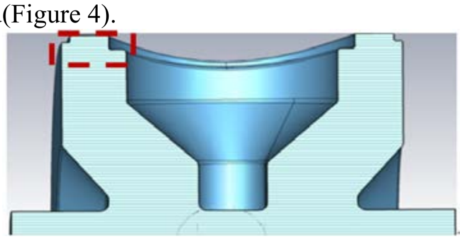

Figure 3: Cavity shape modification.

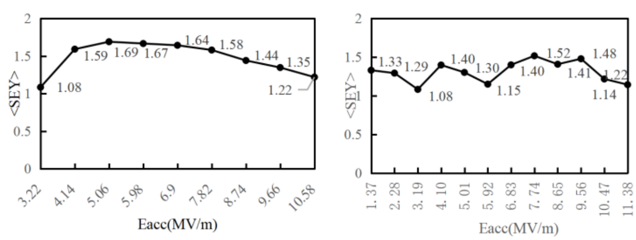

Figure 4: <SEY> result vs. Eacc: Original shape(left), New shape(right).

COULPING PORT DESIGN

When EM design is finished, coupling ports and cleaning ports for HPR should be considered. For 648MHz single spoke resonator, two ports with Φ50mm perpendicular to the spoke bar at outside wall are provided for power coupling and evacuation, in which the electromagnetic field strength is much lower than the Epeak and Bpeak, as Figure 5 illustrated.

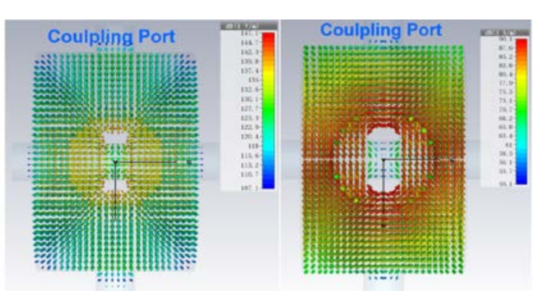

Figure 5: Electric field map (left) Magnetic field map (right).

An antenna is used to adjust coupling coefficient with cavity by tuning insert length into the cavity (Figure 6). Assuming cavity running at Eacc=7MV/m with H^- beam current changing from 1mA to 30mA, according to equation Qe=Vacc/(I*R/Q), the matched Qe is 7.44e6 to 2.48e5. A coaxial line with 50Ω matching impedance is used to reach design Qe. The Qe value vs insert length of antenna is showed as Figure 6.

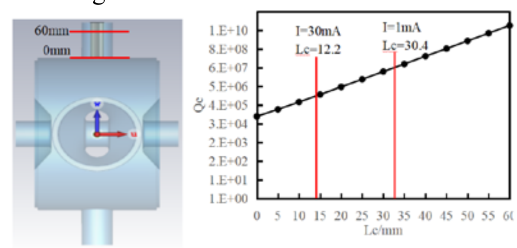

Figure 6: Inserting antenna length vs. Qe.

CONCLUSION

The beam power of CSNS increase from 100kW to 500kW by upgrading Linac output energy from 80MeV to 300MeV in phase II. The combined layout of spoke cavity and elliptical cavity will be adopted. Two operation frequencies and structures of spoke cavity was compared, a compact 648MHz βg=0.4 single spoke cavity was proposed with RF performance optimized to Epeak/Eacc=4.97 and Bpeak/Eacc=8.42 mT/(MV/m), and MP behavior was also improved by cavity shape modification.

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