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CADS 650 MHz BETA=0.63 ELLIPTICAL CAVITY STUDY

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Abstract

The China Accelerator Driven Sub-critical System (CADS) is a high intensity proton facility to dispose of nuclear waste and generate electric power. CADS is based on 1.5 GeV, 10mA CW superconducting (SC) linac as a driver. The high-energy section of the linac is composed of two families of SC elliptical cavities which are designed for the geometrical beta 0.63 and 0.82. In this paper, the 650 MHz β=0.63 SC elliptical cavity was studied, including cavity optimization, multipacting, high order modes (HOM) and generator RF power calculation.

INTRODUCTION

China strives to develop the nuclear energy and the nuclear power of China will reach to 58 million kilowatts in 2020. The nuclear waste will also accumulate to 10400 tons [1]. The demand of nuclear energy will grow further with economic development. The disposal of nuclear waste and nuclear fuel shortage are increasingly more serious in China. Accelerator Driven Sub-critical System (ADS) is the optimal way to dispose of nuclear waste and solves the problem of shortage of nuclear fuel. CADS is promoted and constructed by Chinese Academy of Sciences (CAS), as a long-term energy strategy for China.

CADS is composed of a SC linac, a spallation target and nuclear reactor operating in subcritical mod. The 650 MHz β=0.63 elliptical cavities accelerate proton beams from 180 MeV to 360 MeV. This paper is mainly concerned with the RF properties, multipacting, damping of the higher order modes and required generator power of the elliptical cavity

CAVITY RF DESIGN

The following consideration is needed for high-current SC elliptical cavity design:

1) HOM damping is primarily concerned in high-current SC elliptical cavity design. The larger cavity aperture reduces the interaction between the cavity and beam and improve the cell-to-cell coupling to reduce potential for the rapped HOM and beam instability.

2) The accelerating efficiency improves by increasing the numbers of cells per cavity, but also make it difficult to extract and damp the HOM. Five cells per cavity compromises among the accelerating efficiency, the particle acceptance of TTF, and damping the HOM.

A 650 MHzβ=0.63 superconducting cavity was designed by Superfish. The achieved cavity RF and geometry parameters are listed in Table 1. The final β=0.63 five-cell cavity design is depicted in Figure 1.

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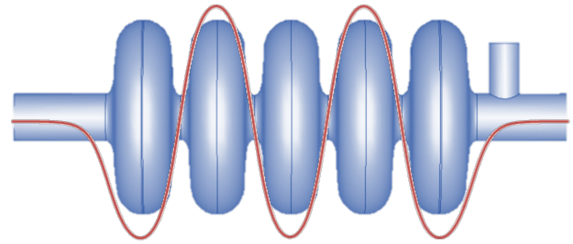

Figure 1: the final β=0.63 five-cell cavity design.

Table 1: The RF Parameters of the 650 MHz β=0.63 Elliptical Cavity

Parameter	unit	value
βg		0.63
frequency	MHz	650
equator diameter	mm	394.4
iris aperture	mm	90
beam pipe aperture	mm	96
cell-to-cell coupling	%	0.9
R/Q(βg)	Ω	333.5
G	Ω	192.7
Epeak/Eacc		2.34
Bpeak/Eacc	mT/(MV/m)	4.63

MULTIPACTING SIMULATION

Multipacting barriers restrict SC cavity performance and accelerating gradient enhanced since a great deal of electrons reach resonance and absorb RF power. Multipacting leads to temperature rise of SC cavity and eventually thermal breakdown. It is crucial to optimize the shape of cavity to eliminate the unexpected multipacting barriers. Multipac 2.1 code [2] was used to simulate the multipacting in the cavity. Fig. 2 shows the enhanced counter function. The result indicate that no hard multipacting was found and the cavity be processed by good cavity surface treatment.

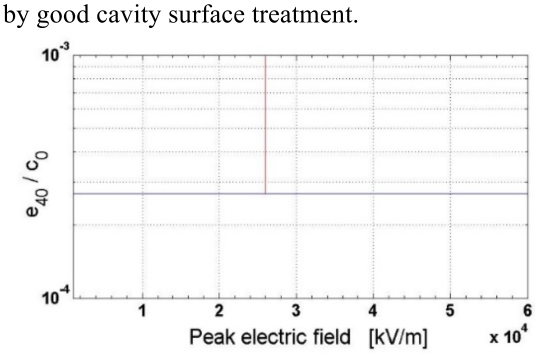

Figure 2: Enhanced counter function- ratio between the number of particles after the 40th impact and the initial number of particles.

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HIGH ORDER MODE

HOMs excited by the beam need to be analysed in detail in SC cavity since HOMs not only conversely impact on the beam and degrade the beam's quality, even leading to beam breakup and beam loss. HOMs also interact with cavity and induce the additional power dissipation and thermal breakdown.

The effect of HOM for beam instability in the proton linac is much lower. In the case of CADS, HOM simulations show that the effect of longitude (mainly monopole) and transverse parasitic mode (mainly dipole) is not a big concern. And the effective transverse emittance induce by HOM increase is lower than the tolerable limit even for the external Q=10^8 and the beam current is 100 mA [3]. If the frequency of HOMs are far away from the machine line and R/Q are much smaller, the longitudinal beam instability induced by HOMs has little effect [4].

The power dissipation induced by TM-monopoles in cavity wall is much larger than that induced by multipoles such as dipoles and quadrupole. Figure 3 shows the actual power dissipated induced by HOMs in cavity walls in the parameter space of Qex , which does not take consideration of the beam noise. We can conclude that the dissipated power exponentially increases with Qex at resonance and drops faster with Qex when the frequency is far away from the machine line

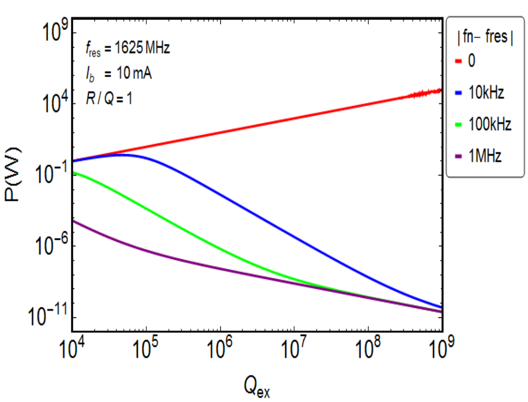

Figure 3: HOM power dissipation in cavity wall versus Qex.

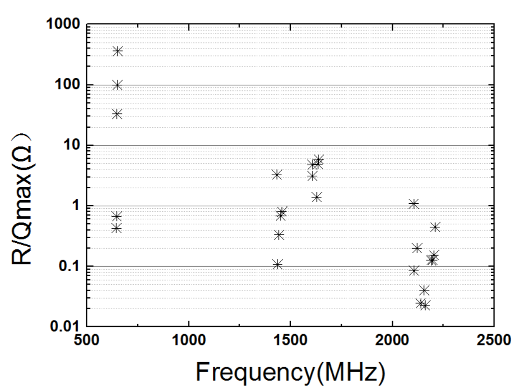

Figure 4: The maximize R/Q from 180 MeV to 360 MeV of TM-monopoles. R/Q of monopoles.

Frequency, Qex and R/Q of each HOM can be found with the 3D CST Studio Suite code. Table 2 depicts the frequency and Qex of TM-monopoles of the elliptical cavity. And Fig. 4 shows the maximize R/Q from 180 MeV to 360 MeV of TM-monopoles. R/Q of monopoles except for the fundamental modes is much small compared to the accelerating mode and the Qex of most of monopole is about ~10^8. The theoretical dissipated power of Monopole is about ~10^{-10} without considering the beam noise and variation of HOMs' frequency in actual operation.

Table 2: the Frequency and Qex of TM-Monopoles of the Elliptical Cavity

Frequency (MHz)	**off resonance (MHz)**	**Qex**
1432.95	29.55	7.30E+08
1436.52	25.98	2.86E+08
1442.81	19.69	2.53E+08
1450.6	11.9	3.69E+08
1457.31	5.19	1.13E+09
1606.9	18.1	1.65E+07
1606.97	18.03	4.92E+07
1628.56	3.56	1.28E+09
1634.21	9.21	1.10E+09
1638.85	13.85	3.20E+09
2104.32	8.18	3.56E+05
2105.81	6.69	4.21E+05
2121.64	9.14	3.07E+06
2138.55	26.05	1.60E+02
2155.22	42.72	6.32E+07

REQUIRED GENERATOR POWER

The 650 MHz β=0.63 SC cavity is design to operate at the accelerating gradient (Eacc) of 15 MV/m. We need to get the optimum eternal Q to minimize the generator power of the input power. The RF power needed for the 650 MHz β=0.63 SC cavity versus the external Q at Eacc = 15 MV/m is illustrated in Fig. 9. We could get the optimum external Q is in rang of 2.9×10^6 to 3.3×10^6 and the moderate generator power is 120 kW.

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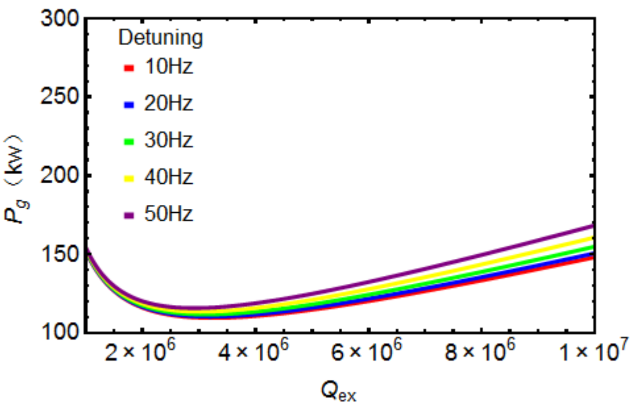

Figure 5: The RF power versus the external Q at Eacc = 15MV/m.

SUMMARY

A 650 MHz β=0.63 SC elliptical cavities are designed for the ADS accelerator, accelerating proton beams from 180 MeV to 360 MeV. The RF and geometry parameters are suitable for ADS accelerator. The multipacting was checked by the Multipac 2.1 and no hard multipacting barriers are found in the cavity. The problems induced by HOMs are theoretically not a main concern in the β=0.63 SC elliptical cavity. The optimum external Q is in range of 2.9×10^6 to 3.3×10^6 and the moderate generator power is 120 kW for the designed Eacc=15 MV/m.

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