ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB032

SUPERCONDUCTING ELLIPTICAL CAVITIES DEVELOPED IN IMP FOR THE CiADS

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Abstract

Multicell superconducting radio frequency (SRF) elliptical cavities are proposed for efficient acceleration of proton beam in the Chinese initiative Accelerator Driven Subcritical System (CiADS). Two families of such cavities will be used in the driver SRF Linac, the first family corresponding to β_{opt}=0.62 cavities that will be used to accelerate the H^+ beam from 175 MeV to 377 MeV and the second family corresponding to β_{opt}=0.82 cavities that will accelerate the H^+ beam from 377 MeV to 500 MeV, with the possibility to upgrade to 1 GeV and higher. The electromagnetic optimization of the cavities with the HOM, wakefield and multipacting analysis will be discussed in this paper.

INTRODUCTION

CiADS is a multi-MW proton source based on a superconducting linac (SCL) which composed of 162.5 MHz half wavelength resonators (HWR010 and HWR019), 325 MHz spoke resonators (DSR042), and 650 MHz elliptical cavities (LB650_062 and HB650_082) [1]. With the successful operation of the 25 MeV demo facility [2] and the design and test of a double spoke cavity [3], key technologies to operate a SCL with HWR and spoke cavities have been demonstrated, such as the cavity design and optimization, industry fabrication and frequency control, post processing and assembly, online operation and LLRF control, et al. Prototypes of the LB650 and HB650 cavities and cryomodules are currently under development for the CiADS 500 MeV initial facility.

GEOMETERY OPTIMIZATION

The elliptical cavity can be parameterized with the geometrical parameters shown in Fig.1. The goal of the geometry optimization is to achieve higher G* R/Q thus lower cryogenic losses and at the same time keep the ratio of E_{pk}/E_{acc} and B_{pk}/E_{acc} as low as possible.

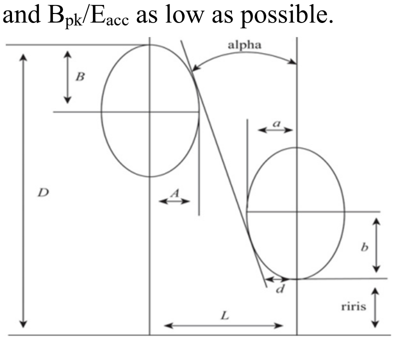

Figure 1: Schematic of the half-cell of an elliptic cavity.

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The iris radius *risis* was fixed to 50 mm for both 062 and 082 cavities due to beam dynamics requirements; the wall angle *alpha* was selected to be 2 degree for both cavities as a balance of RF performance and mechanical performance, also with the consideration of the present post-processing techniques; the half-cell lengths *L* are determined by the optimum β of two cavities; the equator radius *D* were adjusted to tune the frequencies to the targets. Then three independent parameters A, B, b were swept in large ranges for both cavities, and the contour plot of the G*R/Q verse E_{pk}/E_{acc} and B_{pk}/E_{acc} were plotted in Fig.2. The design points for the middle cells were arrow pointed in the figure. The end cells for both cavities were further optimized to get the required field flatness and also for HOM propagation.

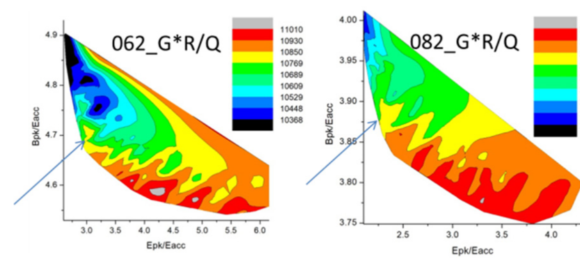

Figure 2: Contour plot of the G*R/Q verse E_{pk}/E_{acc} and B_{pk}/E_{acc} for LB650 (left) and HB650 (right) cavities.

The choice of the cavity cell number is a balance of the acceleration efficiency, cavity acceptance and extraction of the HOM modes. With the consideration of matching between different cavity structures and the possibility to keep the lengths of cryomodules to be the same，which is 6 m in our design, LB650_062_6cell scheme and HB650_082_5cell scheme were adopted, as shown in Fig. 3.

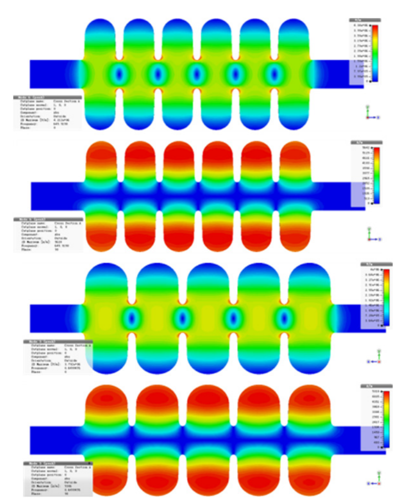

Figure 3: Electric and magnetic field distribution of the 6 cell LB650_062 and 5 cell HB650_082 cavities.

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The optimized geometry parameters were summarized in Table 1 with the unit in *mm* for length and *degree* for angle. The RF Parameters of the optimized geometries for the π mode operation were summarized in Table 2.

Table 1: Optimized Geometry Parameters

Para.	LB650_062		HB650_082	
Cell	Middle	End	Middle	End
2D	390.989	390.989	393.003	393.003
2riris	100	100	100	100
L	68.2	65.4	89.6	89.6
b	16	16	20	20
a	11.38	8.88	13.47	13.67
B	50	59	67	73
A	54	54	74	74
alpha	2	2	2	2
L_{tube}		180		180
D_{tube}		100		100

Table 2: RF Parameters of the Optimized Geometry for the π Mode Operation

Parameter	Unit	LB650	HB650
Cell number		6	5
β_{opt}		0.62	0.82
TTF_opt		0.73	0.74
E_{pk}/E_{acc}		2.94	2.33
B_{pk}/E_{acc}	mT/(MV/m)	4.69	3.87
R/Q_β_{opt}	Ω	347	514
G	Ω	193	237
Field Flatness	%	98.76	99.48
Coupling Factor	%	1.68	1.15
L_{eff}	m	0.82	0.90
L_{total}	m	1.18	1.26
E_{pk}_operation	MV/m	28	28
E_{acc}	MV/m	9.52	12.02
V_{acc}	MV	7.79	10.77
B_{pk}	mT	44.66	46.51
R_{bcs} at 2K	n Ω	2.73	2.73
R_0	n Ω	10	10
R_{trap} at 20mG	n Ω	4.84	4.84
Q_0		1.1e10	1.35e10
P_{loss} at 2K	W	15.92	16.73

HOM ANALYSIS

Although the cavity operates in the TM010-π mode, TE-like and TM-like HOMs will be excited due to interaction of the beam with the cavity. HOMs needs to be damped to an adequately safe level to avoid potential transverse single pass bean breakup (BBU) instabilities, emittance degradation, energy spread, and also to avoid the additional heat on the cavity surface and finally to the helium bath which may trigger a thermal breakdown.

HOM spectrums of the monopole and dipole modes of the LB650 and HB650 cavities are calculated with CST [4] and shown in Fig.4 and Fig.5. Since for a non-relativistic beam HOM impedance depends on beam velocity, maximum R/Qs in the acceleration range were plotted in the figures for both cavities.

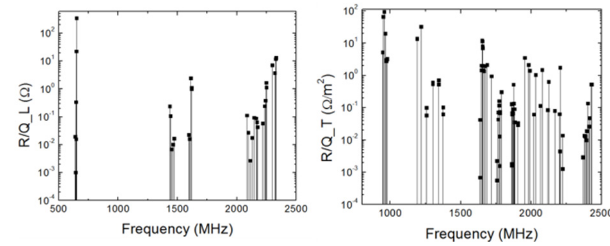

Figure 4: HOM spectrums of the monopole and dipole modes of the 6 cell LB650_062 cavities.

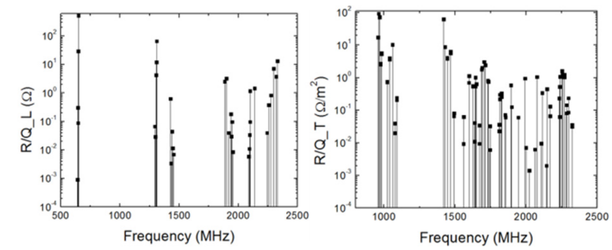

Figure 5: HOM spectrums of the monopole and dipole modes of the 5 cell HB650_082 cavities.

With the spectrums, effects of each HOM on the beam dynamics could be analyzed as described in [5]. The beam breakup instabilities and emittance dilution does not looks to be an issue. Possible accidental resonance excitation of the HOMs could be moved from the dangerous resonance condition by detuning cavity operation mode and then tuning it back.

WAKEFIELD ANALYSIS

The energy loss of a Gaussian bunch to a particular HOM supported by the cavity is described by the loss factor in the following form [6]:

$$k_n = \frac{\omega_n}{4}\frac{R_n}{Q_n}\exp\left(-\frac{1}{2}\left(\frac{\omega_n\sigma}{\beta c}\right)^2\right)$$

Here，σ is the rms length of the Gaussian bunch, which is assumed to be around 1 mm in our calculations.

The integrated loss factor k_{loss} can be obtained by summing the k_n value for all values of n. Assuming that HOMs are excited independently, the incoherent HOM power losses per cavity can be estimated as the following form:

$$P_{ave} = k_{loss} Q_b I_{ave}$$

Here Q_b is the bunch charge; I_{ave} is an average beam current.

The β dependence of the k_{loss} and Pave are shown in Fig.6 and Fig.7 for LB650 cavities and HB650 cavities respectively. The largest incoherent beam energy losses is less than 700 mW per cavity in the final 10 mA scheme, and magnitude lower for the 1 mA and 5 mA cases. Possible losses due to the resonant excitation is calculated follow the procedure discussed in [7], with the Q_{ext} calculated at the main coupler port, total HOM losses were less than 1 W for both cavities. It seems the HOM coupler and dampers are not necessary in CiADS.

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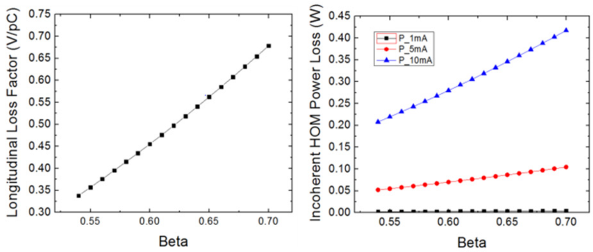

Figure 6: k_{loss} and P_{ave} versus β for LB650 cavities.

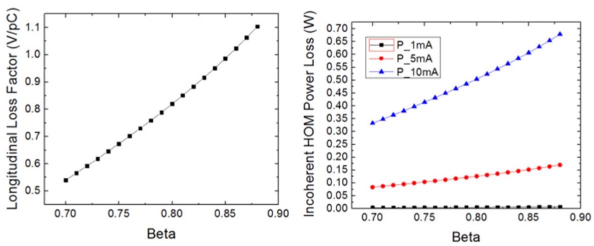

Figure 7: k_{loss} and P_{ave} versus β for HB650 cavities.

MUTIPACTING ANALYSIS

A 2D code MultiPac 2.1 [8] was used to make rough estimates of the multipacting for the 6 cell 062 and 5 cell 082 elliptical cavities. For both cavities, multipacting analyses were done on the middle cells and end cells separately. From the simulation results, there were no hard multipacting barriers for both cavities. The impact energy is less than 50 eV for the whole simulation range (from 0 to 40 MV/m). Fig. 8 shows the final impact energy after 20th impact in the whole simulation range for the end cell of the 6 cell 062 cavity.

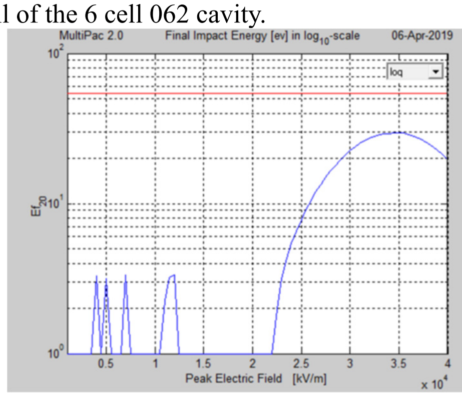

Figure 8: The final impact energy after 20th impact in the whole simulation range for the end cell of the 6 cell 062 cavity.

With a simplistic secondary emission model, it is assumed that all secondary electrons are emitted with the same energy in MultiPac 2.1, thus unable to detect the multipacting correctly. 3D code such as CST-PIC which use a more realistic secondary emission model (Furman Model) by following a probability distribution for the emission energy of secondary electrons are believed to predict the occurrence of the multipacting more correctly.

Multipacting analysis with CST-PIC also shows no risk of multipacting for both cavities and both the middle and end cells. Fig.9 shows the particles vs. time for the end cell of the 5 cell 082 cavity.

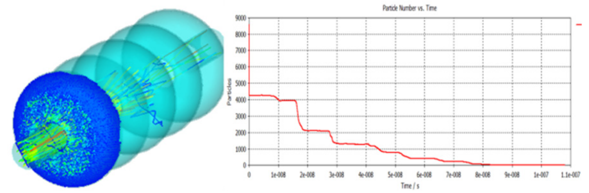

Figure 9: Particles vs. time for the end cell of the 5 cell 082 cavity.

CONCLUSION

The RF designs and optimizations of the 650 MHz 6 cell 062 and 5 cell 082 SC elliptical cavities for the CiADS CW linac were discussed in this paper. The RF and geometry parameters are summarized and meet the design requirements of the CiADS. HOMs analysis and wakefield analysis were done with CST and seems not big concerns in our designs. Multipacting was simulated with MultiPac 2.1 and double checked by CST-PIC, no hard multipacting barriers were found in both cavities. Further optimizations of these two kinds of cavities include the mechanical designs are still on the way.

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