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ANALYSIS OF HIGHER ORDER MODES OF THE SUPERCONDUCTING CAVITIES FOR THE CHINA-ADS INJECTOR-II IN IMP*

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Abstract

The influence of the higher order modes on the beam dynamics and the cryogenic losses has been studied for the superconducting half wave resonators of the China ADS in this paper. In addition, the necessity of HOM dampers in the Superconducting (SC) cavities is discussed.

INTRODUCTION

The Accelerator Driven System for nuclear waste transmutation of China (China ADS) is a high intensity CW proton beam facility which is based on the superconducting accelerating structure with the design specifications of 10 mA beam current and 25 MeV based on the half wave resonator (developed by Institute of Modern Physics) and spoke cavities (developed by Institute of High Energy Physics) [1]. In this work, two types of half wave resonator cavities (f=162.5MHz, β_{opt}=0.10, 0.15 [2]) of IMP have been investigated for their possible dangerous HOMs.

STUDY OF HOMS

For the high current CW acceleration, the higher order modes should be considered, as they may lead to extra heating loads to the superconducting cavity. In the paper, according to the beam parameters of the China ADS as beam current 10 mA and repetition frequency of 162.5 MHz, HOMs have been discussed.

Calculation Methods and Simulation Results

- Monopoles:

When bunches travel along the beam axis, the monopole will be excited, and the equilibrium voltage can be derived for the CW operation at n-order of monopole [3,4,5]:

$$V_{CW,n} = \Delta V_{q,n} \sum_{m=0}^{\infty} exp\left(-m\frac{T_b}{T_{d,n}} + im\omega_n T_b\right) = \frac{\Delta V_{q,n}}{1-exp(-\frac{T_b}{T_{d,n}}+i\omega_n T_b)}. \quad (1)$$

In which, $\Delta V_{q,n}$ =-q*(ω_n/2)*(R/Q)$_n$(β) is voltage excited by the point-like treated bunch, $T_{d,n}=2Q_{L,n}/\omega_n$ is the decay time constant with $Q_{L,n}=1/(Q_0^{-1}+Q_{ext}^{-1})$ the loaded quality factor. The dissipated power can be calculated by:

$$P_{C,n} = \frac{V_{CW,n}^2}{(\frac{R}{Q})_n * Q_{0,n}}. \quad (2)$$

- Dipoles:

The off axis bunch can excite dipole modes, the transverse voltage excited can be expressed [4,5]:

$$\Delta V_{\perp,n} = \frac{1}{2} ixq \frac{\omega_n^2}{c} \left(\frac{R}{Q}\right)_{\perp,n} (\beta). \quad (3)$$

The transverse R/Q can be given as:

$$\left(\frac{R}{Q}\right)_{n,\perp} (\beta) = \frac{\left|\int_{-\infty}^{\infty} E_{n,z}(\rho=a) exp\left(i\omega_n \frac{z}{\beta c}\right) dz\right|^2}{(k_n a)^2 \omega_n U_n}. \quad (4)$$

where $k_n=\omega_n/c$. And the dissipated power of dipole modes can be calculated in the same way as the monopole modes.

The HOM calculations have been done with MWS of CST [6] as presented in Table 1 and Table 2.

Table 1: RF Parameters of HOMs for HWR-0.10

Modes	Frequency (MHz)	V_c (*10^5V)	V^*_c (*10^5V)	R_a/Q_0 (Ω)	$(R_a/Q_0)_1$ (Ω/㎡)
M1	162.5	4.8		113.2	/
M2	346.77	0.005	2.5	~0	1360
M3	500	4.4		30	/
M4	676.6	0.009	5	~0	734
M5	767.4	3		38	/
M6	816.4	0.033	1.4	~0	32
M7	820.4	0.03	1	~0	16.4
M8	832.3	0.064	0.07	~0	0.086
M9	848.2	4.2		17	/
M10	898.8	6		32	/
M11	954.6	0.035	3.2	~0	107
M12	1004	~0	1.18	~0	12.5
M13	1005	0.02	3.14	~0	88
M14	1040	0.16	0.15	0.02	0.18
M15	1130	5.72		23	/

*V_c^*: for some modes with very weak longitudinal electric field along the beam axis, voltage was calculated along the axis off the beam axis 20mm.

Table 2: RF Parameters of HOMs for HWR-0.15

Modes	Frequency (MHz)	V_c (*10^5V)	V^*_c (*10^5V)	R_a/Q_0 (Ω)	$(R_a/Q_0)_1$ (Ω/m^2)
M1	162.5	6.2	/	192	/
M2	317	0.003	0.5	~0	71.3
M3	418	5.6	/	60	/
M4	458	8.6	/	126	/
M5	519	0.006	0.84	~0	45.9
M6	543	0.02	0.05	~0	0.14
M7	544	0.009	0.6	~0	20
M8	589	5.8	/	46	/
M9	630	0.013	1.2	~0	52
M10	650	0.008	1.7	~0	95
M11	712	5	/	28	/
M12	768	0.0009	1.7	~0	58
M13	773	0.006	0.05	~0	0.05
M14	826	5	/	24	/

The effective impedance distribution for monopole and dipole are shown in Figure 1 and Figure 2.

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Table 3: HOM Classification and Dissipated Power for HWR-0.10

Modes	Frequency (MHz)	Mode type	Q_0	Q_{ext}	Pc (W)
M1	162.5	monopole	2.1e9	6.2e6	/
M2	346.77	dipole	8.6e8	1.6e13	1.9e-10
M3	500	monopole	6.4e8	2.4e6	9.5e-10
M4	676.6	dipole	4.6e8	2.0e12	2.3e-9
M5	767.4	monopole	4.5e8	2.5e10	8.5e-10
M6	816.4	dipole	4.3e8	2.0e6	1.9e-9
M7	820.4	dipole	4.5e8	4.8e7	4.1e-10
M8	832.3	/	4.4e8	4.2e10	/
M9	848.2	monopole	3.7e8	1.4e6	5.7e-10
M10	898.8	monopole	3.9e8	8.2e10	7.5e-10
M11	954.6	dipole	3.3e8	3.5e5	2.2e-9
M12	1004	dipole	3.4e8	1.4e8	2.4e-10
M13	1005	dipole	3.1e8	5.6e10	1.8e-9
M14	1040	/	3.3e8	2.3e12	/
M15	1130	monopole	3.0e8	7.3e9	5.1e-9

Table 4: HOM Classification and Dissipated Power for HWR-0.15

Modes	Frequency (MHz)	Mode type	Q0	Qext	Pc (W)
M1	162.5	monopole	4e9	8.8e6	/
M2	317	dipole	1.8e9	1.3e13	8.3e-12
M3	418	monopole	1.4e9	5.3e6	1.4e-10
M4	458	monopole	1.5e9	8.4e11	6.5e-10
M5	519	dipole	1.3e9	2e6	1.5e-11
M6	543	/	1.4e9	1.7e12	/
M7	544	dipole	1.3e9	3e10	4.8e-12
M8	589	monopole	1.2e9	1.4e16	2.7e-10
M9	630	dipole	9.2e8	1.1e10	7.5e-11
M10	650	dipole	9.5e8	4.6e5	4.1e-9
M11	712	monopole	7.9e8	3.3e7	3.6e-10
M12	768	dipole	8.9e8	1.3e11	9.7e-11
M13	773	/	9.1e8	1.9e11	/
M14	826	monopole	6.3e8	2.6e5	2e-9

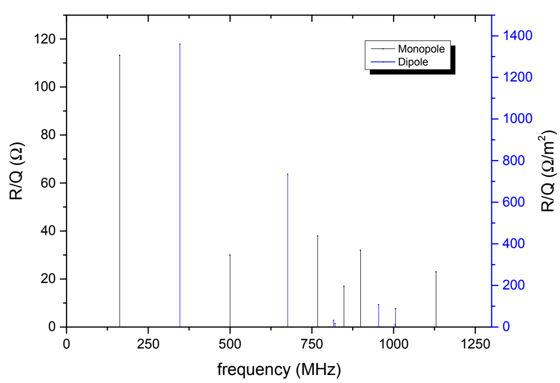

Figure 1: HOM spectrum for HWR-0.10, black for monopole and blue for dipole.

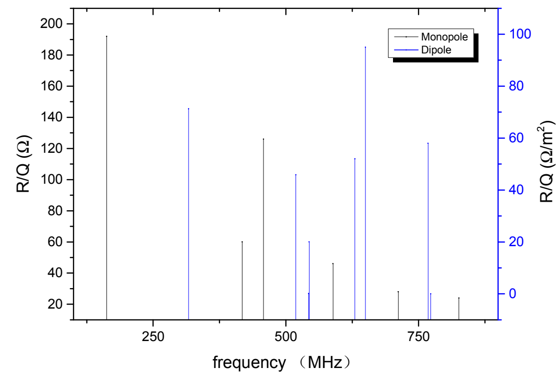

Figure 2: HOM spectrum for HWR-0.15, black for monopole and blue for dipole.

As can be seen in the Table 1 and Table 2, for the monopoles, there is considerable longitudinal electric field along the beam axis of the accelerating gap (mode 1,3,5,9,10,15 for HWR-0.10 and mode 1,3,4,8,11,14 for HWR-0.15); and for most of the dipole modes, off the center axis, longitudinal electric field exists (mode 2,4,6,7,11,12,13 for HWR-0.10 and mode 2,5,7,9,10,12 for HWR-0.15); as for some modes, the longitudinal electric field is very weak in the whole accelerating gaps which are not concerned in this work (mode 8,14 for HWR-0.10 and mode 6,13 for HWR-0.15). For the dangerous modes (the first two types), the dissipated power has been calculated using the formula (2) as shown in Tables 3 and 4.

SUMMARY

Two types of half wave resonators have been studied for higher order modes, and dangerous modes have been investigated. Studies show that the dissipated power can be neglected, and from this point of view the higher order mode dampers are not necessary.

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