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HIGHER ORDER MODES IN CHINA-ADS DEMO LINAC*

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Abstract

The study of higher order modes excited in the China-ADS demo Linac has been presented in this paper. The effects of the cryogenic losses and the influence on beam of the higher order modes have been investigated.

INTRODUCTION

The China ADS demo Linac 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 and spoke cavities [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, and HOMs' effects have been also verified.

HOMS EXCITATION AND CRYOGENIC LOSSES

For the high current CW acceleration, the higher order modes should be considered, as they may lead to extra heating loads and possible beam instabilities to the superconducting cavity. In the paper, according to the beam parameters of the China ADS demo Linac (shown in Figure 1 and Table 1) as beam current 10 mA and repetition frequency of 162.5 MHz, HOMs have been discussed.

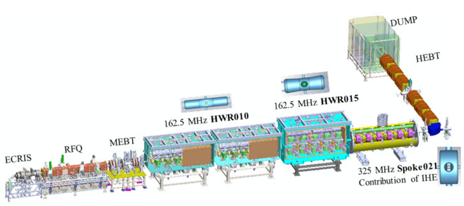

Figure 1: China ADS demo Linac.

Table 1: Cavity Parameters of China ADS Demo Linac

	CM1/IMP	CM2/IMP	CM3/IMP	CM4/IHEP
Frequency	162.5MHz	162.5MHz	162.5MHz	325MHz
Output energy	5 MeV	9 MeV	17 MeV	25 MeV
Cavity type	HWR-010	HWR-010	HWR-015	SPOKE-021
Cavity number	6	6	5	6

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 monopole mode n [3, 4, 5]:

$$\widetilde{V_b} = \mp \frac{V_q}{1-\exp\left(-\frac{T_b}{T_d}\right)\exp(iT_b\Delta\omega)} \quad (1)$$

And the cryogenic loss due to the HOM excitation:

$$P_{c,n} = \frac{{V_{b,n}}^2}{R_a} \quad (2)$$

the worst case is when $T_b \ll T_d$ and $\theta=(\omega_n-\omega)T_b$ very small, some Fourier component of the beam current and a mode's eigenfrequency will be matched closely, then the power loss in the cavity wall in this case will be:

$$P_{c,n} = \frac{{\omega_n}^2 R_a {I_0}^2 {T_d}^2}{4{Q_0}^2} = \frac{R_a {I_0}^2}{(1+\beta)^2} \quad (3)$$

- Dipoles:

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

$$\Delta V_{\perp,n} = \frac{1}{2} ixq \frac{\omega_n^2}{c} \left(\frac{R}{Q}\right)_{\perp,n} (\beta) \quad (4)$$

The transverse R/Q can be given as:

$$\left(\frac{R}{Q}\right)_{n,\perp} (\beta) = \frac{\left|\int_{-\infty}^{\infty} E_{n,z}(\rho=a) exp\left(i\omega_n \frac{z}{\beta c}\right) dz\right|^2}{(k_n a)^2 \omega_n U_n} \quad (5)$$

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

Since some single HOM can be dangerous if not damped sufficiently, it's necessary to check the cavity spectrum adequately.

The first 15 HOM calculations have been done with MWS of CST [6] as presented in Table 2 and Table 3.

Table 2: RF Parameters of HOMs for HWR-0.10

Modes	Frequency (MHz)	V_c (*10^5V)	V^*_c (*10^5V)	R_a/Q_0 (Ω)	$(R_a/Q_0)_l$ (Ω/m²)
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.

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Table 3: RF Parameters of HOMs for HWR-0.15

Modes	Frequency (MHz)	V_c (*10^5V)	V^*_c (*10^5V)	R_a/Q_0 (Ω)	$(R_a/Q_0)_l$ (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 2 and Figure 3.

Table 4: 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 5: 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

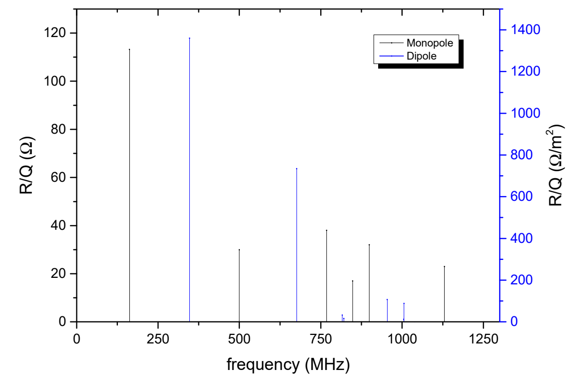

Figure 1: HOM spectrum for HWR-0.10, black for monopole and blue for dipole.

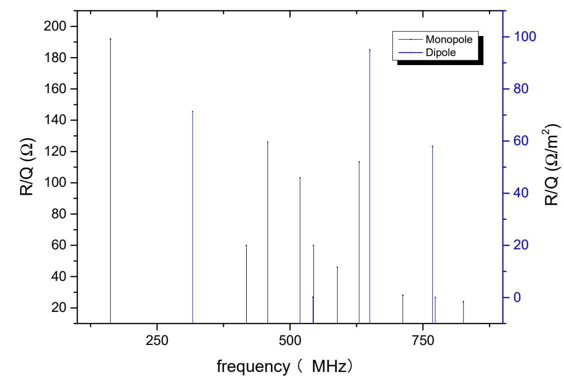

Figure 2: HOM spectrum for HWR-0.15, black for monopole and blue for dipole.

As can be seen in the Table 2 and Table 3, 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 Table 4 and 5.

BEAM INSTABILITIES FROM HOMS

The HOMs can cause degradation of the beam quality, the longitudinal wakefield along the bunch may lead to the energy spread and the transverse wakes can cause emittance growth [5], the beam parameters of China ADS demo Linac can be seen in Table 6.

An estimation for the longitudinal wake caused energy spread is:

$$\frac{\delta E_b}{E_b} = \frac{2qk_\parallel}{E_{acc}} \tag{6}$$

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The influence of transverse wakes can limit the amount of charge in a bunch, the emittance growth can be roughly given as:

$$\frac{\Delta x}{x} = \frac{eNk_{\perp}}{2E_{acc}}\langle\beta\rangle\ln\left(\frac{E_{bf}}{E_{bo}}\right) \quad (7)$$

Table 6: Beam Parameters of China-ADS

Parameters	Unit	Value
RF frequency	MHz	162.5
Eacc	MV/m	4.7(HWR010)/8.3(HWR015)
N of particles/bunch		$3.85*10^8$
$<\beta>$	m	5

Table 7: HOM Caused Beam Instabilities for HWR-0.10

Modes	Frequency (MHz)	Mode type	k// (V/pC-m)	k⊥ (V/pC-m^2)
M1	162.5	monopole	0.029	
M2	346.77	dipole		0.016
M3	500	monopole	0.024	
M4	676.6	dipole		0.063
M5	767.4	monopole	0.046	
M6	816.4	dipole		0.005
M7	820.4	dipole		0.002
M8	832.3	/		
M9	848.2	monopole	0.023	
M10	898.8	monopole	0.045	
M11	954.6	dipole		0.026
M12	1004	dipole		0.003
M13	1005	dipole		0.025
M14	1040	/		
M15	1130	monopole	0.041	

For HWR-0.10, the total longitudinal loss factor is about 0.208 V/pC-m, and the total transverse loss factor is about 0.14 V/pC-m^2; an estimated energy spread is 0.0005% and the emittance growth is 0.0007% .

Table 8: HOM Caused Beam Instabilities for HWR-0.15

Modes	Frequency (MHz)	Mode type	k// (V/pC-m)	k⊥ (V/pC-m^2)
M1	162.5	monopole	0.049	
M2	317	dipole		0.0006
M3	418	monopole	0.039	
M4	458	monopole	0.091	
M5	519	dipole		0.002
M6	543	/		
M7	544	dipole		0.001
M8	589	monopole	0.043	
M9	630	dipole		0.004
M10	650	dipole		0.007
M11	712	monopole	0.031	
M12	768	dipole		0.007
M13	773	/		
M14	826	monopole	0.031	

For HWR-0.15, the total longitudinal loss factor is about 0.284 V/pC-m, and the total transverse loss factor is about 0.0216 V/pC-m2; an estimated energy spread is 0.00004% and the emittance growth is 0.00002%.

From the data of Table 7 and 8, we can see that the beam instabilities caused by HOMs can be ignored in principle.

SUMMARY

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

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