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HOM ANALYSIS OF THE 4-CELL SUPERCONDUCTING CAVITY ON CTFEL FACILITY*

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Abstract

The higher order modes (HOMs) of the 1.3GHz 4-cell cavity on CTFEL facility is analyzed in this paper. The passbands of the HOMs in the 4-cell cavity were simulated, and the most harmful modes were determined. The power of the wakefield was estimated. By microwave test at room temperature, the frequencies of the HOMs were measured, as well as the external Q's of the HOM couplers. Besides, a frequency distribution measurement system was built. The HOM signal excited by beam at 2 K temperature is measured, and some preliminary results are obtained. The measurement techniques and results of the HOM damping performance are presented in this paper.

INTRODUCTION

The terahertz free electron laser facility at China Academy of Engineering Physics has completed fabrication and reached stimulated saturation [1-3]. The main accelerator of this facility is a superconducting linac module developed by Peking University, which consists of double 1.3 GHz 4-cell TESLA-type cavities [4, 5]. The module is designed to accelerate 5 mA CW electron beam from 300 keV to 8 MeV. The 4-cell cavity has the same end-cell and mid-cell shape as the original 9-cell TESLA cavity [6], while 5 mid-cells are removed. As shown in Fig. 1, the cavity consists of 4 cells, beam pipes, two HOM couplers, input coupler port and pickup port.

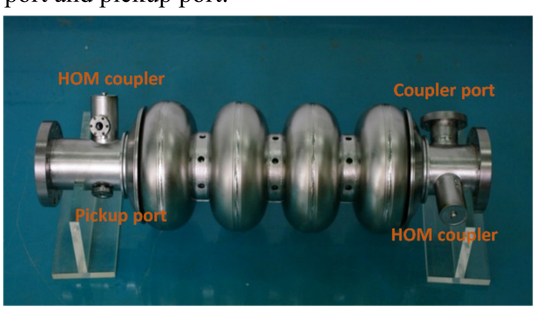

Figure 1: The 4-cell TESLA-type cavity.

When beam passes through the cavity, the higher order modes (HOMs) will be excited, which will cause beam instability and beam loss [7]. HOMs also increase the cryogenic losses due to the additional power dissipation in accelerating cavity walls. The effects are significant especially while CW beam loading. Therefore, the HOMs should be anlayzed and measured.

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SIMULATION OF THE HOMS IN 4-CELL CAVITY

The passbands of the HOMs in 4-cell cavity have been simulated by CST Microwave Studio. The frequencies and R/Qs of the HOMs are listed in Table 1. The most harmful mode is identified to be the TM_{011}-4 mode, which has the biggest R/Q besides the fundamental mode. It is necessary to equip the HOM couplers on the cavity to damp the HOMs power excited by beams.

Table 1: The Frequencies and R/Qs of the HOMs

Mode	Frequency [MHz]	R/Q [Ω/cm^n]
TM_{010}	1279.69	0.00082
	1288.28	0.056
	1297.01	0.063
	1300.00	439.91
TE_{111}	1624.53	0.13
	1654.18	0.88
	1703.55	6.14
	1764.91	5.58
TM_{110}	1802.65	0.87
	1857.34	3.93
	1877.40	3.26
	1884.75	0.18
TM_{011}	2382.26	1.18
	2401.27	2.60
	2427.12	26.48
	2447.78	106.72
TM_{020}	2669.49	0.17
	2690.69	1.69
	2723.88	0.14
	2754.00	0.21

The power of the HOMs excited by beam is also simulated by ABCI. The frequency spectrum of loss factor is show in Fig. 2. The peaks of the loss factor are appeared at the frequency 1.3 GHz, 2.4 GHz ~ 2.5 GHz and 2.6 GHz, corresponding to the TM_{010}, TM_{011} and TM_{020} mode.

The average beam current in 4-cell cavities is 5 mA, while repetition frequency is 54.17 MHz, and the beam length is 3.6 mm. The simulation results indicate that the loss factor is 2.7 V/pC, and the wakefield power is 1.25 W, including 0.83 W HOMs power and 0.42 W fundamental mode power.

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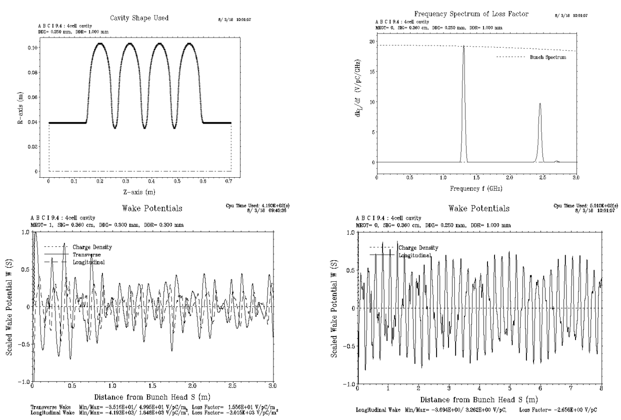

Figure 2: The simulation results by ABCI.

MICROWAVE MEASUREMENT AT ROOM TEMPERATURE

The frequency and the field distribution of the HOMs are measured at room temperature by network analyzer. The modes types are identified by comparing with the simulation results before. The performance of the HOM coupler is measured by S-parameters. To avoid fundamental mode leaking out from HOM couplers, the S_{21} of the fundamental mode is adjusted to lower than -100 dB, as shown in Fig. 3. The Q_e of the HOMs are $10^3 \sim 10^6$, as shown in Fig. 4, which means the HOM couplers are able to damp HOM power effectively.

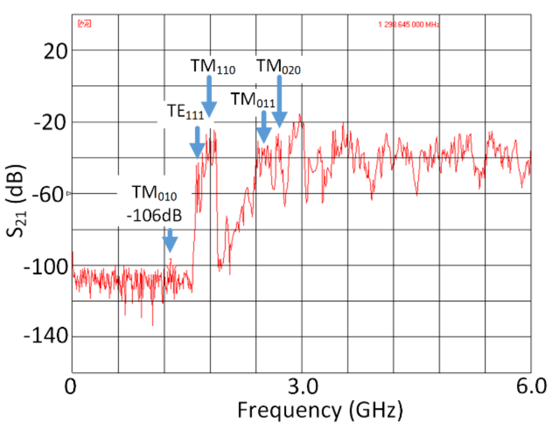

Figure 3: The frequency spectrum distribution of the HOM passbands.

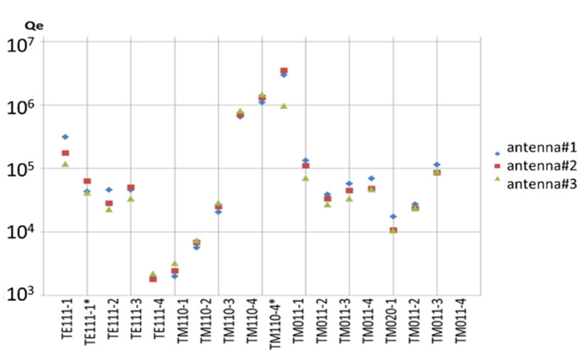

Figure 4: The Q_e of the HOM modes.

HOM SPECTRUM MEASUREMENT AT 2 K TEMPERATURE

In order to study on the interaction between beam and HOMs, the frequency spectrum of the HOMs excited by beam in 4-cell cavity is measured. A frequency distribution measurement system has been built. The HOMs signal is picked up from the HOM coupler port of the 4-cell cavity. As the 1.3 GHz fundamental mode signal is much stronger than the HOMs, it should be damped. With two VHF-1300+ high-pass filters and two ZRL-2400LN+ amplifiers, the signal above 1.5 GHz is amplified while fundamental mode is filtered. The HOMs signal is measured by a FSU spectrum analyser, with the passband 20 Hz ~ 67 GHz. The steering magnet is used to allow beam pass though the superconducting cavity in different paths. And the BPMs are used to measure the beam offsets at both upstream and downstream of the superconducting module, as shown in Fig. 5.

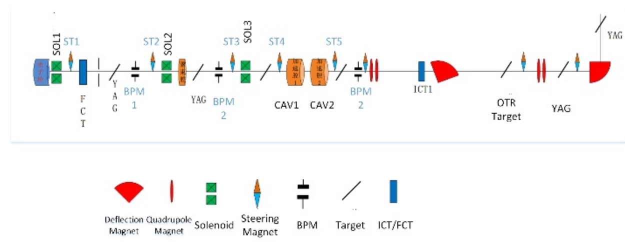

Figure 5: The sketch of the CTFEL beam line.

The measured frequency spectrum is composed of two types of peaks. First ones are the eigen mode peaks, which is labelled by blue numbers in Fig. 6. And the second ones (the peaks with red number labels in Fig. 6.) are integer multiples of 54.17 MHz, because the HOMs are excited repeatedly by bunches with the repetition frequency 54.17 MHz. The latter ones are much stronger than eigen modes peaks, which makes it difficult to identify the modes in Table 1.

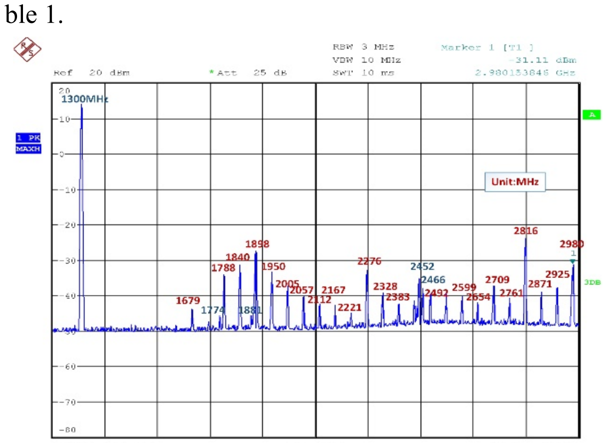

Figure 6: The measured frequency spectrum of HOMs.

We changed the beam current and beam offsets, to get the HOMs signal excited by beam with different parameters. The amplitude of 1300 MHz kept at 13.95 dBm during this process, since there is LLRF system to maintain the amplitude of the fundamental mode. Measurement result

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indicates that there is a good linear relation between the amplitudes of the integer multiple peaks and beam current, as shown in Fig. 7. The FCT voltage is proportional to the beam current.

However, the changes of the amplitudes are not significant while the beam offset changes in this experiment. That's because the HOMs signal is not strong enough to measure the small difference when beam offset changes. Before the HOMs signal gets more amplified, the fundamental mode should be filtered further. The filter and amplifier are planned to be updated in next experiment this year.

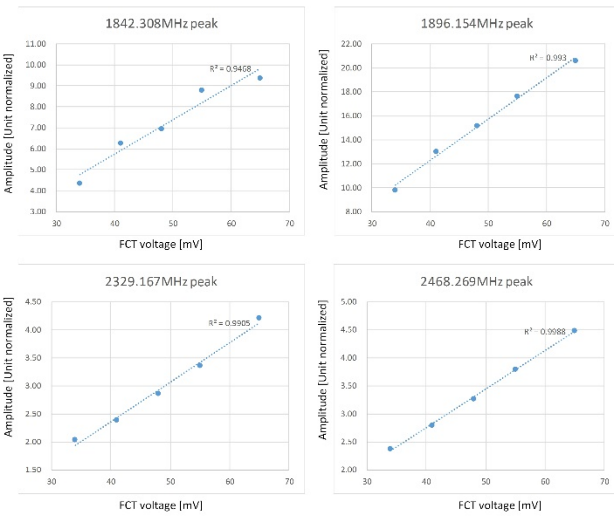

Figure 7: The linear relation between the amplitudes of the integer multiple peaks and beam current.

CONCLUSIONS

The higher order modes (HOMs) of the 1.3GHz 4-cell cavity on CTFEL facility has been analysed. The passbands of the HOMs have been simulated by CST Microwave Studio. The frequencies and R/Qs of the HOMs have been listed, and the most harmful mode is identified to be the TM011-4 mode. The power of the HOMs excited by beam is also simulated by ABCI. The simulation results indicate that the HOMs power excited by beam is 0.83 W. Microwave measurement indicated that the Qe of the HOMs are 103 ~ 106, which means the HOM couplers are able to damp HOM power effectively. Besides, the frequency spectrum of the HOMs excited by beam in 4-cell cavity at 2 K is measured. There is a good linear relation between the amplitudes of the integer multiple peaks and beam current. But the HOMs signal is not strong enough to measure the difference while beam offset changes in this experiment. The measurement system is planned to be updated by using more appropriate filters and amplifiers.

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