HOM PARAMETERS SIMULATION AND MEASUREMENT RESULT OF IHEP02 LOW-LOSS CAVITY

H. J. Zheng, J. Y. Zhai, T. X. Zhao, S. Jin, Z. C. Liu, J. Gao, Z. H. Mi, Y. L. Liu
IHEP, Beijing, 100049, China

Abstract

In cavities, there exists not only the fundamental mode which is used to accelerate the beam but also higher order modes (HOMs). The higher order modes excited by beam can seriously affect beam quality, especially for the higher *R/Q* mode. This paper reports on recent measured results of higher order modes in the IHEP02 low-loss SRF cavity. Using different methods, the Q_{ext} of the dangerous modes passbands have been got. The results are compared with TESLA results. *R/Q* of the first three passbands have also been got by CST and compared with the results of TESLA cavity.

INTRODUCTION

The layout of IHEP02 low-loss 9-cell superconducting cavity is shown in Fig. 1. In order to damp HOMs, two HOM couplers were mounted respectively at the upstream and downstream beam tube. Distances from the HOM couplers to end cells were 65mm and 50mm, which were different from TESLA cavity [1]. Length of upstream beam tube was also different from downstream.

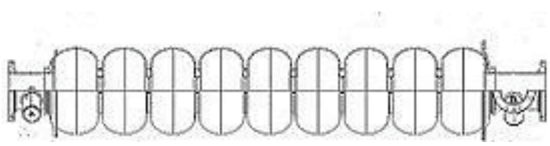

Figure 1: Layout of IHEP02 9-cell cavity.

Damping of HOMs in ILC linear collider is necessary. Parasitic modes excited by the accelerated beam may lead to loss of beam quality and additional power dissipation. For HOMs with frequency lower than cut off frequency of the beam tube, their power loss must be extracted by external load. When the moving relativistic particles encounter geometric variations along the structure, such as RF accelerating cavities, vacuum bellows, and beam diagnostic chambers, there are wakefields after the particles go through [2]. The influence of the HOMs on beam can be divided into short range effect and long range effect. The single bunch effect is caused by short range wakefields. In order to meet the requirements of ILC beam dynamics, choose the appropriate RF phase to compensate for the energy spread from the longitudinal short range wake effect. Transverse short range wakefield is small, so no BNS damping is needed. Longitudinal long range wake effect can be ignored. Transverse long range wakefield mainly consider the influence of dipole modes, which requires the Q_{ext} of the HOMs less than 10^5.

SIMULATION RESULT OF R/Q

The ratio *R/Q* is a very important quantity related to the interaction of the beam and cavity. The higher value of *R/Q* stands for larger energy change between beam and cavity. For monopole HOMs, beam energy loss will be more. For dipole modes, the transverse displacement of the beam will be larger, which will causes emittance larger and even worse it will leads beam loss. It becomes very important to measure modes with large *R/Q*.

An important parameter describing the transverse beam-cavity interaction is transverse shunt impedance. From the Panofsky-Wenzel theorem [2], the transverse momentum change of the particle passing through a cavity excited in a single mode is proportional to a parameter $(R/Q)_\perp$. In this paper, for dipole modes, $(R/Q)_\perp$ is defined as:

$$(\frac{R}{Q})_\perp = \frac{\left|\int E_z e^{j\omega z/c} dz\right|^2}{k^2 r^2 \omega U} = \frac{V_{//}^2}{k^2 r^2 \omega U} \quad (1)$$

The unit of $(R/Q)_\perp$ is ohms. k is the wave number. $V_{//}$ is the accelerating voltage of a cavity which is defined as:

$$V_{//} = \int_0^d E_z e^{j\omega z/c} dz \quad (2)$$

d is the length of cavity. In this paper, we define a new $(R/Q)_\perp$ called $(R/Q)_\perp^{'}$ as:

$$(\frac{R}{Q})_\perp^{'} = \frac{V_{//}^2}{r^2 \omega U} \quad (3)$$

The unit of $(R/Q)_\perp^{'}$ is Ω / cm^2 .

Energy generated by HOMs can be coupled by HOM couplers and absorbed by external load. HOMs energy loss can be divided into two parts, power dissipated in the cavity walls P_0 and power coupled by the external circuit P_e. U Is the energy stored in the cavity. It is better

$$Q_e = \frac{\omega U}{P_e} \quad (4)$$

to get small Q_e in order to damp the HOMs enough.

Dangerous modes' Q_e can be got by measuring the microwave parameters of 9-cell cavity. The measured results affect how to optimize HOM coupler structure.

CST was used to calculate the first three passbands of HOMs' *R/Q*. The results of *R/Q* compared with TESLA cavity's results are shown in Fig. 2. In Fig. 2, modes in the box represent the most dangerous three modes which have largest *R/Q* in that passband. The most dangerous modes need to be measured carefully.

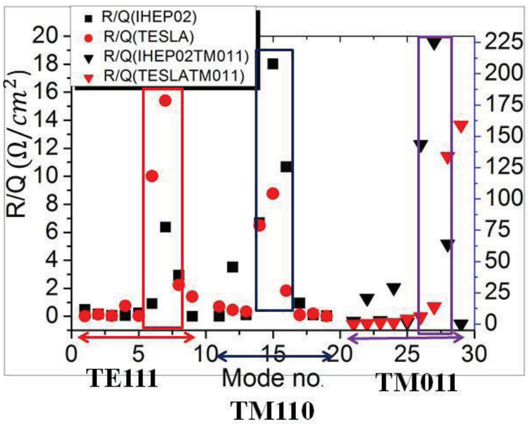

Figure 2: HOMs' *R/Q*.

STRUCTURE OF HOM COUPLER

There are three major varieties of HOM couplers [2]: waveguide, coaxial, and beam tube. Consider the purpose of 1.3GHz superconducting cavity, it requires the connection between cavities short. The coaxial type was chosen, because of their more compact size [3]. The coupler used for IHEP02 superconducting cavity is shown in Fig. 3. According to the rules of excitation, frequency of modes TE111, TM110 and TM011 are all under the cut-off frequency of beam tube whose radius is 40mm.

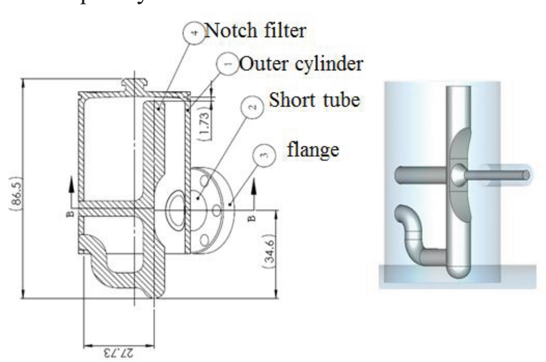

Figure 3: Profile and model of HOM couplers.

In order to sufficiently attenuate the HOMs, there were two HOM couplers mounted respectively on the upstream and downstream [1]. The position of the HOM coupler was 65mm from the edge of the end cell on the upstream and 50mm from the edge of the end cell on the downstream. The design value of the insertion length of the coupling loop tip was 30.25mm from the beam axis.

The mounted angle of the upstream coupler and downstream coupler are shown in Fig. 4.

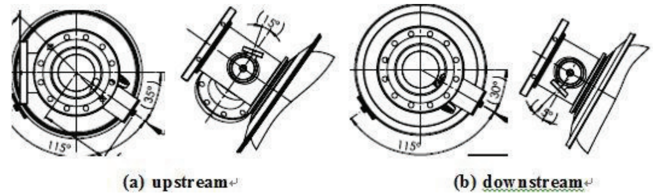

Figure 4: (a) shows the upstream coupler's position and (b) shows the downstream coupler's position.

HOMS MEASUREMENT

The characteristic of HOMs were measured by using a network analyzer. The ports of the two HOM couplers were used as the excited input and output ports. Measuring device schematic diagram is shown in Fig. 5. Measured results of HOMs peak frequencies and the Q_{ext} were performed at room temperature.

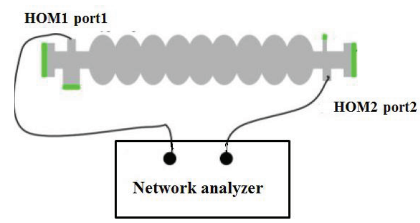

Figure 5: Schematic diagram of the HOM's measurement.

Measurement of IHEP-02 Cavity's HOM Frequency and Passband

The measured results of frequencies and passbands are shown in Fig. 6. The most dangerous modes were recognized.

Measurement of IHEP-02 Cavity's HOM Q_{ext}

The excitation signal was imported to the cavity by upstream HOM coupler and the output signal was extracted by downstream HOM coupler. The measured microwave parameters were received from the network analyzer. Bead pulling method [2] was used to measure the field profile.

Q_{ext} of the first three modes with frequencies under the beam tube cut-off frequency were measured. Q_{ext} of the mode TM111 was also measured even if its frequency was above the beam tube cut-off frequency. There was a mode during TM111 passband with the largest *R/Q* not only of the modes of this passband but also of all calculates modes [4] [5].

Three methods were used to measure Q_{ext}, impedance method [6] [7], reflection method [8] and transmission method [9]. Reflection method has a limitation that the coupling coefficient was not too small. Transmission method was used for one port weak coupling. The measured results of Q_{ext} compared with TESLA design goal are shown in Fig. 7. Modes in the box are the most

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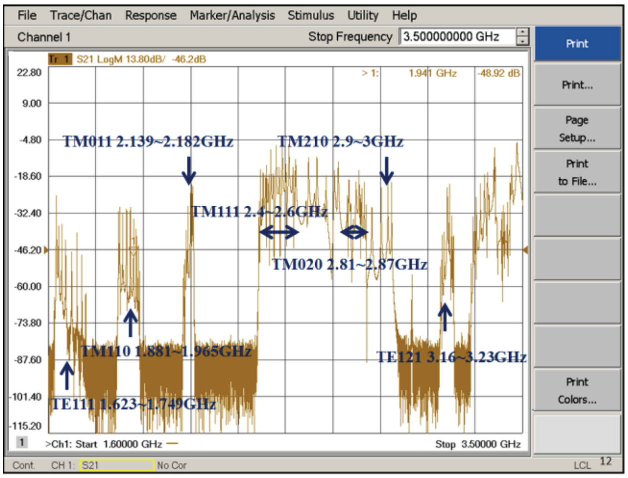

Figure 6: IHEP-02 cavity's HOM frequency and passband.

dangerous modes in that passband. From the results, the most dangerous modes' Q_{ext} of TE111 modes are larger than TESLA results. The lengths from HOM coupler to end cells of IHEP-02 cavity were 65mm and 55mm while 45mm for TESLA cavity. From equation $Q_e = \frac{\omega U}{P_e} \propto \frac{1}{E^2} \propto e^{2\alpha z}$ [10], one can got a conclusion that the longer the length, the smaller value of Q_{ext}.

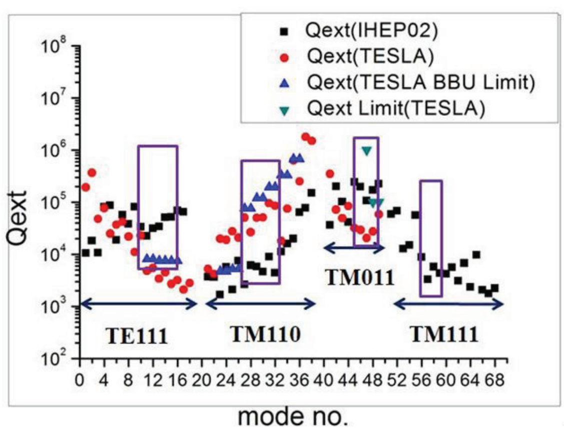

Figure 7: Q_{ext} of IHEP-02 cavity compared with TESLA results

For the dangerous mode TM110, the damping effect of IHEP-02 cavity is better than TESLA cavity. Q_{ext} are lower than TESLA BBU limit. For the third dipole mode TM111 whose frequency is above the cut-off frequency, the measurement results show a good damping with all the modes under 10^5.

In order to get the relationship between Q_{ext} and feedthrough gap, Q_{ext} values with different gaps were also measured. The fifth mode of TM110 (5Pi/9) was choose to measure. Design value of feedthrough gap was 0.5mm. Definition of feedthrough gap is shown in Fig. 8. The measured values are shown in Fig. 9.

Figure 8: Definition of feedthrough gap.

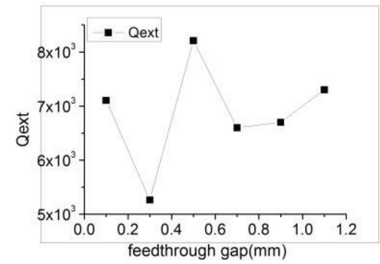

Figure 9: Measurement result of Q_e~feedthrough gap.

CONCLUSIONS

Beam-induced modes have far reaching consequences for power dissipation and beam stability. In this paper, methods of the measurement of Q_{ext} and the measured results are presented. The $(R/Q)_\perp$ simulated results are also got. The results provide a good guidance for the optimization of HOM couplers in the future.

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