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Measuring the performance of the coaxial HOM coupler on a 2-cell TESLA-shape copper cavity*

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Abstract Coaxial High Order Mode (HOM) couplers have been fabricated at Peking University and their RF performance has been measured on a test device consisting of a coaxial transmission line and a 2-cell TESLA-shape copper cavity. The test results on the 2-cell TESLA-shape copper cavity with HOM couplers indicate that the coupler can cut off the fundamental mode TM_{010} and absorb HOMs effectively after a careful adjustment. The optimal angle of the HOM coupler with the beam tube is found. The initial test results of HOM couplers are presented in this paper.

Key words coaxial HOM coupler, 2-cell copper cavity, HOM

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1 Introduction

An electron beam passing through a cavity excites modes which can seriously affect subsequent charges. If not sufficiently damped, they can lead to beam instabilities and beam loss. Even without beam breakup, HOMs can degrade the beam's quality, leading to a loss of luminosity for colliders or a loss of brightness for synchrotron radiation and FEL light sources[1]. In the case of superconducting cavities, HOMs also increase cryogenic losses due to the additional power dissipation in the cavity walls. The required function of a HOM coupler is the extraction of the HOM's power induced by a beam and the rejection of the accelerating mode power supplied by a klystron in a cavity. There are three major varieties of HOM couplers: waveguide, coaxial, and beam tube. The coaxial HOM coupler is compact and suitable for low and medium HOM power extraction. Here we describe the coaxial HOM coupler of the TESLA cavity. In order to test the coaxial HOM coupler, a 2-cell TESLA-shape copper cavity and a coaxial transmission line were designed and fabricated and a measurement of the coaxial HOM coupler performance was taken.

2 Analysis of the HOMs of the 2-cell TESLA-shape cavity

To accelerate a high current beam by the cavity, the dangerous modes must be determined. They can be divided into three types. 1) The longitudinal electric field is strong at the beam axis. 2) There is a longitudinal electric field away from the beam axis, but it vanishes at the beam axis. 3) The electric field is transverse and strong. For the 2-cell TESLA-shape

Table 1. RF parameters of 12 modes of the 2-cell TESLA-shape cavity calculated with the Microwave Studio.

mode	f/MHz	$Q_0(\times10^4)$	$(r/Q)/(\Omega/\mathrm{cm}^n)$
M1:TM_{010}^+	1288.8	2.9	0.0108
M2:TM_{010}	1301.5	2.9	216.9
M3,4:TE_{111}^+	1636.5	2.3	1.298
M5,6:TE_{111}	1724.4	2.9	2.525
M7,8:TM_{110}^+	1815.2	2.6	4.190
M9,10:TM_{110}	1882.1	3.4	1.805
M11:TM_{011}^+	2397.1	3.1	6.740
M12:TM_{011}	2442.1	3.1	58.43

Note: Superscript + denotes the $\pi/2$ mode in the passband, the other one is the π mode. The dipole mode of the ideal cavity is doubly degenerate. The monopole modes are characterized by $n=0$, the dipole modes by $n=2$[3].

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cavity, as well as the accelerating mode TM_{010}, the most dangerous HOMs are TE_{111}, TM_{110}, and TM_{011} according to the electric field[2]. Table 1 lists the results of 12 modes of the 2-cell TESLA-shape cavity obtained with a Microwave Studio simulation.

3 Measurement of the resonate modes

The RF parameters (frequency f, quality factor Q_0, field distribution) of the modes are measured by a computer-controlled vector network analyzer schematically shown in Fig. 1, where the dashed line of Port 2 indicates the connection that is used for the HOM coupler measurement. In order to confirm the type of the modes, the electric field profile of the modes is measured by bead pulling, where a dielectric ball with a diameter of 10 mm is used. By comparing the measured electrical fields with the simulated ones, all the modes are obtained. They are shown in Table 2.

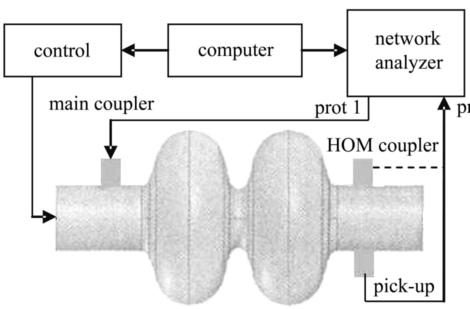

Fig. 1. Block diagram of the test bench for RF measurements of the resonate modes.

Table 2. Measured frequencies and quality factors of the 2-cell copper cavity.

mode	f/MHz	$Q_0(\times 10^4)$
M1:TM^+_{010}	1290.3	2.6
M2:TM_{010}	1303.2	2.9
M3:TE^+_{111}	1639.2	2.2
M4:TE^+_{111}	1639.5	2.2
M5:TE_{111}	1726.3	1.1
M6:TE_{111}	1728.1	1.1
M7:TM^+_{110}	1816.5	1.8
M8:TM^+_{110}	1817.2	1.8
M9:TM_{110}	1883.6	3.4
M10:TM_{110}	1883.9	3.4
M11:TM^+_{011}	2408.0	1.7
M12:TM_{011}	2449.3	1.3

The measured results are almost the same as the simulated ones; however, they show a small frequency shift, caused by the fact that the shape of the fabricated 2-cell copper cavity is not exactly the same as the simulated one. The presence of the couplers breaks the dipole mode degeneracy, so the two polarized modes have different frequencies.

4 Design and principle of the coaxial HOM coupler

The HOM coupler of the TESLA cavity is of coaxial type[4]. It consists of the following three parts:

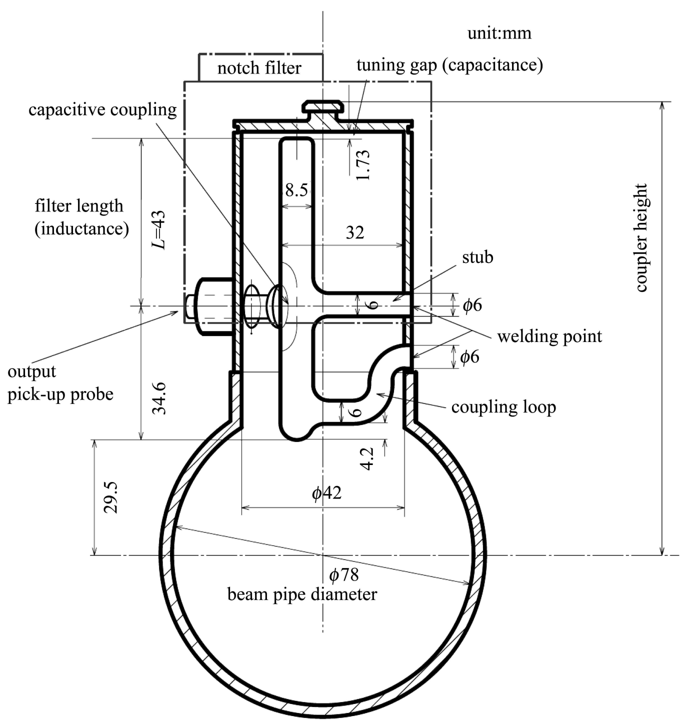

Fig. 2. Coaxial HOM coupler of the TESLA cavity.

(1) A notch filter to reject the power of the accelerating mode in the cavity.

(2) A loop antenna to couple the beam-excited HOM power at the outside of both end cells.

(3) A pick-up probe to extract the HOM power from the cavity.

A cross-section of the HOM coupler of the TESLA cavity is shown in Fig. 2. The dash dotted square in the figure indicates the notch filter part. It is an LC resonant circuit that includes the capacitance of the tuning gap and the inductance of the inner conductor that extends to the upper stub of length L. The extraction of the HOM power by the pick-up probe is performed by capacitive coupling.

5 Measurement of the stop band characteristic of the coaxial HOM coupler[5]

The stop band of the HOM coupler has been measured on a coaxial transmission line which was especially designed for the HOM coupler test. The frequency of the stop band should be the same as the frequency of the fundamental mode of the cavity. In this case the working frequency of the cavity can be effectively cut off by the HOM coupler.

6 RF measurement of the HOM damping on the cavity

The HOM coupler is mounted on the tube with a constant height, so it can be rotated on the beam tube. The diameter of the pick-up probe is 8 mm and the length is variable. A notch frequency tuner was designed and fabricated to adjust the gap between the inner part and the end plate of the HOM coupler. The angle of the HOM coupler influences the extraction of the HOMs and also the accelerating mode. Table 3 shows the results of the measurement. All the modes are identified by their frequencies according to the results obtained without the HOM coupler. The frequencies of all the HOMs are shifted roughly by 3 MHz to higher values after the mounting of the HOM coupler. When the HOM coupler is rotated on the beam tube, the angle between the plane of the HOM coupler inner part and the vertical section plane of the 2-cell copper cavity changes. If those two planes are parallel and the two welding points are farther to the cell, the angle is 180 degrees. We rotate the HOM coupler clockwise.

Table 3. The variation of the frequency and external factor of the TM_{010} mode with angle.

angle/(°)	f/MHz	$Q_{\text{ext}}(\times 10^{11})$
60	1303.24	0.8
90	1303.25	95.7
120	1303.23	176.2
180	1303.23	47.16
210	1303.22	2.99
240	1303.22	1.012
270	1303.21	3.255

According to the measurements, there is almost no influence on the resonating frequency and the field profile of the accelerating mode; however, the Q_{ext} change. One prefers larger Q_{ext} of the accelerating mode. Measurements of the HOMs have also been performed. Fig. 3 shows a typical curve of S_{21}, which is obtained at an angle of 120 degrees after careful tuning on the coaxial transmission line. According to Fig. 1, S_{21} is the forward voltage gain of the cavity, wherein the incident voltage port is the main coupler (Port 1) and output voltage port is the HOM coupler (Port 2). From the figure one sees that the dangerous modes TE_{111}, TM_{110}, and TM_{011} are damped and the fundamental mode TM_{010} is cut off. Table 4 shows the Q_{ext} of the HOMs for the coaxial HOM coupler at different angles. The two modes of similar frequencies in Table 4 are the polarization modes of the dipole mode.

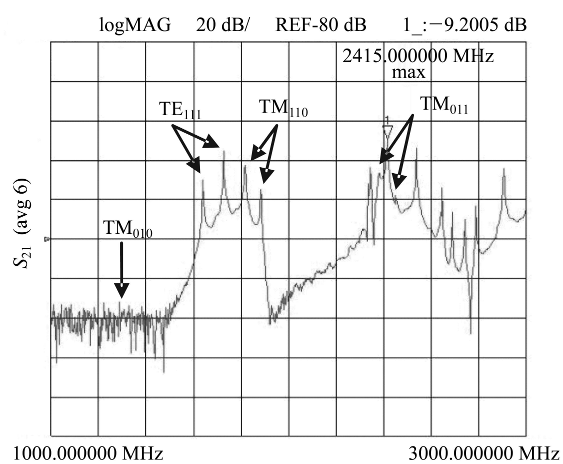

Fig. 3. S_{21} of the HOM coupler at an angle of 120 degrees.

From Table 4 it can be seen that the optimal angle is 120 degrees corresponding to the smaller Q_{ext} of the HOMs. The damping of the HOMs at 120 degrees is listed in Table 5. Because of the polarization of the modes, there are two modes per dipole mode and correspondingly also two Q_{ext} values.

Table 4. $Q_{\rm ext}$ of the HOMs of the 2-cell copper cavity.

f/MHz	$Q_{\rm ext}(\times 10^5)$						
	60°	90°	120°	180°	210°	240°	270°
1639.088	3.445	1.525	1.356	2.509	2.007	360.8	13.99
1639.531	36.35	17.88	16.23	197.2	2.041	2.840	4.948
1726.199	5.818	2.401	2.115	11.78	2382	54.07	16.12
1727.569	0.3328	0.2562	0.2365	54.49	411.2	2.298	79.31
1816.462	0.5957	0.5276	5.178	9.961	156.5	90.97	20.33
1817.15	0.7972	1.221	0.5113	1.201	328.4	4.825	1.751
1883.631	24.69	8.960	9.356	21.00	11770	28.41	19.43
1883.993	50.06	0.5185	0.1511	103.1	118.4	33510	2542
2407.913	10.83	0.2077	0.7481	248.9	108.7	120.1	161.5
2449.238	15.86	28.07	83.11	951.4	272.4	91.42	27.28

Table 5. Quality factors of the HOMs of the 2-cell TESLA-shape cavity at 2 K and $Q_{\rm ext}$ of the HOMs with the HOM coupler at 120 degrees.

mode	$Q_0(\times 10^9)$	$Q_{\rm ext}(\times 10^5)$
$\rm TE_{111}^{+}$	9.1	1.4, 16.2
$\rm TE_{111}$	10.7	2.1, 0.2
$\rm TM_{110}^{+}$	8.8	5.2, 0.5
$\rm TM_{110}$	11.0	9.4, 0.2
$\rm TM_{011}^{+}$	6.9	0.7
$\rm TM_{011}$	6.7	83.1

Table 5 indicates that the HOM coupler damps all the HOMs; however, in case of the dipole modes, the extraction of one polarization mode is ten times higher than the other one. This can only be improved if one HOM coupler is mounted on one side of the 2-cell copper cavity and another one on the other side. Damping $Q_{\rm ext}$ of the HOMs to less than 10^5 is acceptable[6]. There is nearly no change in the $Q_{\rm ext}$ of all the modes when the cavity is cooled down from room temperature to 2 K, i.e., the HOM coupler will work perfectly at 2 K after this tuning.

7 Conclusion

The test result of the coaxial HOM coupler on the 2-cell copper cavity indicates that the coupler works efficiently after a careful adjustment. A coupler mounted at an angle of 120 degrees on the beam tube is optimal. The initial test results can be a guide to a 9-cell cavity working at 2 K.

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