Stop band characteristics of a TESLA cavity coaxial-type HOM coupler*

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Abstract A TTF-type coaxial higher order modes (HOM) coupler has been used in a TESLA 9 cell cavity. It is impossible to measure the stop band characteristics of the HOM coupler with the cavity. A measurement device for the coaxial transmission line type for the HOM coupler has been designed at Peking University. Experimentally it was shown that the average voltage standing wave ratio of the coaxial transmission line is smaller than 1.08. The experimental results of the stop band characteristics of the TTF-type HOM coupler have been fitted for the simulation. This paper describes the design of the measurement device and discusses the experimental and simulation results of stop band characteristics of the HOM coupler.

Key words HOM coupler, notch filter, stepped coaxial transmission line, stop band characteristics

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1 Introduction

Higher order modes (HOM) excited by charged particle beams in accelerating structures are often the main cause of emittance growth in RF accelerators[1]. The TESLA cavity works at 1.3 GHz in the π mode as the accelerating mode. The HOM excited by bunches can seriously affect the subsequent charges passing through the cavity. So the HOM needs to be damped in order to avoid resonant buildup of beam-induced voltage and beam instability[2]. The HOM coupler used in the TESLA cavity is the TTF coaxial type[3]. The function of the HOM coupler is to extract the energy which is induced by the accelerated beam and reflect the fundamental mode energy which is supplied to accelerate the subsequent charges.

Two HOM couplers are mounted on both ends of the cavity with a nearly perpendicular orientation to ensure the damping of dipole modes of either polarization. The HOM coupler consists of three parts as shown in Fig. 1: a notch filter to reject the accelerating mode power; a loop antenna to couple the HOM power at both sides of the beam pipes; a pick up probe to extract the HOM power. A loop antenna couples mainly to the magnetic field for TE modes and to the electric field for TM modes[4].

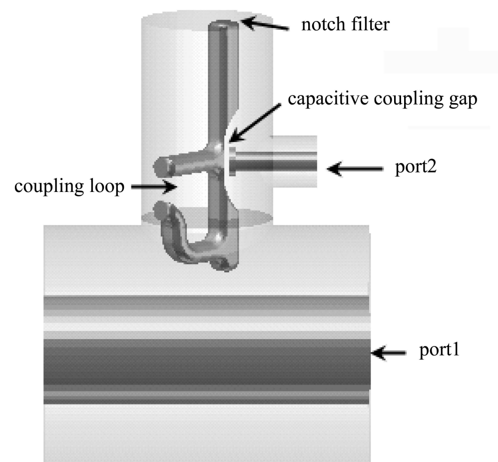

Fig. 1. Model of the HOM coupler and the coaxial transmission line for simulation.

A coaxial transmission line is the best choice for measuring the transmission characteristics of a coax-

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ial HOM coupler. The frequency range of interest in the HOM is between 1.3 GHz and 6 GHz. The resonance cavity filters out large frequencies; measuring the HOM coupler with the resonance cavity cannot obtain the full transmission characteristics. The design and fabrication of the coaxial transmission line for measuring the HOM coupler has been finished and the simulation fitted to the results of the experiments.

2 The design of the coaxial transmission line

The microwave transmission character of the HOM coupler in the frequency range from 1 GHz to 6 GHz is very important when designing and measuring a HOM coupler. The response at the transmission frequency will be measured by using the coaxial transmission line. The key feature of the coaxial line is that its bandwidth characteristic is very high[5]. The fundamental mode of operation is transverse electromagnetic (TEM), where the electric and magnetic fields are transverse in the direction of propagation. The energy of the TEM mode will be attenuated during its propagation in the coaxial line. The attenuation will decline sharply while the reflection is small. To obtain a credible result for the transmission characteristics of the HOM coupler in the range from 1 GHz to 6 GHz, one has to design it such that the VSWR of the coaxial line is smaller than 1.5 and the fluctuation of S21 is smaller than −40 dB.

The aluminous coaxial transmission line is composed of two standard N type connectors, a stepped transition part, a transition part with conical shape, a HOM coupler connector and a 50 Ω terminal. The TEM mode transmits in the coaxial line as a traveling wave. One part of the energy is absorbed by the antenna of the HOM coupler, and the other is absorbed by the terminal. The diameter of the outer conductor has to be bigger than 50 mm at the central part of the transmission line, because the diameter of the HOM coupler is 44 mm. The characteristic impedance is 50 Ω. To support the inner conductor, two regions of the step-type transition part are filled with Teflon as dielectric. The diameter of the transition part with steps varies from 3 mm to 8.6 mm, so without optimization the TEM mode will undergo a reflection at this place.

In order to reduce the voltage standing wave ratio (VSWR) of the stepped transition part, the steps of the inner conductor and the outer conductor have to be located on different plates. The distance between the two plates can be calculated by an empirical formula[4],

$$x=\frac{d}{a}\ln\left(\frac{D}{d}\right),$$

D is the diameter of the big outer conductor; d is the diameter of the small outer conductor and x is the distance between the two plates. a is a constant which is determined for different materials with the simulation.

After fixing D and d, x can be determined when VSWR reach its smallest and the S21 parameter is the largest value in the frequency range from 1 GHz to 6 GHz as is shown in Fig. 2. Thus a can be calculated (the space between the outer and inner conductors can be filled either by Teflon or air). The obtained parameters of the stepped transition part are given in Table 1 and Fig. 3.

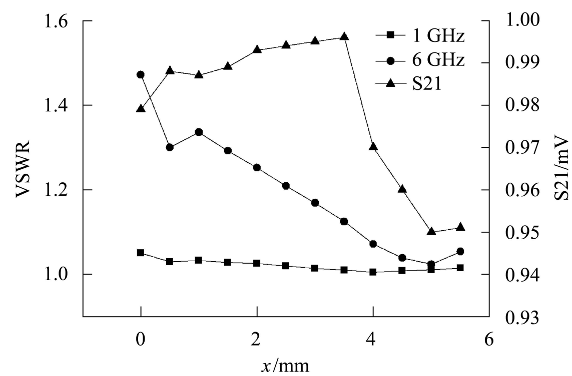

Fig. 2. VSWR and scatter parameter as a function of x at 1 GHz and 6 GHz while the diameter of the outer conductor change from 18.4 mm to 23 mm.

Table 1. The parameters of the stepped transition part.

	diameter of outer conductor/mm	diameter of inner conductor/mm	x/mm	filled material
part 1	21.3	6.4	2.09	Teflon
part 2	12.9	5.6	0.37	air
part 3	11.7	3.5	1.16	Teflon
part 4	7	3		air

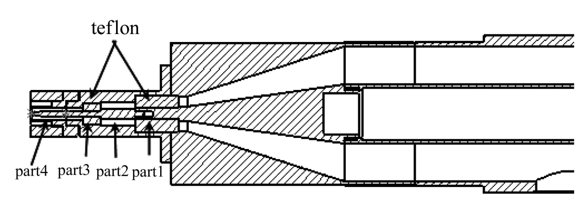

Fig. 3. Structure of the coaxial transmission line with the step part.

A cone is a good choice for another transition part, because of the small reflection as compared to the stepped shape. An exponential shape has still better characteristics than a cone, but it is not easy to machine.

For easily installation, the inner conductor is also divided into 5 parts. The stepped transition part is inserted into the cone transition part. The cone transition part is screwed into the hollow inner cylindrical conductor. It is important to keep the seams of every part smooth during the installation. The standard N type connectors are made of stainless steel. The outside of the middle outer conductor is produced with a cubic shape to provide a stable experimental condition.

The VSWR of the coaxial transmission line has been simulated by CST microwave. The biggest VSWR is smaller than 1.28 and the fluctuation range is smaller than −45 dB from 1 GHz to 6 GHz. This fits the requirement for the measurement of the HOM transmission characteristics.

3 Time domain analyzer of the coaxial transmission line

Time domain reflectometry can show the effect of each discontinuity as a function of time or distance. To obtain stop band characteristics from 1 GHz to 6 GHz, it is important to keep the reflection small in this range. A coaxial transmission line has been developed by Peking University as shown in Fig. 4. Measurements have been performed to test the place of discontinuities with two different devices: an HP 8753d network analyzer using the band pass mode, and 1502C m using the step signal mode. Fig. 5 shows that the VSWR is smaller than 1.08 in the range between mark 1 and mark 3. The mark 4 tick is the place where the 50 Ω terminal connects to the coaxial transmission line. The reflection coefficient of the coaxial transmission line is 36.4 mρ as can be seen from Fig. 5. According to the calculations, the VSWR is 1.08 at the highest reflection place, which is similar to data from the HP 8753d. This result shows that the device can test the HOM coupler well because of the small reflection in any place of it.

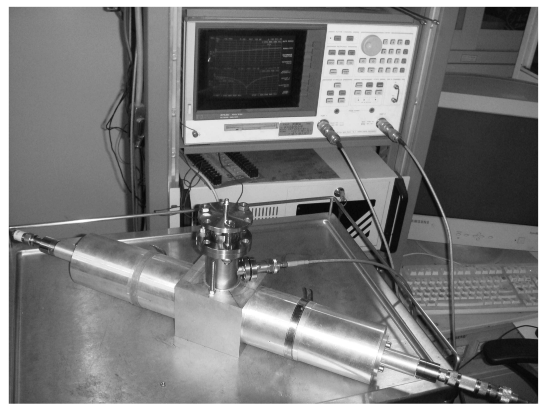

Fig. 4. A photograph of the coaxial transmission line with the HOM coupler.

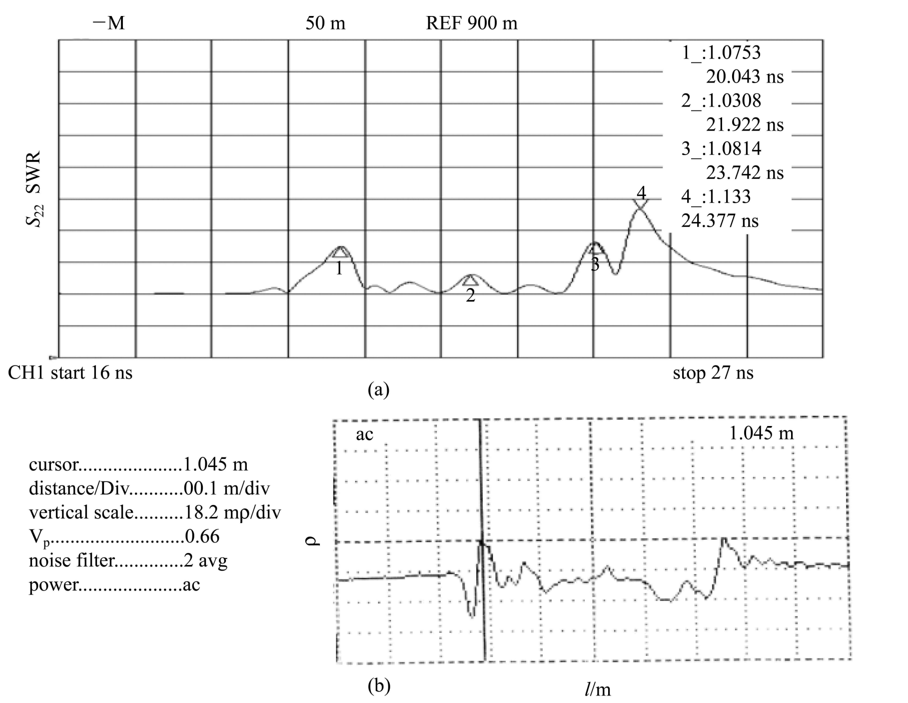

Fig. 5. Reflection coefficient of coaxial transmission line measured by 1502C metallic TDR.

4 Simulation of the transmission characteristics of the coaxial HOM coupler

The transmission characteristics of the HOM coupler on the coaxial line is simulated with the CST microwave studio 8. The HOM coupler of the TESLA cavity is of the TTF type. The antenna couples the HOM energy to outside the cavity. The antenna shape of the HOM will be determined by simulation and experiment. The model for simulating the CST microwave is shown in Fig. 1.

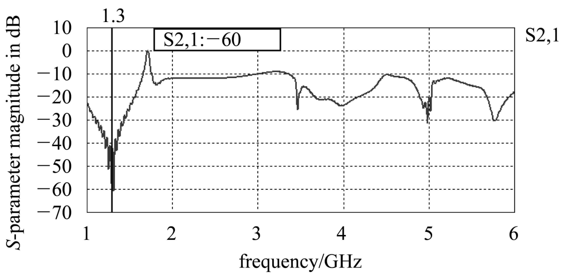

Fig. 6. The scattering parameter of the HOM coupler with the coaxial transmission line.

The scattering parameters are shown in Fig. 6. The S21 parameter of the notch frequency is lower than −60 dB at 1.3 GHz which means that the energy at this point is reflected into the cavity well. However, there are two dip frequency points other than the notch frequency at 5 GHz and 5.8 GHz. The higher order modes of the TESLA 9 cell cavity which will greatly affect the beam are listed in Table 2. The S21 parameter remains −10 dB in the frequency range of 1.59 GHz to 2.45 GHz and this means that the HOM coupler extracts well in this range.

Table 2. The dangerous modes in the TESLA 9 cell cavity[3].

mode	freq./(MHz)	$R/Q/(\Omega/\text{cm}^2)$
TE111-6	1590—1780	10
TE111-7		15.4
TE111-8		2.23
TM110-4	1785—1881	6.47
TM110-5		8.75
TM110-6		1.83
TM011-7	2360—2450	6.93
TM011-8		67
TM011-9		79.5

Three parts of the HOM coupler can be adjusted to fit the working condition. The notch filter is an LC resonant circuit that includes the capacitance of the tuning gap and the inductance of the inner conductor[3]. Adjusting the gap can change the resonant frequency. Adjusting the angle of the loop antenna can change the coupling of energy in the cavity. The pickup antenna absorbs the energy to an external load through capacitive coupling, so the distance of the pick up gap demonstrates the capability of the coupling. Adjusting the distance of the gap will change the characteristics of the HOM coupler[6].

5 Measurements on the HOM coupler on the coaxial transmission line

With the HP 8753d, the TTF-type coaxial HOM

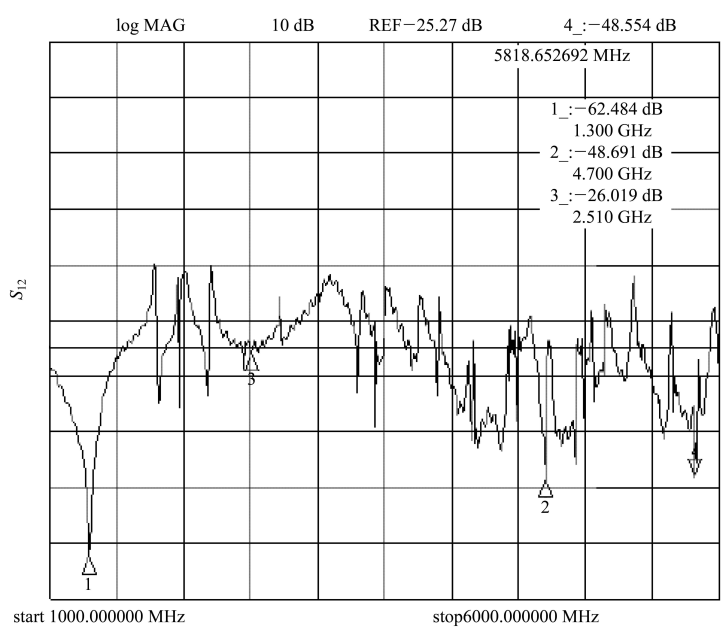

Fig. 7. The stop band characteristics of the TTF type HOM coupler.

coupler has been measured on the coaxial transmission line. The first step is keeping the capacitive coupling gap smaller than 0.5 mm, feeding in the signal from the coaxial transmission line and picking up the signal from port 2 as shown in Fig. 2. Then measure the S21 parameter with HP 8753d. The second step is tuning the notch frequency to 1.3 GHz. Fig. 7 shows the stop band characteristics of the TTF type HOM coupler. The S21 parameter of the notch frequency is −62 dB and the S21 parameter at high frequency is around −25 dB. This proves that the TTF type HOM coupler is a good notch filter at 1.3 GHz. Simultaneously, the S21 parameter falls to −42 dB at 4.8 GHz. This is another higher resonance frequency of the LC circuit. The main frequency of the HOM is smaller than 3 GHz, so it will not affect the effect of the HOM coupler. Due to tuning the gap, a notch frequency motion can be observed clearly by this device. The experimentally obtained tuning sensitivity of the notch frequency for the TTF-type is about 175 MHz/mm. The bandwidth of the notch frequency for the notch filter is +/−10 MHz.

6 Conclusion

The coaxial transmission line for the HOM coupler RF characteristics measurement has been designed and machined.

To obtain the smallest VSRW, the stepped transition part has been optimized and the cone has been chosen for another transition part. This device can fit the requirements of the experiment. This paper also analyzes the scattering parameter of the TTF-type coaxial HOM coupler with a simulation. A relationship is obtained for the gap distance and the effect of reflection at the notch frequency. The transmission characteristics of the TTF type HOM coupler has been measured on the new coaxial transmission line device. Every new HOM coupler fabricated needs to be checked and the notch frequency tuned by this device.

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