

RF characters study of a pick-up parallel-setting HOM coupler^{*}

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Abstract A pick-up parallel-setting high order mode coupler (pps-HOM coupler) has been fabricated at Peking University. It has been tested on a coaxial transmission line and a 2-cell TESLA-shape copper cavity. The test result of the 2-cell TESLA cavity shows that the coupler can cut off the fundamental mode TM_{010} and absorb HOMs electively. As its RF properties are insensitive to the probe dip length, there is no need to adjust the probe repeatedly during practical operation.

Key words HOMs, pps-HOM coupler, superconductive cavity

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1 Introduction

When a charged particle beam goes through an accelerating cavity, many resonant modes will be excited. These are called HOMs. If not sufficiently damped, especially for a superconducting accelerator, the HOMs could cause beam instability and beam loss [1]. HOMs also increase cryogenic losses due to the additional power dissipation in accelerating cavity walls. An effective solution is to use a HOM coupler to damp the HOMs' power.

There are three major types of HOM couplers: waveguide, coaxial and beam tube. The coaxial HOM coupler is compact and suitable for low and medium HOM power extraction, but its RF property strongly depends on the position of the pick-up probe. Therefore, adjusting the pick-up probe in, regular coaxial HOM coupler is troublesome. In order to solve the adjusting problem, a new pick-up probe is designed here, which changes the means of coupling between the probe and the inner conductor.

2 Principle of coaxial HOM coupler

The HOM coupler of the TESLA cavity is of the coaxial type [2]. Fig. 1 shows a cross-section of the coaxial HOM coupler of the ILC, which is a modified

version of a TTF HOMs coupler. This consists of the following three parts [3]: (1) a coaxial resonant cavity with a capacitance (the dash dotted square), to reject the power of the accelerating mode in the cavity; (2) a loop antenna to couple the beam-excited HOM power outside both end cells; and (3) a pick-up probe to pick up the HOM power from the cavity.

The coaxial cavity is an LC resonant circuit that includes the capacitance of the tuning gap and the inductance of the inner conductor. The extraction of the HOM power by the pick-up probe is performed by capacitive coupling.

To increase the coupling ability, a DESY and SLAC collaboration re-designed the TTF coupler by cutting a part of the loop antenna and increasing the end area of the pick-up probe, as shown in Fig. 2.

3 Concept of the pps-HOM coupler

The structures of the actual coaxial HOM couplers are shown in Fig. 2. The left one is the ILC HOM coupler with a disc pick-up probe. The capacitive coupling is sensitive to the distance between the probe disc plane and the concave of the inner conductor. Therefore, the length of the probe dip into regular HOM coupler should be adjusted repeatedly to reach the best coupling in practical operation.

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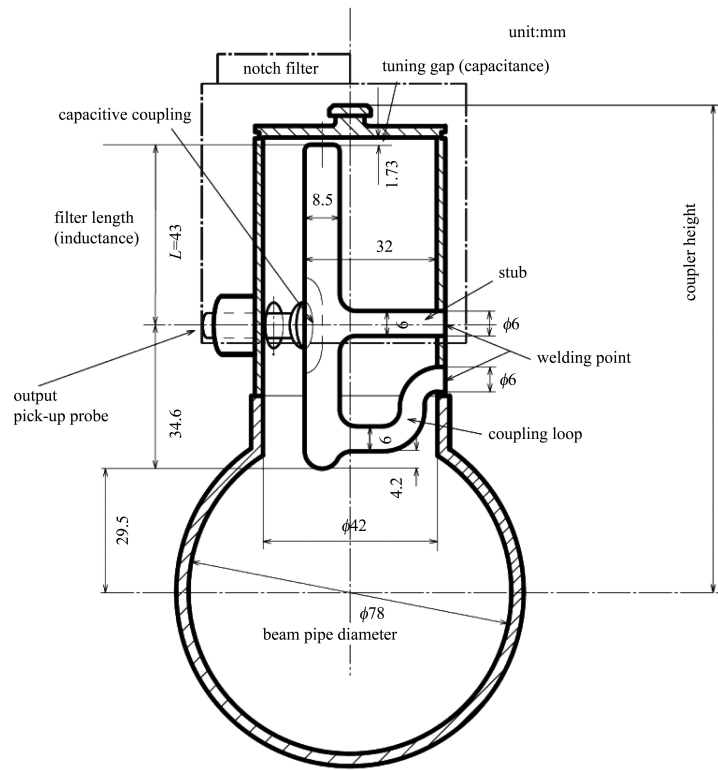


Fig. 1. Coaxial HOM coupler of the TESLA cavity.

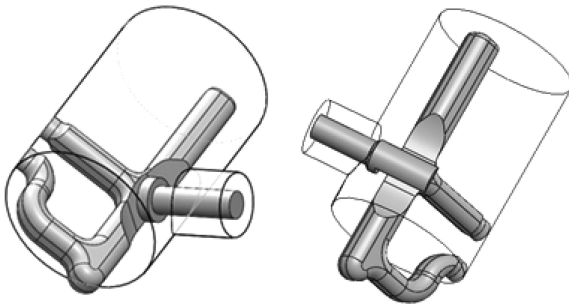


Fig. 2. The regular HOM coupler (left) and the pps-HOM coupler (right).

If rotating the outer cylinder by 90° , the HOM's power will be transported along the parallel direction, as shown in the right figure. We call it a pick-up parallel-setting HOM coupler (pps-HOM coupler for short). An L-shaped pick-up probe is designed to be used in the pps-HOM coupler, as shown in Fig. 3. The front part is a cylinder (10 mm in diameter) with a part removed. This makes a rectangular plane and a semicircular plane coupled with the inner conductor. The diameter of the posterior segment is set to 7 mm, with the outer tube to form the coaxial line of 50Ω characteristic impedance. The other parameters of the L-shaped probe depend on the internal space of the pps-HOM coupler. As long as all the parameters are identified, the two coupling planes and their

distance to the inner conductor are identified, as well as the capacitive coupling.

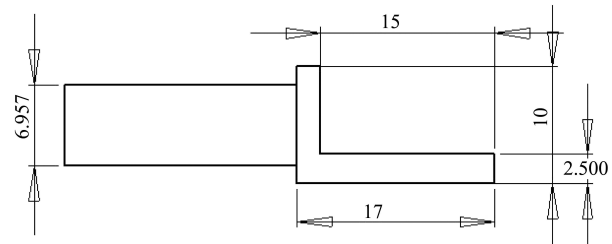


Fig. 3. The L-shaped pick-up probe for the pps-HOM coupler (unit: mm).

4 Simulation of HOM damping on the 2-cell TESLA cavity

HOM damping on the 2-cell TESLA cavity has been simulated by CST MWS 2008. For the 2-cell TESLA cavity, the 12 most dangerous modes were considered, as well as the accelerating mode TM_{010} . Q_e of the HOM coupler port is used as a standard of HOM damping.

In simulation, the stop frequency of the HOM coupler doesn't coincide with the fundamental mode TM_{010} exactly. Therefore, Q_e of Mode 2 just reaches 10^9 – 10^{10} . Q_e (10^3 – 10^5 for HOMs) of the regular HOM coupler and the pps-HOM coupler perform nearly the

same, as shown in Table 1. As Q_e is much lower than Q_0 of the superconducting cavity (10^9 – 10^{10}), the HOM's power is absorbed effectively by the pps-HOM coupler.

Table 1. The simulated result of HOM damping on the 2-cell TESLA cavity. Q_e of the HOM reaches 10^3 – 10^5 .

mode	regular HOM coupler		pps-HOM coupler	
	f /MHz	Q_e	f /MHz	Q_e
M1:TM ₀₁₀ ⁺	1296.0	4.622×10^9	1296	3.055×10^{10}
M2:TM ₀₁₀	1307.7	2.499×10^9	1307.7	1.109×10^{10}
M3:TE ₁₁₁ ⁺ *	1649.7	2.458×10^4	1649.7	3.603×10^4
M4:TE ₁₁₁ ⁺	1651.8	5.302×10^4	1651.5	4.351×10^4
M5:TE ₁₁₁ [*]	1731.3	3.228×10^3	1731.3	2.707×10^3
M6:TE ₁₁₁	1735.5	9.374×10^3	1735.2	9.360×10^3
M7:TM ₁₁₀ ⁺ *	1824.6	7.866×10^3	1824.6	6.877×10^3
M8:TM ₁₁₀ ⁺	1828.2	5.723×10^3	1827.9	3.632×10^3
M9:TM ₁₁₀	1892.4	9.158×10^4	1892.4	5.594×10^4
M11:TM ₀₁₁ ⁺	2408.4	9.033×10^4	2408.4	3.725×10^4
M12:TM ₀₁₁	2450.7	3.996×10^5	2450.4	9.622×10^4
M13:TM ₀₂₀ ⁺	2694.0	2.976×10^5	2693.7	1.450×10^5
M14:TM ₀₂₀	2743.5	3.520×10^5	2743.2	1.280×10^3

Note: Superscript + denotes the $\pi/2$ mode in the pass-band, and the other one is the π mode. The dipole mode of the ideal cavity is doubly degenerate [4]. Superscript * denotes one polarization mode, and the one without superscript * is the other polarization mode.

5 Measurement of the stop band characteristic of the pps-HOM coupler

The stop band of the pps-HOM coupler has been measured on a coaxial transmission line, which has been specially designed for the HOM coupler test [5]. As shown in Fig. 4, the working frequency of the cavity can be effectively cut off by the pps-HOM coupler, while the higher frequency band can be passed.

6 RF measurement of HOM damping on the 2-cell TESLA cavity

The HOM coupler is mounted on the beam tube, with the plane of the inner conductor located perpendicular to the beam direction. The RF parameters (frequency f , quality factor Q_1 , S parameters) are measured by a computer-controlled vector network analyzer, schematically shown in Fig. 5. All of the modes are identified by their frequencies according to the results in Ref. [3].

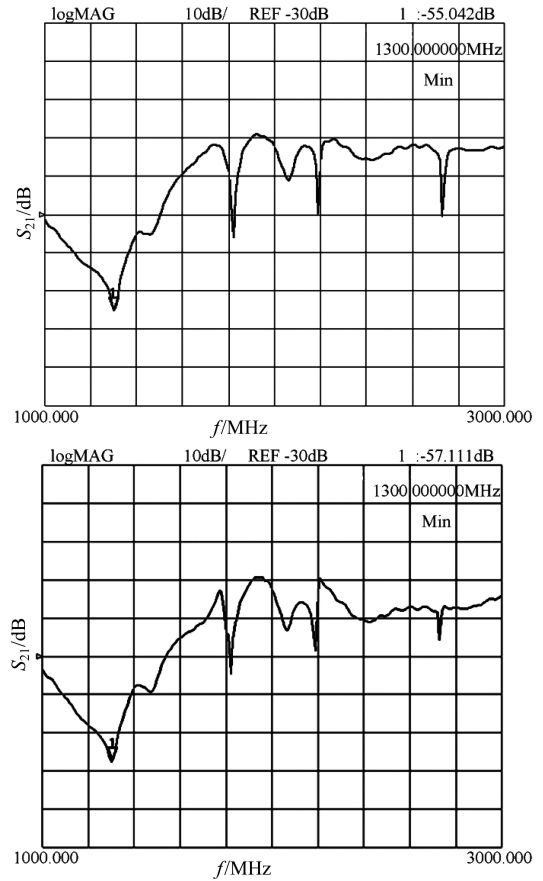


Fig. 4. The stop band characteristic curves of a regular HOM coupler (top) and a pps-HOM coupler (down). The two basically have the same stop-band characteristics.

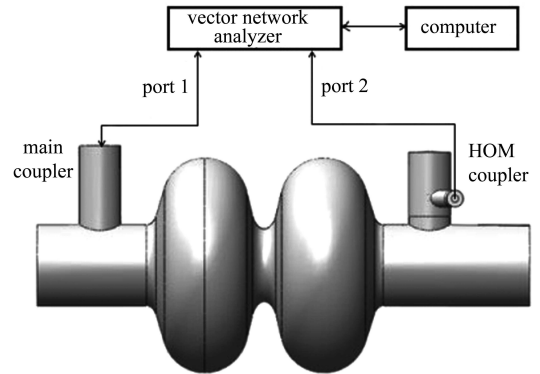


Fig. 5. Block diagram of the test bench for RF measurements of HOM damping on the 2-cell TESLA cavity.

From the S_{21} curve shown in Fig. 6, one can see that the dangerous modes (TE₁₁₁, TM₁₁₀) are damped and the fundamental mode TM₀₁₀ is cut off. The Q_0 at 2 K in Table 2 is calculated from Q_0 of the normal temperature cavity and the surface resistance. Table 2 indicates that, in both couplers, Q_e reaches 10^{13} for the fundamental mode, and 10^3 – 10^6

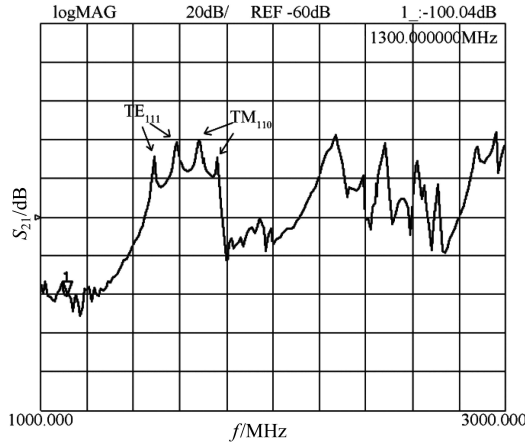


Fig. 6. S_{21} of a pps-HOM coupler on the 2-cell TESLA cavity. The HOMs are damped and the fundamental mode is cut off.

Table 2. Q_e of a regular HOM coupler and a pps-HOM coupler on the 2-cell TESLA cavity Q_e of HOMs reaches 10^3 – 10^6 .

mode	regular HOM coupler		pps-HOM coupler		Q_0 at 2 K
	f /MHz	Q_e	f /MHz	Q_e	
M1:TM $_{010}^+$	1290.246	1.83×10^{10}	1290.280	3.25×10^{10}	1.3×10^{10}
M2:TM $_{010}$	1303.081	1.31×10^{13}	1303.116	2.63×10^{13}	1.3×10^{10}
M3:TE $_{111}^{+*}$	1638.290	1.04×10^5	1638.368	1.92×10^5	1.9×10^9
M4:TE $_{111}^+$	1639.170	2.81×10^4	1639.215	5.22×10^4	6.3×10^9
M5:TE $_{111}^*$	1723.852	2.70×10^4	1724.326	5.85×10^4	1.6×10^9
M6:TE $_{111}$	1727.317	4.60×10^3	1727.130	9.24×10^3	1.2×10^9
M7:TM $_{110}^{+*}$	1813.781	2.23×10^4	1814.652	2.62×10^4	1.1×10^9
M8:TM $_{110}^+$	1816.930	5.79×10^3	1816.871	1.18×10^4	1.7×10^9
M9:TM $_{110}^*$	1883.382	2.86×10^4	1883.430	1.92×10^4	3.9×10^9
M10:TM $_{110}$	1884.294	1.25×10^6	1884.406	1.18×10^6	4.2×10^9
M11:TM $_{011}^+$	2407.694	1.35×10^6	2407.630	7.08×10^6	2.0×10^{10}
M12:TM $_{011}$	2448.599	5.49×10^4	2448.666	1.25×10^5	1.3×10^{10}
M13:TM $_{020}^+$	2687.578	2.27×10^5	2687.691	1.02×10^6	7.6×10^9
M14:TM $_{020}$	2739.602	4.39×10^5	2739.740	1.50×10^6	8.8×10^9

Table 3. Q_e of a pps-HOM coupler on the 2-cell TESLA cavity with different probe dip lengths.

dip length mode	34 mm		33 mm		32 mm	
	f /MHz	Q_e	f /MHz	Q_e	f /MHz	Q_e
M1:TM $_{010}^+$	1290.28	3.25×10^{10}	1290.268	3.13×10^{10}	1290.3	4.68×10^{10}
M2:TM $_{010}$	1303.116	2.63×10^{13}	1303.118	1.59×10^{14}	1303.1	1.19×10^{14}
M3:TE $_{111}^{+*}$	1638.368	1.92×10^5	1638.367	3.68×10^5	1638.356	2.73×10^5
M4:TE $_{111}^+$	1639.215	5.22×10^4	1639.197	8.45×10^4	1639.195	6.34×10^4
M5:TE $_{111}^*$	1724.326	5.85×10^4	1724.482	9.57×10^4	1724.375	7.43×10^4
M6:TE $_{111}$	1727.13	9.24×10^3	1727.106	1.55×10^4	1727.106	1.16×10^4
M7:TM $_{110}^{+*}$	1814.652	2.62×10^4	1814.818	2.10×10^4	1814.698	2.32×10^4
M8:TM $_{110}^+$	1816.871	1.18×10^4	1817.006	1.36×10^4	1816.935	1.22×10^4
M9:TM $_{110}^*$	1883.43	1.92×10^4	1883.404	1.50×10^4	1883.416	1.72×10^4
M10:TM $_{110}$	1884.406	1.18×10^6	1884.431	6.96×10^5	–	–
M11:TM $_{011}^+$	2407.63	7.08×10^6	2407.616	9.66×10^6	2407.609	1.27×10^7
M12:TM $_{011}$	2448.666	1.25×10^5	2448.674	1.67×10^5	2448.663	1.52×10^5
M13:TM $_{020}^+$	2687.691	1.02×10^6	2687.709	9.44×10^5	2687.712	9.15×10^5
M14:TM $_{020}$	2739.74	1.50×10^6	2739.755	1.16×10^6	2739.753	1.10×10^6

for HOMs. Q_e is much lower than Q_0 , which means that the pps-HOM coupler can effectively absorb HOM's power. It can satisfy the superconductive cavity's requirement for a HOM coupler. The difference between the measurement result and the simulation is caused by cavity asymmetry and the non-ideal mechanical contacts, increasing the surface loss of the HOMs.

By changing the length of the pick-up probe dip into the HOM coupler from 32 mm to 34 mm, there is nearly no influence on Q_e of the pps-HOM coupler, as shown in Table 3. The capacitive coupling nearly doesn't change with the dip length. Therefore, in practical operation, adjusting the dip length is much more convenient. Its insensitivity to the probe length will also reduce the impact of low-temperature deformation on Q_e .

7 Conclusions

The test result indicates that the RF properties of the pps-HOM coupler are basically the same as the regular HOM coupler. Q_e of the pps-HOM coupler on the 2-cell TESLA cavity is 10^{13} for the fundamental mode and 10^3 – 10^6 for HOMs. This can satisfy the requirement of superconductive cavity. More importantly, because of its insensitivity to the probe dip length, there is no need for repeated tuning in practical operation, which means that it is more convenient than the regular HOM coupler.

In order to get a better performance from the pps-HOM coupler, the parameter of the L-shape pick-up probe can be changed to achieve better coupling.

After simulating with a CST MWS 2008, four ways are found to optimize the L-shaped probe: (1) reduce the gap distance between the coupling plane on the L-shaped probe and the concave on the inner conductor; (2) increase the diameter of the forepart cylinder, which increases the coupling area; (3) use smooth corners instead of sharp saltation between the two cylinder parts; and (4) change the coupling plane into a convex to fit with the concave on the inner conductor.

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