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DEVELOPMENT OF A HIGH-POWER HIGH-DIRECTIVITY DIRECTIONAL COUPLER AND FOUR POWER DIVIDERS FOR S-BAND*

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Abstract

A novel Bethe-hole S band directional coupler has been designed based on some structural optimizations, the prototype has been tested with a Directivity of more than 30 dB. The new directional coupler can also hold high power compared to the old type, which is more useful for the future accelerator applications. Four power dividers using different structures are studied and the best one is chosen for fabrication. The prototype with matching rod in the middle has got qualified microwave cold test results and has been used during the whole microwave commissioning of an accelerator structure, the performance is quite stable.

INTRODUCTION

Modern accelerators always use waveguides to transmit the microwave power from the power source to the beam line in the Radio Frequency Transmitting System (RFTS). For controlling the power, many waveguide devices such as directional coupler, power divider, power combiner, etc. are widely used.

The directional couplers [1] are often used at the input or output of the power source such as a klystron or a Solid-State Amplifier (SSA) as well as the power consuming device such as an accelerating structure or a resonant cavity. Usually, about one millionth power are picked out for on-time power monitoring and interlock protection.

A novel Bethe-hole directional coupler [2] has been developed. By changing the vacuum sealing position and the shape of the coupling-piece in the coupling part, the new directional coupler can stand much higher peak power with a higher Directivity for better isolation between the forward and backward microwave. The fabrication process is also easier because of the new shape coupling-piece.

On the other hand, the power dividers are used to equally divide the input microwave power and most needed when feeding a dual-feed accelerating structure or two single-feed accelerating structures next to each other. The most important performance of a power divider is to have two equal microwave power outputs on the aspects of both the magnitudes and the phase.

The dual-feed are used in many accelerating structures for low beam emittance applications [3], in which the power divider is used in the feeding waveguides. Four power dividers with different structures are simulated and compared, finally the one with a matching rod in the middle of its structure has been chosen for the best simulation performance. The prototype has got a qualified microwave test results and works quite stable during the whole microwave commissioning together with a dual-feed accelerating structure.

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DEVELOPMENT OF THE DIRECTIONAL COUPLER

Structure

The traditional goat-horn directional coupler uses a piece of ceramic plate on the coupling hole for vacuum sealing, which is just in the middle of the wide wall of the waveguide where exists the maximal electrical field in the whole structure. When the peak microwave power is quit big, for example 200 MW, the ceramic plate will be a very fragile part for vacuum leakage after cracking. In the Bethe-hole directional coupler, the ceramic plate is cancelled and the vacuum sealing relies on the two N-type feed through connector on the top of the coupling part, where the electrical filed is much smaller (~1/100 according to the simulation result).

In addition, an inversely placed T-shape coupling-piece directly connected to the inner conductors of the two N-type feed through is used. While in the goat-horn directional coupler, only a tiny thin piece of metal plate is used as a coupling-piece and the two inner conductors are connected tilted. Obviously, the T-shape one has got more sizes to adjust for better microwave performance and can be connected to the inner conductors more accurate and reliable. The specific details of the Bethe-hole coupling part is shown in Fig. 1.

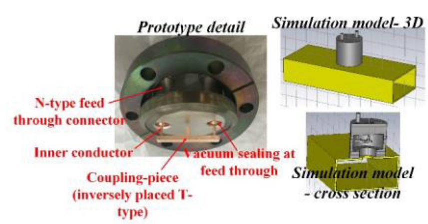

Figure 1: Specific details of the coupling part of the Bethe-hole directional coupler.

Simulated and Tested Results

For optimizing the microwave performance, we need the Voltage Standing Wave Ratio (VSWR) and Insertion Loss (IL) to be as low as possible, while the Directivity (the Isolation subtracts the Coupling Degree) to be as high as possible for a given Coupling Degree (usually 60 dB). In the novel Bethe-hole directional coupler, the excellent VSWR and IL are easily achieved, so the main task is to get better Isolation while keeping an acceptable Coupling Degree.

The radius of the coupling hole in the middle of the wide wall of the waveguide is used for controlling the Coupling

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Degree, while the rotation angle as well as the sizes of the inversely placed T-shape coupling-piece is used for controlling the Isolation. However, the two parameters are not independent, so the optimization of them need to be executed repeatedly and alternately.

Finally, the qualified prototype has been finished optimization, all the simulation is done by the Computer Simulation Technology (CST) software. The fabricated prototype and the test photo are shown in Fig. 2 while the simulated Directivity curve is shown in Fig. 3. The compare between the simulated and tested results are shown in Table 1 (at central frequency 2.856 GHz).

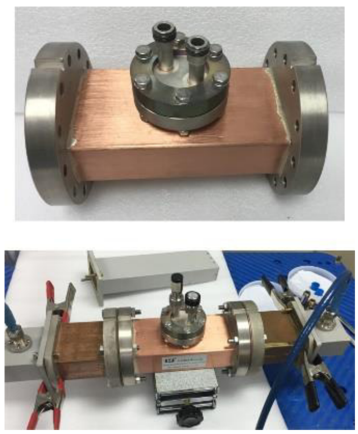

Figure 2: Photo of the fabricated prototype and test.

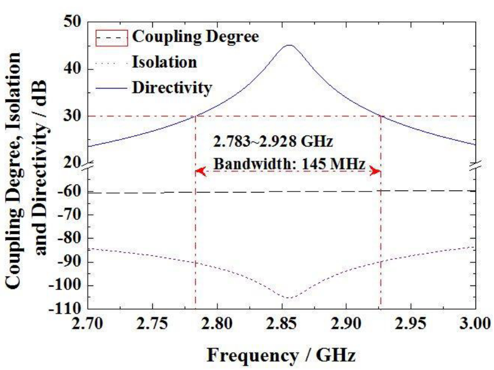

Figure 3: Simulated Directivity curve of the Bethe-hole directional coupler.

Table 1: Compare Between the Simulated and Tested Results of the Bethe-hole Directional Coupler

Parameter	Design Requirement	Simulated Results	Tested Results
VSWR	< 1.1	1.011	1.052
IL (dB)	< -0.2	-0.004	-0.01
Coupling Degree (dB)	60±0.5	60.09	59.2
Directivity (dB)	> 30	45.15	33.4

We can see that both the simulated and tested results are acceptable, although the VSWR as well as the Coupling Degree of the tested results is a little unsatisfactory. However, the simulated bandwidth for the Directivity of more than 30 dB is 145 MHz which is good. In the future, the fabrication process can be more efficient because of the experience gained from the first prototype.

DEVELOPMENT OF THE POWER DIVIDERS

Structure

Four kinds of waveguide power dividers are simulated in CST, their structures are shown in Fig. 4 and are named as Model 1 to 4 respectively. All the four power dividers are simulated with their vacuum models with all the ports the same definition: Port 1 on the top is the input port while Port 2 and 3 on the left and right are the output ports respectively. Except for model 4 with a matching rod in the middle of the structure, the other 3 models are all matched by part of the side wall narrower, as shown in Fig. 4.

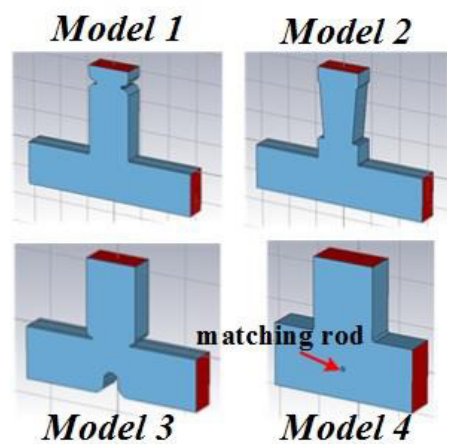

Figure 4: Structures (simulation models) of the four power dividers.

Simulated and Tested Results

The microwave power comes in from Port 1 and are divided equally into Port 2 and 3. The compare between the simulated results (all the 4 models) and the tested results (only model 4) are listed in Table 2.

We can see that Model 3 and 4 are better than Model 1 and 2 with a wider VSWR bandwidth and a much lower maximal electrical field. Finally, Model 4 is chosen for fabrication considering the simplicity of the structure. The prototype has got a VSWR of 1.018/1.043 at central frequency 2.856 GHz, a bandwidth for VSWR less than 1.1 of 350.3/70.8 MHz, a magnitude of S21 (S31) of -3.011/ -3.13 dB as well as a phase difference 0/0.5 degree for simulated/tested results respectively. The fabrication error maybe the main reason for a worse tested results compared to the simulated ones, however, both the results are qualified and acceptable.

The simulated power flow is shown in Fig. 5, in which the power is seen being divided equally into Port 2 and 3.

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Table 2: Compare Between the Simulated and Tested Results of the Waveguide Power Dividers

Parameters	**Mod. 1**	**Mod. 2**	**Mod. 3**	**Mod. 4**	**Mod. 4 (test)**
VSWR at 2.856 GHz	1.039	1.043	1.058	1.018	1.043
Bandwidth in MHz (VSWR≤ 1.1)	10.7	20.4	196.0	350.3	70.8
Magnitude of S21 & S31 (-dB)	3.062 (both)	3.071 (both)	3.019 (both)	3.011 (both)	3.13 (both)
Phase difference of S21 & S31 (degree)	0	0	0	0	0.5
Maximal electrical field in structure (V/m)	1245	1301	777	676	/

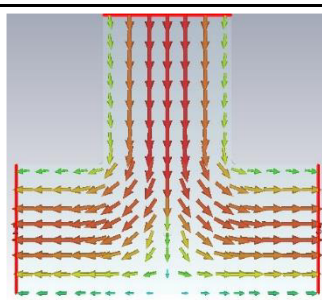

Figure 5: Simulated power flow of the waveguide power divider (Model 4).

Microwave Commissioning with the Accelerating Structure

In June of 2016, the fabricated waveguide power divider was assembled together with a dual-feed accelerating structure on the High Power Test Facility (HPTF), which is in the experimental hall of Beijing Electron-Positron Collider II (BEPCII). The maximal klystron output power was 40 MW (corresponding to a high voltage of 40 kV) with a Pulse Repetition Ratio (PRR) of 10 Hz and a pulse width of 3 µs, the power divider prototype worked stable for more than one week at this power level.

The VSWR of the power divider connecting with the accelerating structure was also tested before starting the commissioning (shown in Fig. 6). The tested VSWR was 1.018 at 2.856 GHz while the bandwidth for VSWR less than 1.2 was 4.7 MHz (2853.23~2857.93 MHz), which was very close to the test results in the Accelerating Structure Test Laboratory indicating the power divider to have a good microwave performance from another angle.

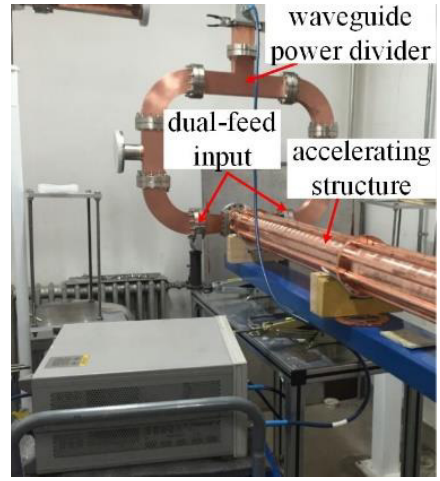

Figure 6: The VSWR test of the accelerating structure together with the power divider on HPTF in BEPCII.

CONCLUSION

A novel Bethe-hole directional coupler has been developed, the modification of the structure makes it be able to hold higher power as well as much easier for fabrication. The tested results of the prototype is satisfactory and the experience can make future fabrication more effective. Four waveguide power dividers with different structures are designed and compared, finally the one with a matching rod is chosen. The fabricated prototype has got good microwave performance for both the cold test and the microwave commissioning with a dual-feed accelerating structure.

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