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DEVELOPMENT OF FLEXIBLE WAVEGUIDE FOR HIGH POWER HIGH VACUUM APPLICATIONS IN S-BAND*

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Abstract

A novel flexible waveguide is developed for S-band 2856 MHz, which is a standard WR284 waveguide. The surface of the flexible waveguide is plated with Oxygen-free High Conductivity (OFHC) copper for the purpose of welding with the stainless steel flange in the vacuum furnace, for the flexible waveguide itself is made of brass. The prototype has got a certain amount of deformation which will be much more convenient for the connection between two hard waveguides. It also has a good measurement results of the low power microwave test, and the 72 hours' vacuum leakage test shows a satisfactory vacuum performance, no obvious surface collapse is observed. The high power test will be conducted after our high power test facility is available, which will tell us the maximal power level of the flexible waveguide prototype.

INTRODUCTION

The Radio Frequency Transmitting System (RFTS) is one of the essential systems in modern accelerators, the waveguides are most widely used compared to other microwave transmission mediums because of its high power capacity and low transmission loss.

The various waveguides used in the S-band high-power high-vacuum environment are basically hard waveguides made of OFHC material, which are brazed with various forms of stainless steel flanges. If the RFTS system is very long, the last two flanges maybe very difficult to connect because of the accumulated errors during the waveguide processing and installation, where a flexible waveguide is an ideal solution.

However, the flexible waveguides are never used in the high-power high-vacuum environment, either from P-band to X-band [1-3], or from large colliders to small industrial or medical accelerators [4-5].

The flexible waveguides are always used in the air or gas-filled environment, for the purpose of isolating vibration, fine-tuning the phase or solving the problems of thermal expansion and collimation error. In all cases the peak power is very limited which maybe several megawatts at most.

For S-band 2856 MHz a novel flexible waveguide is developed. In cases of various artificially created deformations, the prototype maintains a good measurement results of the low power test, and the 72 hours' vacuum leakage test result is also satisfactory with no obvious surface collapse observed after. The high power test will be on schedule after high power test facility available.

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DEVELOPMENT OF THE FLEXIBLE WAVEGUIDE

Structure

The flexible waveguide consists of a typical bellows-shaped waveguide welded with two stainless steel flange. We model it in the Computer Simulation Technology (CST) program and optimize the sizes of the flexible part, the detailed sizes are shown in Fig. 1. The height of the ripples (indicated as h_1 in Fig. 1) is compromised as 2.5 mm for considering both an acceptable Voltage Standing-wave Ratio (VSWR) and a proper extensibility. The total length of the waveguide is decided to be 100 mm, which is enough for the needed deformation. Longer length is not chosen because of the possible surface collapse after vacuuming, especially on the wide side of wall.

As well known, the traditional flexible waveguide is made of brass, which is not suitable for welding in the vacuum furnace. For solving this problem, the OFHC material is plated on the surface of the flexible part, and can be treated as OFHC in CST because of the skin effect.

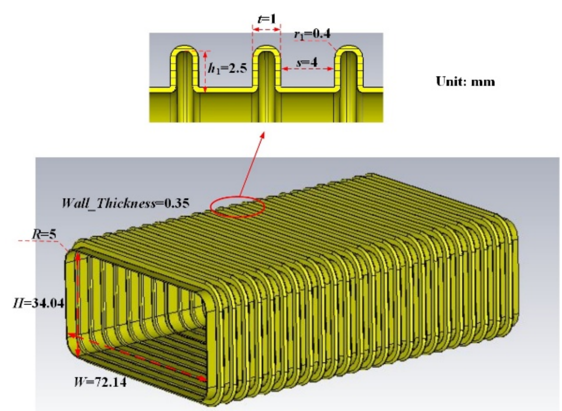

Figure 1: Detailed sizes of the flexible part of the waveguide.

Simulated and Tested Results

For the flexible waveguide is a straight waveguide, the VSWR and Insertion Loss (IL) is easy to be acceptable. All the values of sizes after optimization are shown in Fig. 1.

After sweeping all the sizes of the flexible waveguide (the *W*, *H*, *R*, and *Wall-Thickness* is fixed), the height of the ripples h_1 is the most important size. The frequency response of VSWR and IL (S21) with a changing h_1 is shown in Fig. 2 and Fig. 3, the values are shown in Table 1. We can see that a bigger h_1 value means a worse VSWR which is caused by a greater discontinuity, however, the simulated S21 changes little with varying h_1. Finally, h_1 =2.5 mm is

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chosen for compromise between VSWR and structural extensibility.

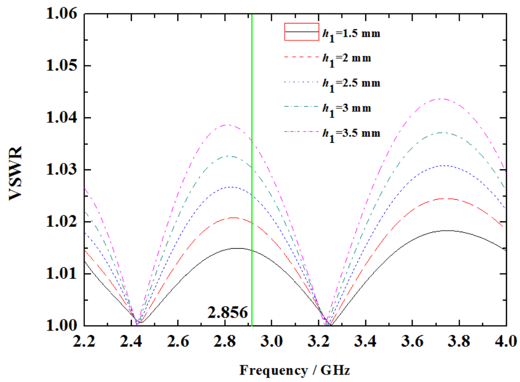

Figure 2: Frequency response of VSWR vs h_1.

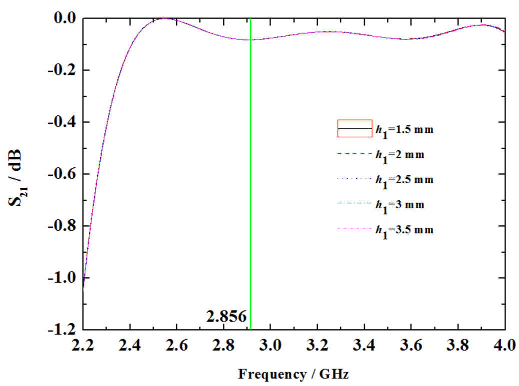

Figure 3: Frequency response of S21 vs h_1.

Table 1: The Values of VSWR and S21 with Different h_1 at Central Frequency 2856 MHz

h_1 (mm)	VSWR	S11 (dB)	S21 (dB)
1.5	1.015	-42.57	-0.079
2.0	1.021	-39.76	-0.079
2.5	1.027	-37.65	-0.079
3.0	1.032	-35.97	-0.079
3.5	1.038	-34.56	-0.079

Considering the chamfer of the cross section (indicated as R in Fig. 1), the flexible waveguide is much higher than traditional hard waveguides, this may result in a reflection at the four corners where the flexible part welded with the hard stainless steel flanges. So it is also simulated, the simulation model is shown in Fig. 4 while the results in Table 2. The VSWR result changes little while changing the length of the two added hard waveguides (indicated as L in Fig. 4), however, the total VSWR is higher than the situation without hard waveguides added but still acceptable (shown in Fig. 5), which means that there is indeed a reflection at the junction part and is superimposed on the input port. The L is chosen to be 50 mm at last. It is very difficult to simulate all kinds of deformation in real situation, so only the pulling up and compressing of the total length is simulated by multiplying a factor on the length. The factor is limited between 0.95 and 1.05, which means the total length of the flexible waveguide varies between 95 and 105 mm. This is quite enough for simulating the pulling up and compressing situation, because in reality, the total length is impossible to change up to 5 mm for a 100 mm long straight waveguide. The simulated frequency response of VSWR with varying *factor* is shown in Fig. 6, which shows only a frequency shift happens when pulling up and compressing the waveguide.

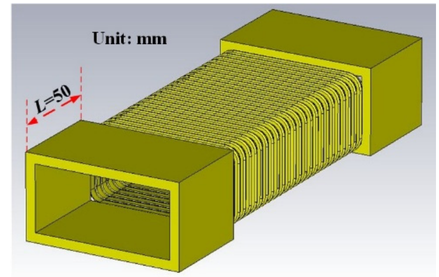

Figure 4: Simulation model with added hard waveguides.

Table 2: The Values of VSWR and S21 with Different L at Central Frequency 2856 MHz

L (mm)	VSWR	S21 (dB)
10	1.045	-0.093
20	1.043	-0.101
30	1.043	-0.102
40	1.043	-0.105
50	1.041	-0.107
60	1.041	-0.113
70	1.046	-0.116
80	1.040	-0.119
90	1.041	-0.120
100	1.042	-0.124

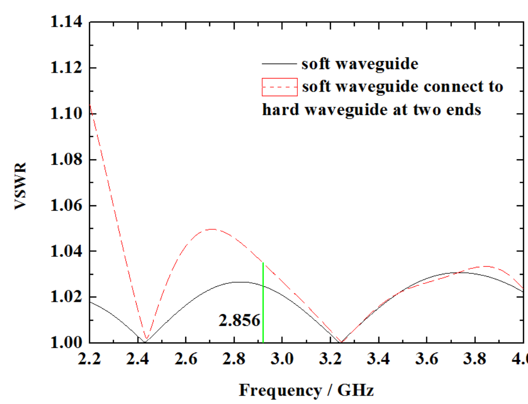

Figure 5: Frequency response of VSWR before & after adding hard waveguides.

Finally, a prototype is fabricated and tested for low microwave power as well as the vacuum leakage. The picture of the prototype is shown in Fig. 7. The low power test results are shown in Table 3 which is basically consistent with the simulated results. The narrower VSWR frequency

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bandwidth results from the more complicated situation for a prototype compared with simulation.

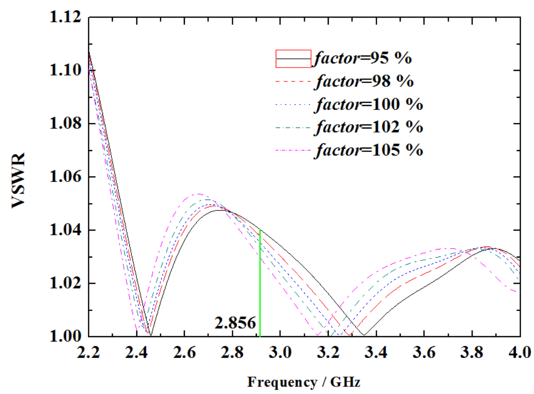

Figure 6: Frequency response of VSWR vs *factor*.

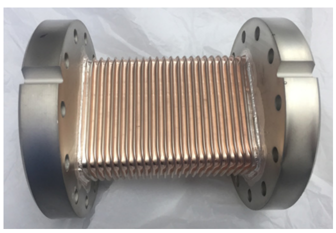

Figure 7: Picture of the flexible waveguide prototype.

Table 3: Compare Between the Simulated and Tested Results of the Flexible Waveguide Prototype

Parameter	Simulated Results	Tested Results
VSWR at 2856 MHz	1.041	1.034
Frequency bandwidth of VSWR less than 1.05 (MHz)	2320.6~4000(1679.4)	2684.0~2865.3（181.3）
Frequency bandwidth of VSWR less than 1.1 (MHz)	2210.8~4000（1789.2）	2639.9~2926.8（286.9）
IL at 2856 MHz (dB)	-0.1073	-0.10
Worst VSWR when deformation	1.044	1.045
Worst IL when deformation (dB)	-0.110	-0.15

After that, the vacuum leakage test is conducted, the leakage rate is better than $2*10^{-10}$ Torr·L/s in any deformation situation. And the vacuum state is kept for 72 hours, the vacuum is stable during the whole process, and no obvious collapse is observed after the vacuum leakage test. The picture of the test is shown in Fig. 8.

CONCLUSION

A novel flexible waveguide is developed. The sizes are optimized considering the connection with hard waveguides as well as the pulling up and compressing situation. The simulation results are acceptable. A prototype is fabricated, and the low power microwave test as well as the vacuum leakage test is done, both the results are acceptable. The high power test will be conducted after the high power test facility is available in the near future.

Figure 8: Picture of the vacuum leakage test.

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