Study and design of RF coupler for Chinese ADS HWR superconducting cavity

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Abstract: An RF power coupler is a key component of the superconducting accelerating system in Chinese ADS proton linac injector I, which is used to transmit 15 kW RF power from the power source to the superconducting HWR cavity. According to the requirement of working frequency, power level, transmission capability and cooling condition, the physics design of coupler has been finished, which includes RF structure optimization, thermal simulation, thermal stress analysis and so on. Based on this design, the prototype of HWR coupler has been fabricated, and it has successfully passed the high power test.

Key words: RF coupler, HWR cavity, superconducting

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1 Introduction

In Chinese ADS (Accelerator Driven Sub-critical system) proton linac injector Ⅰ, HWR (Half Wave Resonator) superconducting cavity is chosen as the main accelerating structure. In this case, a new type of specified coupler should be de developed to meet the requirements of 162.5 MHz HWR cavity. When the beam load reaches 10 mA, the cavity needs to deliver about 15 kW radio frequency (RF) power to the beam, which means that the coupler should have the capability to transmit 15 kW continuous wave (CW) RF power in travelling wave (TW) mode. Based on the design idea of IFMIF coupler [1], and the successful experience of BEPCⅡ coupler [2], the structure of the coupler's each part has been determined for further optimization. The parameters of HWR coupler are shown in Table 1.

2 RF optimization of coupler

2.1 Resonant mode in the window

After the main structure of coupler has been determined, the RF simulation should be done first. The RF structure of the coupler is shown in Fig. 1. As seen from the picture, the coupler consists of three parts, which are T-box, ceramic window with choke structure and coaxial power transmission line, from top to bottom. The window with choke is a local resonant structure [3]. Resonant modes near the working frequency 162.5 MHz will

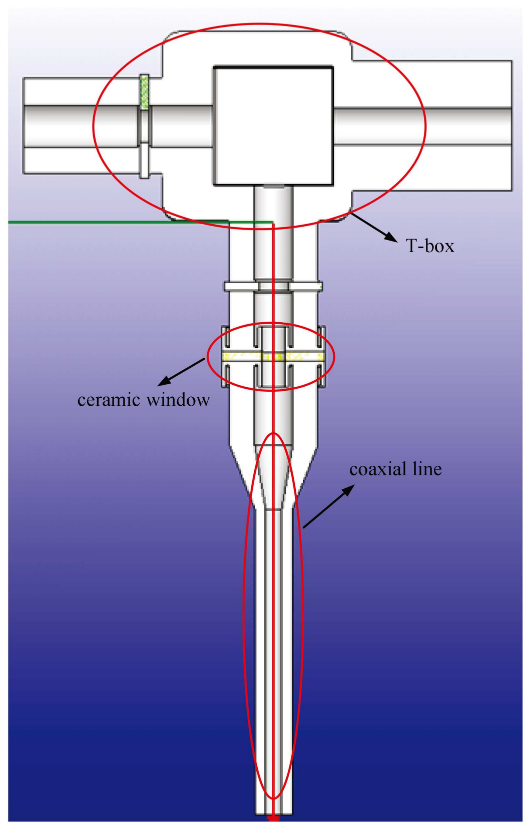

Fig. 1. RF structure of HWR coupler, consisting of T-box, ceramic window, and coaxial line.

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Table 1. Parameters of HWR cavity.

frequency/MHz	162.5
impedance/ohm	50
structure type	coaxial coupler
window type	single, disk ceramic
coupling method	Antenna coupling
power level	CW, TW, 15 kW

influence the power transmission, and form high local E field which can further cause multipacting or an arc. After the eigen simulation of the window structure with two kinds of boundary conditions (i.e. H boundary and E boundary), the first resonant mode is found at 1.16 GHz. This mode is far from the working frequency to make sure that the window can work in a safe condition.

2.2 *S*-parameter optimization

Since the window with choke is not a standard coaxial structure, the size of T-box should be chosen seriously to guarantee the impedance matching for the whole coupler. As shown in the figure, the left side of T-box is used to connect to the RF power source through the standard Φ105 coaxial line. On the right-hand side of T-box, there is a short-circuit face that can be moved to adjust the mismatching. During the simulation, the size of outer box and inner box, the radius of chamfer, and the position of short-circuit face are sensitive for the *S*-parameter. Finally, a good *S*-parameter result has been found. As shown in Fig. 2, the $S_{11}=-40.5$ dB at central frequency 162.5 MHz, and the bandwidth is about 20 MHz for $S_{11}<-20$ dB.

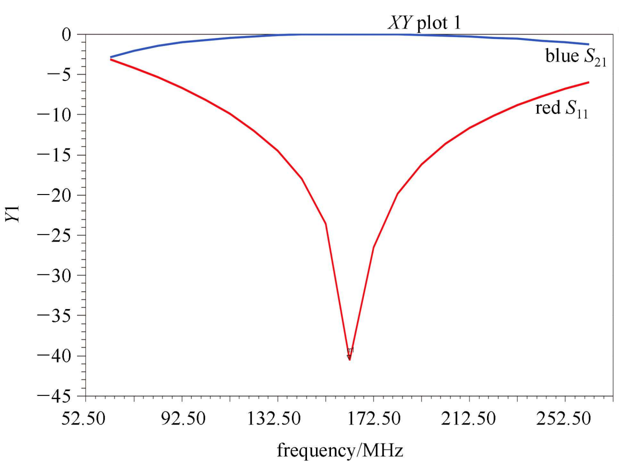

Fig. 2. (color online) Optimized *S*-parameter of coupler, $S_{11}=-40.5$ dB @162.5 MHz.

3 Thermal stress analysis of ceramic window

An important function of the coupler is to make the separation between air (power source side) and high vacuum (cavity side); therefore, the ceramic window is a core component. When the RF power pass through the window, the dielectric loss of ceramic and Joule loss on the surface of copper will cause the temperature to rise. As a result, it will change the window's shape and generate considerable thermal stress [4]. In our calculation, there are two kinds of cooling condition adopted for comparison: one is 25 ℃ water cooling in inner conductor; and, the other one is no cooling in the inner conductor. In both of these two conditions, the outer wall of the window can transfer heat to a room temperature environment through the natural-convection method.

In the thermal simulation, the RF power is selected as 15 kW, which equals the maximum design value. From the temperature distribution results, it can be found that, without water cooling, the maximum temperature at the inner conductor is 321 K, but with water cooling the maximum temperature at the outer conductor is just 300 K. Through this comparison it can be seen that water cooling is a good method to control the temperature rise of the window. Based on the thermal simulation, the thermal stress of the window structure can be further calculated. As shown in Fig. 3, the maximum thermal stress is 55.1 MPa without cooling, and the maximum thermal stress with cooling is only 5.23 MPa. Due to the cooling, the thermal stress has been reduced by one order. Since the mechanical strength of ceramic is about 200–300 MPa, this analysis indicates that 15 kW is a safe power level for our coupler in real operation.

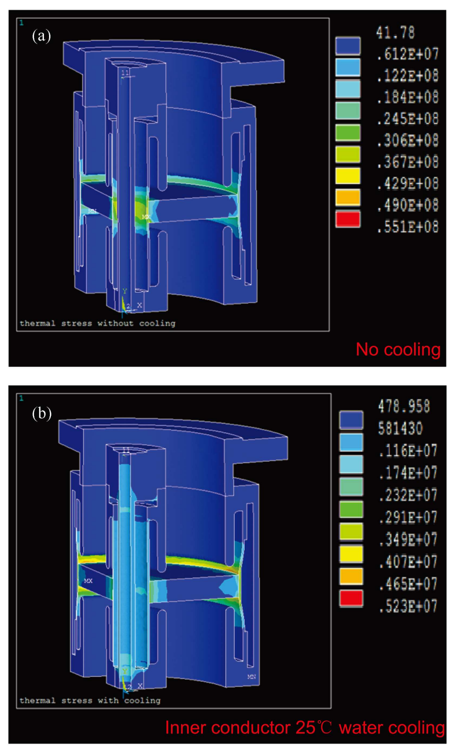

Fig. 3. Thermal stress distribution of the window: (a) thermal stress without cooling; and, (b) thermal stress with water cooling.

4 Cooling type of the outer conductor

In a superconducting RF system the coupler is a component that is used to achieve the thermal transition between room temperature and liquid He temperature. When the coupler is assembled in the cryomodule, the outer conductor of the coupler will transfer heat from outside to the cavity, which is working at 2–4 K. At the same time, if the RF power is on, the Joule heat generated on the metal surface will also transfer to the cavity through outer conductor. To relieve the load of the refrigerator, the heat leakage through outer conductor should be kept as low as possible. In the cryomodule, the 80 K thermal anchor can be chosen as the first cooling step. In addition, the He gas, which needs to be recycled from the liquid He evaporation, can be used to cool the outer conductor as a second step [5].

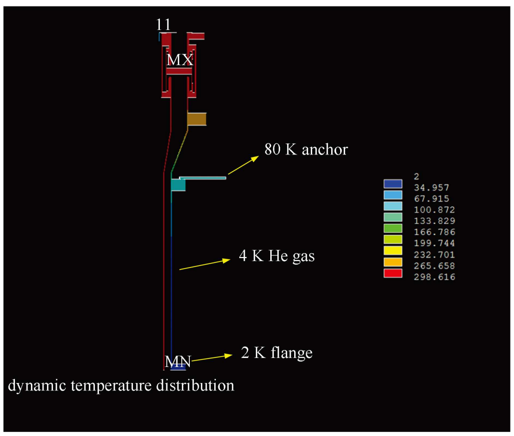

Fig. 4. Cooling condition and dynamic temperature distribution.

At the beginning of the design, the working temperature of the HWR cavity is not determined between 2 K or 4 K. As a conservative estimate, the 2 K cavity temperature is selected in the simulation. The cooling condition and the dynamic temperature distribution of the coupler are shown in Fig. 4. When the RF power is off, the static heat leakage at 2 K is 0.026 W. While 15 kW RF power passes through the coupler, the dynamic heat leakage at 2 K is 0.69 W. These values are adequate for the cryomodule requirements. In this case, a combination of 80 K thermal anchor and 4 K cooling He gas is adopted to cool our outer conductor.

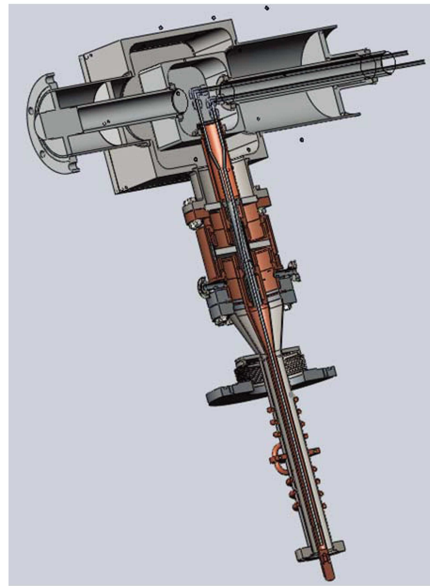

Fig. 5. Machine drawing of HWR coupler.

5 Summary

After the RF, thermal, and mechanical design are accomplished, a prototype coupler has been fabricated (Fig. 5). The high power test has proceeded to investigate the performance of this coupler. During the test, by adjusting the position of short-circuit face, the VSWR (voltage standing wave ratio) of system can be reduced to 1.16, which shows a good agreement with our design. Through several days of power conditioning, the RF power has passed 15 kW and finally reached to 20 kW. Due to the limitations of our power source, the experiment could not be continued at a higher power level. With the help of water cooling in the inner conductor, the temperature of the window is constantly maintained at around 30 ℃. The successful test of our prototype means that the physical design of our coupler is reasonable for real operation. Since there are still some problems of out-gassing and multipacting at low power in the test, some modification of our design should be developed in the future.

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