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Development of a 500 MHz high power RF test stand*

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Abstract: A flexible high power RF test stand has been designed and constructed at IHEP to test a variety of 500 MHz superconducting RF components for the upgrade project of the Beijing Electron Positron Collider (BEPCⅡ), such as the input coupler, the higher order modes (HOMs) absorber and so on. A high power input coupler has been conditioned and tested with the RF power up to 250 kW in continuous wave (CW), traveling wave (TW) mode and 150 kW CW in standing wave (SW) mode. A prototype of the HOMs absorber has been tested to absorb power of 4.4 kW. An introduction of the test stand design, construction and high power tests is presented in this paper.

Key words: high power test stand, high power input coupler, HOMs absorber

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1 Introduction

Two 500 MHz superconducting cavities (SCCs) have been used in the BEPCⅡ RF system, instead of the four 200 MHz normal conducting cavities used in BEPC [1]. Each superconducting cavity has one high power input coupler to feed power for the beam current and two HOMs absorbers to absorb HOMs excited power. During the R&D of the input coupler and the HOMs absorber, it is very important to study the characteristics of the conditioning phenomena in order to improve their performance and increase the power to meet the design requirements. So, as a necessary tool, a high power test stand is developed at IHEP to serve as a conditioning and test platform.

The test stand is a complex system consisting of a flexible experimental set-up which can be reconfigured and modified to test different components, such as an input coupler, an HOMs absorber and so on. A high power RF source serves as the test stand power feed. A low-level RF (LLRF) system is used for rapid monitoring and interlock control. A vacuum system is used for vacuum pressures below 1E-9 Torr[2] and a cooling system provids water and air cooling for devices under test (DUTs)

Up to now, several high power tests have been carried out for the input coupler and the HOMs absorber with successful test results achieved that well verify the effectiveness and applicability of the test stand.

2 The test stand set-up

One of the most important design considerations for our requirements is how to build a flexible test stand set-up which can be easily reconfigured to test different RF components including the input coupler, the HOMs absorber and so on. For this purpose it is essential to share instrumentation as much as possible in different component tests. A test stand set-up shown in Fig. 1 is designed based on the above considerations and the test space available at IHEP. High RF power from a transmitter with an output power of 250 kW is transmitted through a WR1800 waveguide and converted to a WR1500 waveguide through

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[2] 1 Torr=1 mmHg=1.33322×10^2 Pa

a section of waveguide transition. After the transition, a 90° H-plane waveguide miter bend, a flexible waveguide and a waveguide directional coupler are adopted. The directional couplers are arranged just before and after DUTs for power monitoring. The RF power passing through the DUTs will be absorbed by a water-cooled terminal load for the traveling wave (TW) test or fully reflected by a short plane with variable phase for the standing wave (SW) test.

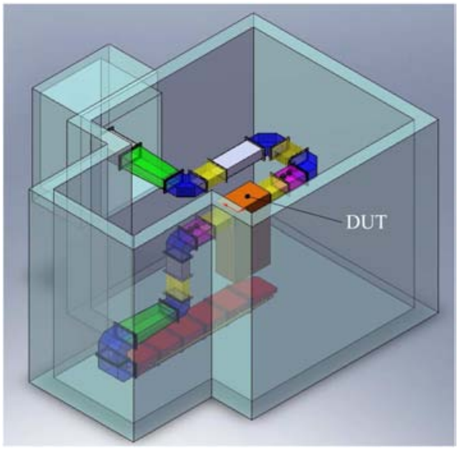


Fig. 1. The test stand set-up.

The schematic diagrams of the test stand for the input coupler and the HOMs absorber are shown in Fig. 2 [2] and Fig. 3 separately. Besides the set-up, the test stand system also includes a high power RF source, low level controls, a vacuum system and a cooling system.

2.1 The input coupler test set-up

The objective of the input coupler test is to test its power transferring capability and measure the vacuum, electron and discharging responses [3]. The coupler set-up consists of a pair of couplers installed back to back, one connected waveguide, vacuum pumps and monitors, as shown in Fig. 4 [4]. RF power is transmitted from an upstream testing coupler, through the connected waveguide to a well-tested downstream reference coupler, and dissipated in the water load for the TW test mode or fully reflected by a short plane for SW test mode finally. Impedance matching of the whole set-up is optimized carefully by HFSS simulation and proved to have a good transmission performance in the following test. An arc sensor attached close to the window and a view port located at the down side of the connected waveguide are adopted to observe visible lights such as glow discharge by multipacting. A vacuum gauge is intalled near the window to observe outgasing and realize vacuum interlock control further. Eight electron probes are equipped on the outer conductor to identify multipacting positions and intensities. Several Pt100s are placed on the doorknob and the outer conductor to measure their temperature changes.

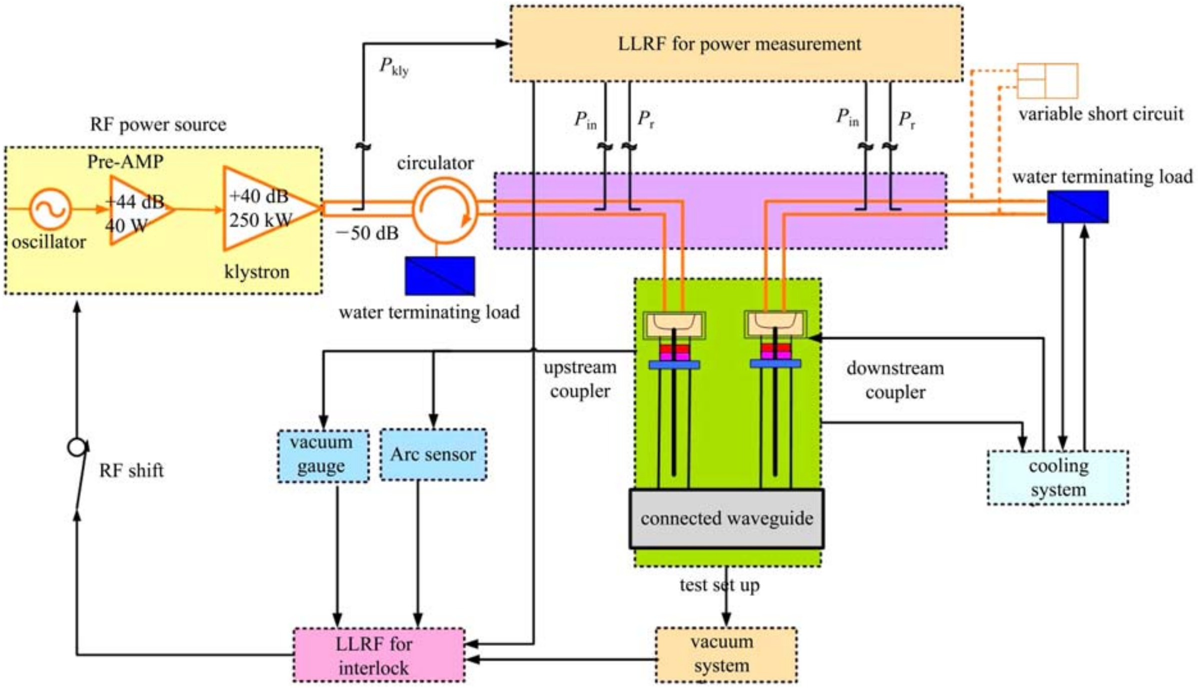


Fig. 2. Schematic diagrams of the test stand for the input coupler.

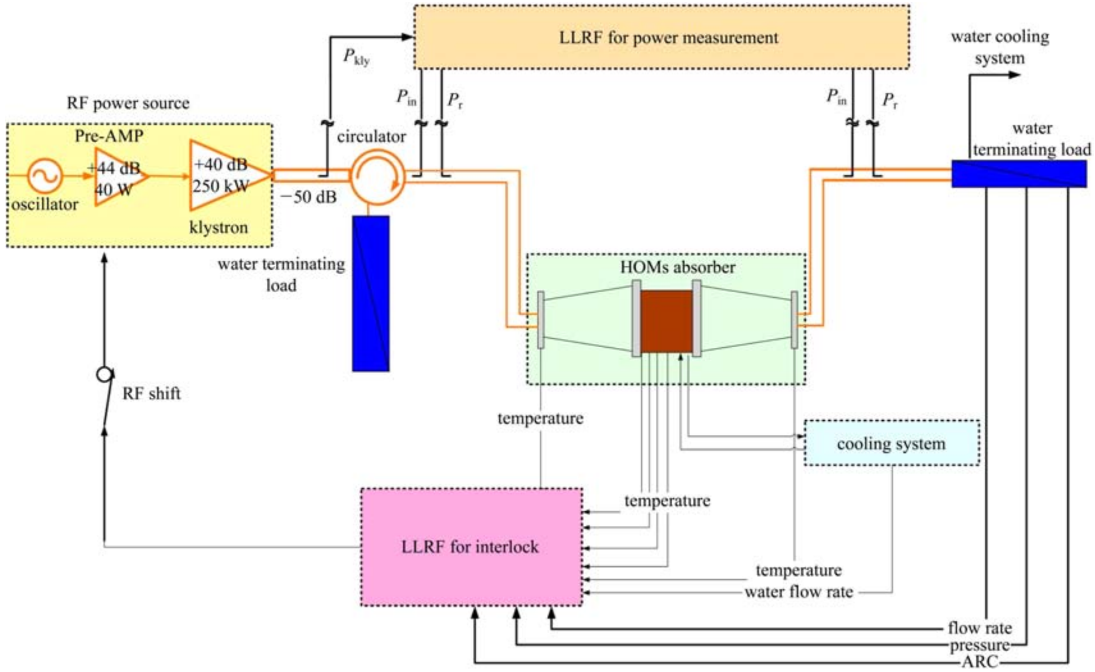


Fig. 3. Schematic diagrams of the test stand for the HOMs absorber.

Fig. 4. The input coupler test set-up.

Fig. 5. The HOMs absorber test set-up.

2.2 The HOMs absorber test set-up

In order to check the power capability and the temperature increasing range of the HOMs absorber, a test set-up shown in Fig. 5 is built, which includes two transitions of a waveguide to coaxial line and two specially designed coaxial transitions. The dimensions of the coaxial transition have been optimized to provide a good power transmission performance. Several Pt100 sensors are attached on the outer surface of the absorber and the coaxial transitions to measure the temperature increase.

3 Subsystems

3.1 The high power RF source

Considering the cost reduction of the construction, the BEPCⅡ high power RF source (see Fig. 6) is used for the test stand when BEPCⅡ is shut down. it is composed of a 500 MHz 250 kW CW klystron and a PSM power supply with an EPICS-based control panel.

Fig. 6. The PSM power supply with an EPICS-based control panel (left); klystron (right).

3.2 The LLRF system

A LLRF system is designed to provide monitoring and rapid interlock control of the RF power, temperature, vacuum, arc, secondary electrons, etc. The LLRF includes interlock modules, power control modules, power meters, data recorders and so on. For input coupler test (see Fig. 7), signals of arc, vacuum, forward and reflection power must be monitored and interlock-controlled at all times in order to prevent fatal discharge near the ceramic window. Electron currents accepted by the electron probes are displayed by an oscilloscope. During the HOMs absorber test, several thermocouples are attached outside the absorber to measure the temperature increase and protect the ferrite crack due to the excessive heat expansion.

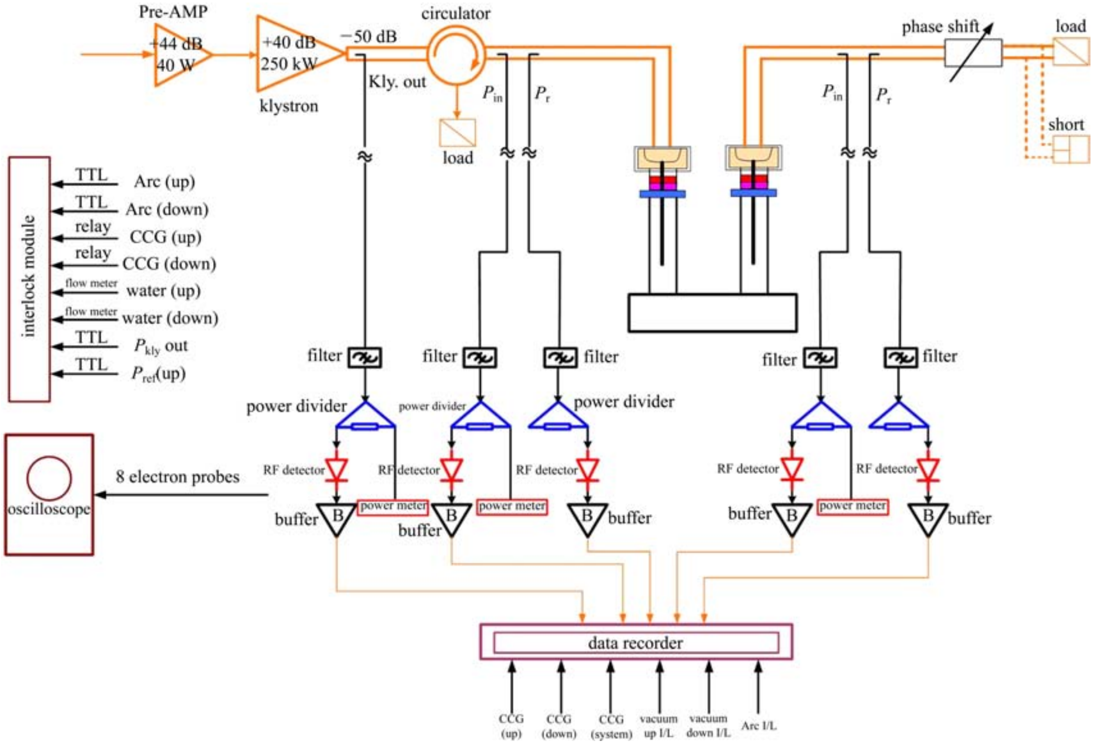


Fig. 7. Schematic diagram of the LLRF system for input coupler testing.

3.3 The vacuum system

Since all DUTs should be tested under high vacuum, a vacuum system is used to obtain and measure vacuum pressures. The vacuum system contains one turbo molecular pump of 70 L/s and two ion pumps of 150 L/s as shown in Fig. 8. Initially, a pressure of 1E-5 Torr is obtained by using the turbo pump in tandem with an oil-free pump. Then the ion pumps start to get a higher vacuum up to 1E-9 Torr.

3.4 The cooling system

A cooling system is set up to provide water cooling to the inner conductor of the input coupler and the HOMs absorber; and air cooling for the input coupler doorknob. For the cooling stability, a cooler with temperature controlling accuracy of +/−0.1 ℃ is applied. Several thermocouples and flow meters are also equipped for temperature increase monitoring and calorimetric measurement of the RF losses.

Fig. 8. The vacuum system: (left) turbo molecular pumps of 70 L/s; (right) ion pumps of 150 L/s.

4 High power tests

4.1 The input coupler test

As the first step, all components of the input coupler are carefully cleaned in a Class 100 clean room. After that, the coupler is immediately assembled onto the test stand in a Class 1000 clean room. Then, the whole test stand is baked at 150 ℃ for 24 h prior to RF conditioning.

Coupler conditioning is carried out to increase the power passing through the input coupler step by step under strict controlling of discharging and outgasing; and finally it reaches the designed power. The conditioning procedure is shown in Fig. 9. As the first step, conditioning with pulse power is adopted. The pulse amplitude, width, and repetition rate are adjusted continuously to keep outgasing, discharging and electron current intensities just below the interlock levels. After one hour, a continuous wave (CW) is applied to check the pulse conditioning effect. Once discharging or outgasing occurs, the CW conditioning is converted again to pulse conditioning. The conditioning process of pulse-continuous-pulse is repeated to increase the RF power up to the nominal power level.

Finally, CW RF power of 250 kW in TW mode (see Fig. 10) and 150 kW in SW mode (see Fig. 11) have been reached in the input coupler high power test.

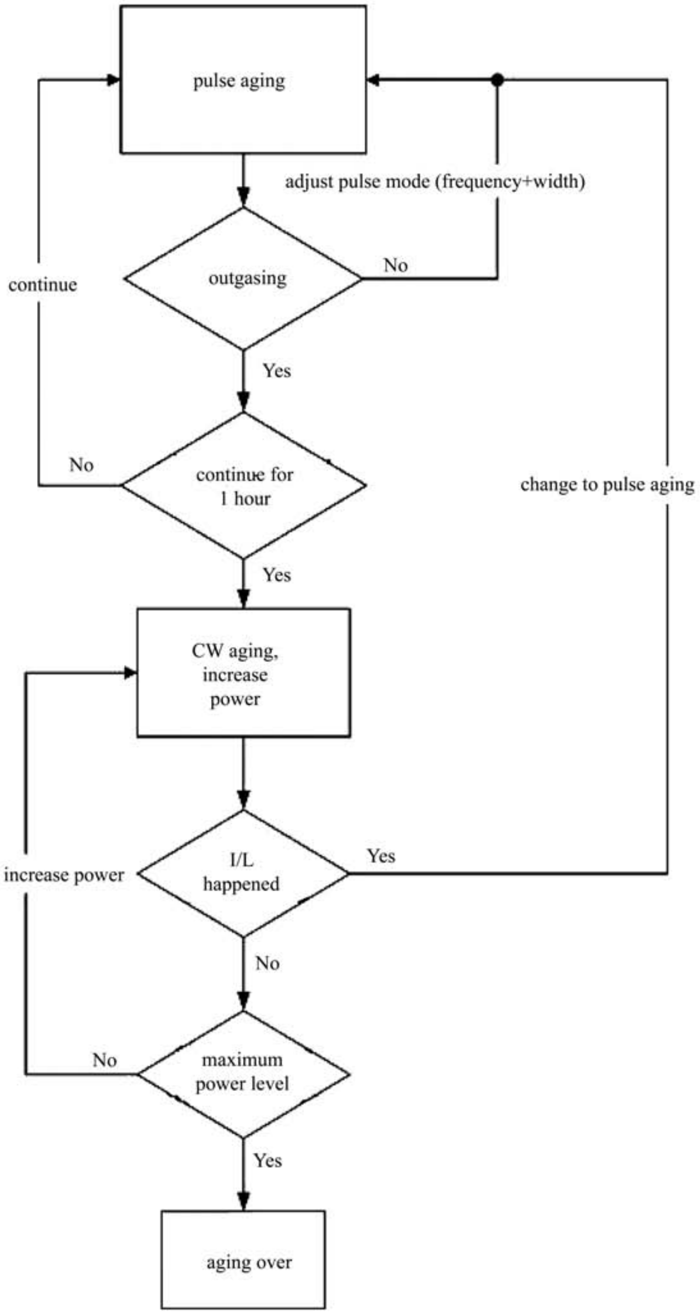
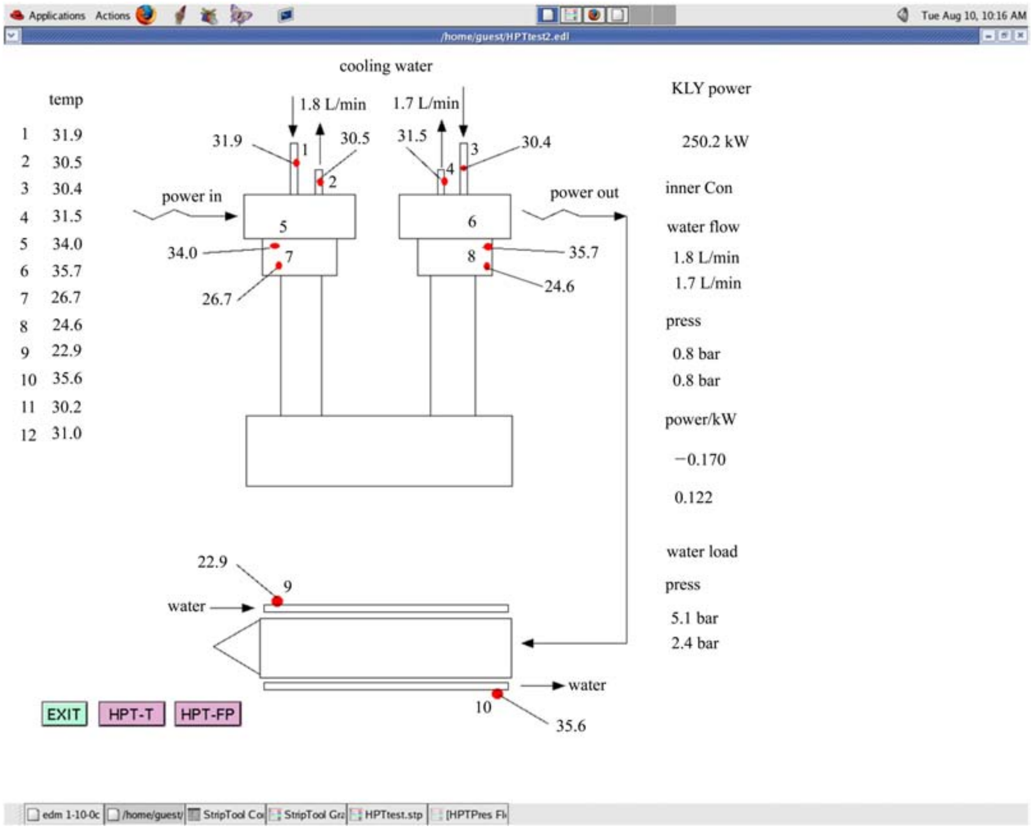


Fig. 9. The input coupler conditioning procedure.



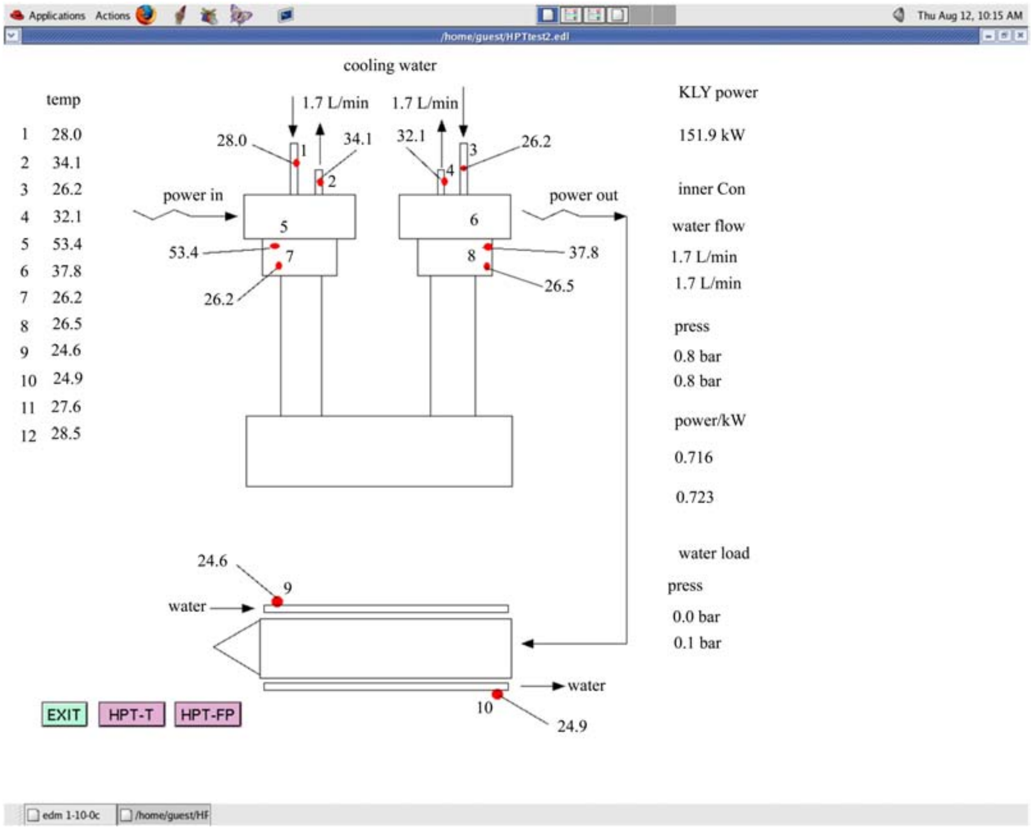
temp	
1	31.9
2	30.5
3	30.4
4	31.5
5	34.0
6	35.7
7	26.7
8	24.6
9	22.9
10	35.6
11	30.2
12	31.0

KLY power
250.2 kW

inner Con
water flow
1.8 L/min
1.7 L/min
press
0.8 bar
0.8 bar
power/kW
−0.170
0.122

water load
press
5.1 bar
2.4 bar

Fig. 10. The high power input coupler test result: 250 kW CW RF power in TW mode.



temp	
1	28.0
2	34.1
3	26.2
4	32.1
5	53.4
6	37.8
7	26.2
8	26.5
9	24.6
10	24.9
11	27.6
12	28.5

KLY power
151.9 kW

inner Con
water flow
1.7 L/min
1.7 L/min
press
0.8 bar
0.8 bar
power/kW
0.716
0.723

water load
press
0.0 bar
0.1 bar

Fig. 11. The high power input coupler test result: 150 kW CW RF power in SW mode.

4.2 The HOMs absorber test

As RF power passes through the HOMs absorber, most of the power will be absorbed and converted into heat, which results in a temperature increase of the ferrite material of the absorber and causes an excessive expansion of the copper holding the ferrite. So, the HOMs absorber high power test aims to test its power absorbing efficiency and capability for temperature increase under different power levels [5].

The RF power increases to 9 kW with the step of 0.5 kW and stays around 5 min at every step to check the temperature increase. Water cooling is applied on the outer surface of absorber during the test. The input and absorbing power as shown in Fig. 12 are measured by the waveguide directional couplers. A prototype HOMs absorber has been tested to pass CW RF power of 9 kW and absorb power of 4.4 kW without significant temperature increase, which satisfies the requirements of the HOMs absorber at BEPCⅡ 500 MHz SCC.

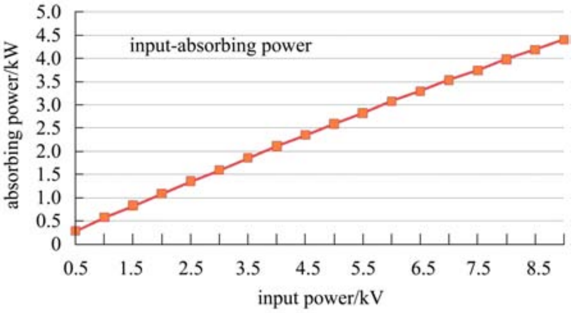


Fig. 12. The input power and absorbing power during the HOMs absorber test.

5 Conclusion

The first domestic 500 MHz high power RF test stand has been developed and passed the acceptance test at IHEP in September 2010. The high power input coupler and the HOMs absorber for BEPCⅡ SCCs have been conditioned and tested successfully by means of this test stand, which provides a deep study of the limitations for higher power. As a result, it has enabled us to find the best way to improve the RF performances. This test stand will also serve as a conditioning and testing platform for other key components such as ceramic windows and waveguide components.

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