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HIGH-POWER RF TEST OF COAXIAL COUPLERS FOR THE INJECTION LINAC OF XIPAF

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Abstract

For the high-power RF test of the coaxial couplers which will be employed on the linac injector of the XiPAF (Xi'an Proton Application Facility) project, a high-power conditioning cavity was designed and manufactured [1]. There are some optimized aspects on the cavity and couplers to obtain better RF performance during the high-power testing process. The traveling-wave test and full-power-reflection test were executed to check whether the coupler can afford the enough power level for the linac operation, and whether only one coupler can afford the total power for the RFQ. The construction of the testing stand, optimization of RF parameters and results of high-power RF test are presented in this paper.

INTRODUCTION

The RFQ accelerator of XiPAF (Xi'an Proton Application Facility) is designed to be powered by two coaxial power couplers [2], because that the maximum power limitation the ceramic can afford in the coaxial power coupler is not affirmed by the experiment. To check the upper limited power of the couplers and execute a high-power RF conditioning process, the high-power conditioning cavity has been manufactured and measured. The multipacting power intervals occurring in the couplers shall be suppressed or broke through. If the spark is detected by the arc detector, the RF exciting need to be cut off immediately. If the vacuum is higher than breakdown level, the RF exciting need also be cut off to prevent possible sparking. A high-power conditioning stand with interlock security has been constructed. Some optimization of the cavity and couplers have been performed to make the high-power conditioning be impelled.

CONFIGURATION OF THE TEST STAND

The core of the test stand is the conditioning cavity and two couplers. The conditioning cavity is a resonant structure which is designed to couple the RF power from one coupler to the other [1]. They are driven by a tetrode-based RF power source of which output peak power is about 500 kW at 150 μs pulse width and 1 Hz repetition rate. One coupler is connected to the RF power source by the 6-1/8 inches coaxial RF transmission line which includes a 700 kW circulator to prevent the reflection power from returning to the final cavity of the 4616 tetrode. Another coupler is connected to a load or a λ/2 short.

To obtain the vacuum degree lower than 1×10^{-3} Pa, two vacuum groups are employed. Each of them consists of a mechanical pump and a molecular pump. The vacuum gauge is positioned at an appropriative port mounted on one of the couplers. The vacuum degree will be measured by a vacuum meter which is used to monitor the vacuum and supply an interlock signal.

To monitor the spark occurring near the ceramics in the couplers, two fibre-optics probes are employed at the quartz windows mounted on the couplers. The sparking signals will be transmitted to an arc detector which can sense the sparking light and send an electrical level to the monitor system within 100 ms.

The forward and reflection powers from the directional coupler just at lower of the output port of the RF power source are measured by a RF power meter to get the precise pulsed power. The trigger signal, the screen grid current of the RF power source, the forward and reflection power from the directional coupler just at the lower of the circulator are monitored by an oscilloscope.

To prevent the couplers and the RF power source from destroying, the vacuum level of the cavity and couplers, the sparking status of the ceramics of two couplers, the reflection power detected by the directional coupler placed on the output port of the RF power source are connected in series in the interlocking protection logic. If any condition described above occurs, the change will be recorded, and interlock protection will be triggered by an interlock code.

There are two stages of high-power conditioning and test. One is under traveling-wave condition, another is under full-power-reflection condition. With the former condition, whether the couplers can afford 500 kW traveling-wave RF power or not shall be affirmed. With the later condition, whether the couplers can afford 500 kW full-power-reflection RF power or not shall be affirmed.

The block diagrams of the traveling-wave and full-power-reflection conditioning and test are shown in Fig. 1. The biggest difference is the load of the 2# coupler. Under the traveling-wave condition, the load is a 700 kW dummy load. Under another condition, the load is a removable λ/2 short, and the 700 kW dummy load is used as an absorbent load of the circulator.

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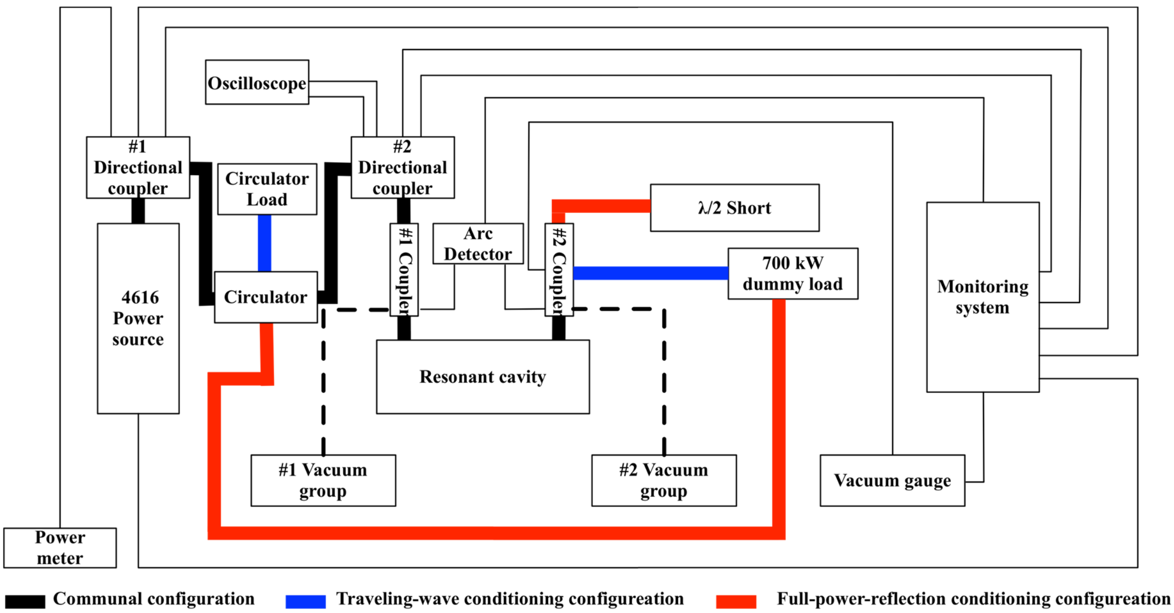

Figure 1: Block diagrams of high-power conditioning and test. Blue line is the configuration of the traveling-wave conditioning. Red line is the configuration of the full-power-reflection conditioning.

CONFIGURATION OF THE TEST STAND

The configuration of traveling-wave conditioning of the coaxial couplers is described by the blue line and other black-line communal configuration line in Fig. 1.

First off, the multipacting can be indicated with a re-flection waveform shocking as Fig. 2. The purple indicates the forward power, and the rose red indicates the reflected power. One can notice that the multipacting cause the reflection after several tens of microseconds of the pulse feeding. The multipacting power level is verified by the scanning-power experiment. It can be found that the multipacting phenomenon always occurs below 100 kW. The multipacting power level intervals from 50 kW to 100 kW are suppressed by a repeating conditioning process. The conditioning process is started from the high-power level which is proved as a more efficient approach [3]. The multipacting power below 50 kW was broke through by increasing the output power of the RF power source directly, because the RF power below 50 kW will not be used in operation and not lead to unstable of high-power level.

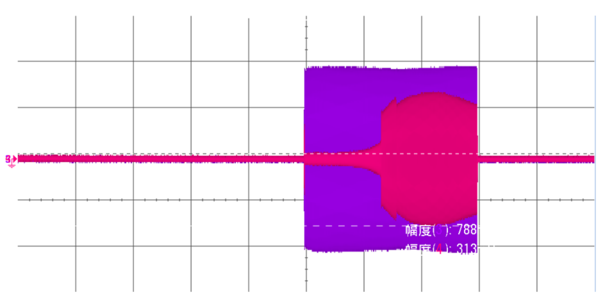

Figure 2: The waveform of the forward power and reflected power from #2 directional coupler.

Since the pulse width is 150 μs, the multipacting is not difficult to suppress. After two-days multipactor-suppressing, high-power conditioning was started from 50 kW. The RF power from RF power source is increased every 50 kW. If there is no sparking or obvious outgassing after the former increasing power, the next increasing power can be executed. The upper limitation of the increasing power is 500 kW. In the entire conditioning process, the pulse width of the RF power is 150 μs, and the repetition rate is 1 Hz. The conditioning process is recorded in Fig. 3. Under the traveling-wave condition, the maximum input power fed into the #1 coupler was 471 kW. After exchanging the connected ports of two couplers, the same process was executed, and 470 kW high-power conditioning was held for 30 minutes as the former process.

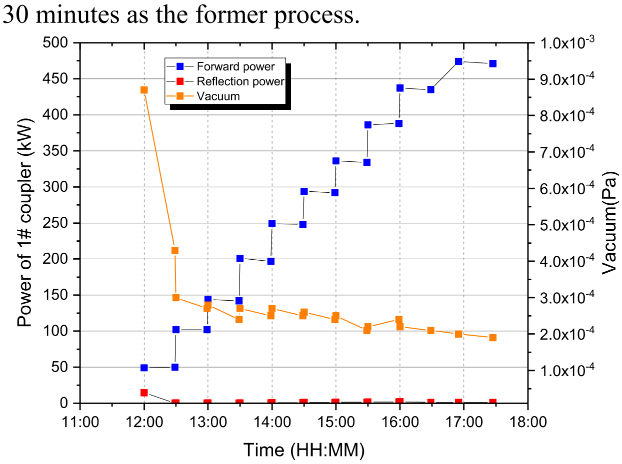

Figure 3: the process of traveling-wave conditioning.

The configuration of full-power-reflection conditioning is described by the red line and communal configuration line in Fig. 1. The full-power-reflection conditioning stand is shown in Fig. 4. The absorbing load is replaced by the

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700 kW dummy load which was connected to the #2 coupler, and a λ/2 short line was connected to the #2 coupler for compensation. The λ/2 short line could be shifted by a wheel connected with its screw. The position of the short plate in the short line will be shifted every 26 mm to over at least a λ/4 length. It's a consideration to make the ceramic to suffer the full-power-reflection test.

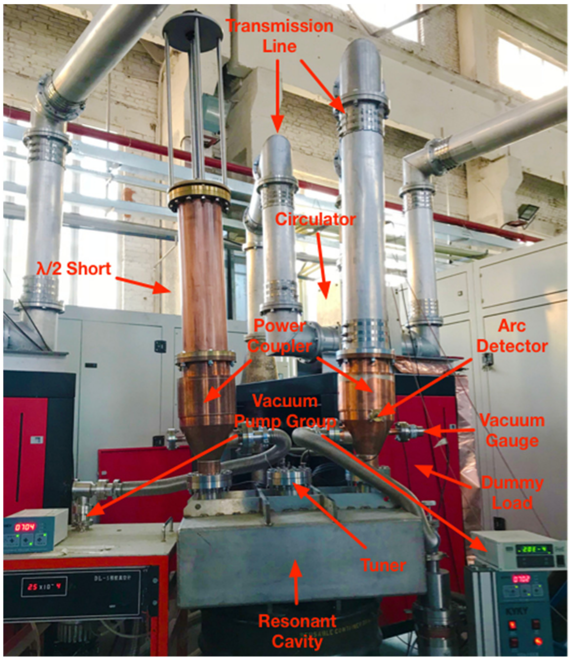

Figure 4: Picture of full-power-reflection conditioning configuration.

Deriving the aim of full-power-reflection conditioning, there are only two power levels to be used, 300 kW and 500 kW. The 300 kW is promised by the manufacturing factory of the couplers. The 500 kW is the requirement of single-coupler feeding design. The process of the 500 kW full-power-reflection conditioning was recorded as shown in Fig. 5. The lower forward and reflection power after circulator is in accord with the return loss performance of the λ/2 short. Then a same process was executed after the two couplers were exchanged. The conclusion can be made that the coupler can afford 500 kW full-power-reflection, and the ceramic can afford at least 300 kW full-power-reflection.

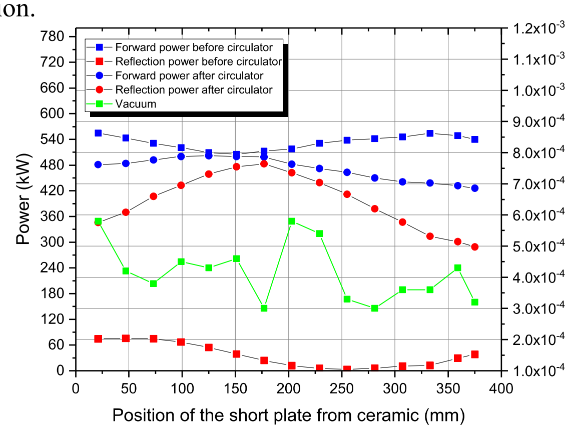

Figure 5: Process of the full-power-reflection conditioning.

OPTIMIZATION FOR THE CORE OF THE TEST STAND

In Ref [1], the unideal parameters for high-power conditioning has been introduced. One is the highest resonant frequency of the conditioning cavity is lower than 325 MHz which is the operating frequency and of course the conditioning frequency. Another is the coupling coefficient between the couplers and resonant cavity is too small which could lead to a large reflection.

For the former problem, a #-type stiffener has been welded to resist the sink at the center of the cavity upper surface. The sink is positioned at the strangest E-field which will make the frequency lower according to the perturbation theory when the volume of the position decreases. The tuning range after this revamp shifted to 325±3.5 MHz. For the later problem, a series of coupling loops were produced. Finally, the most property square of the coupling loop was affirmed as 18 cm2 which was enclosed with an oxygen-free copper plant.

After welding the #-type stiffener and enlarging the coupling loop, the coupling coefficient of each coupler is 0.91 and 0.90 respectively. The return loss is -26.17 dB and -25.15 dB for #1 coupler and #2 coupler respectively. The insertion loss of the resonant system consisting of two couplers and the resonant cavity is 0.56 dB.

CONCLUSION

The 500 kW test stand for the high-power conditioning is built. This stand can afford either a traveling-wave conditioning or a full-power-reflection conditioning with altering the configuration of the circulator and its load. After some optimization for adjusting the resonant frequency of the conditioning cavity and increasing the coupling coefficient, the 500 kW traveling-wave and full-power-reflection conditioning were executed to prove the high-power affording capacity of the coaxial couplers with the ceramic windows. Finally, it's proved that both of the couplers can afford 500 kW full-power-reflection, and the ceramics can afford at least 300 kW full-power-reflection.

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