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HIGH-POWER TEST OF A COMPACT X-BAND RF ROTARY JOINT

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Abstract

A compact X-band (9.3 GHz) RF rotary joint has been developed in the accelerator laboratory of Tsinghua University. RF measurements on the rotary joint using Vector-Network Analyser showed good results. In recent high-power tests, the RF rotary joint was operated under a 1.6 MW X-band magnetron. The incident power, the transmitted power and the pulse width of this rotary joint have been measured. The transmitted power kept stable in different rotation angles. In this paper, the setup and results of the high-power tests of this RF rotary joint are presented.

INTRODUCTION

With the rapidly increasing requirement of high power microwave, many waveguide-based radio-frequency (RF) components have been developed [1-3]. An RF rotary joint is a widely-used microwave device that can allow the independent movement between the RF power source and the accelerating tube in a linear accelerator (linac) system [4]. For higher position accuracy and compact devices in medical linacs, X-band accelerators are more suitable due to the obvious advantages on the mobility of the accelerator devices. Therefore, an X-band RF rotary joint is needed in application of particle accelerators.

In past two years, a compact X-band RF rotary joint has been designed, fabricated and tested in the accelerator laboratory of Tsinghua University [5]. Recently, the high-power test of the rotary joint has been conducted. The transmitted characteristics of the rotary joint kept stable in the test.

This paper describes the high-power test of the X-band RF rotary joint. A brief review of the design and low power measurements is given in the next section. And the details and results of high-power test are introduced in subsequent sections.

DESIGN AND LOW POWER TEST

Design Procedure

In RF design process, TE_{10}-to-TM_{01} mode converter is the key component. It is optimized to excite TM_{01} mode, the lowest axially symmetric mode, with a minimum of TE_{11} mode in the circular waveguide. The microwave is fed into the circular waveguide by side coupling and a section of rectangular waveguide is added to increase the symmetry of the model for suppression of TE_{11} mode.

Moreover, a clearance between two mode converters is obligated to realize the rotation between two ports. Consequently, an RF choke, which takes the mechanical joint between the two parts out of the high electromagnetic field region and prevents RF leak, is essential for combining the two parts [1]. Quarter wavelength structures are added around the circular waveguide as the choke groove.

The final RF design is shown in Fig. 1. The mechanical design is shown in Fig. 2.

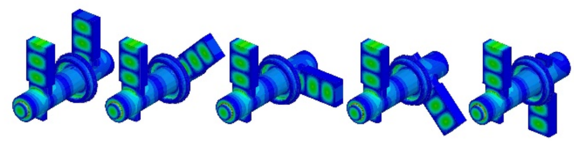

Figure 1: RF design of the rotary joint.

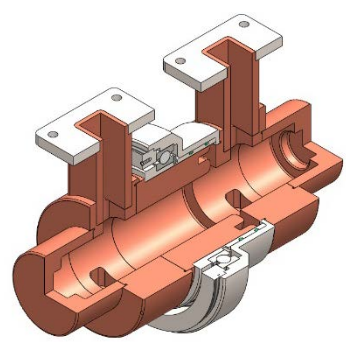

Figure 2: Mechanical design of the rotary joint.

Low Power RF Measurements

The RF performance of the rotary joint has been tested at low power with Vector Network Analyzer before brazing. Complex scattering parameters (S-parameters) have been measured at different rotation angles from 0 degree to 180 degree with a step of 45 degree [5]. The measured reflection before brazing is below -30 dB at the central frequency of 9.3 GHz, which is in good agreement with the simulation results. However, an unexpected frequency drift happened due to the brazing. The maximum of the reflection at the central frequency is -25 dB after brazing, which is not ideal but still satisfied with the applications, as shown in Fig. 3. As for the transmitted characteristics, the phase varies within 0.2 degree under different rotation angles at the central frequency of 9.3 GHz, which is shown in Fig. 4.

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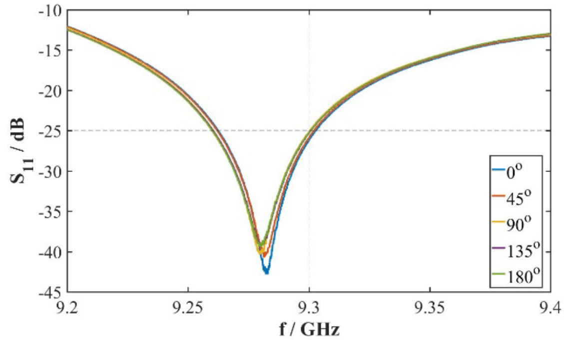

Figure 3: Measured results of reflection with the different rotation angles after brazing.

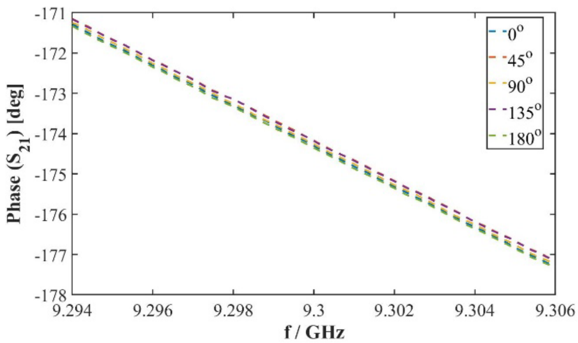

Figure 4: Measured results of phase drift with the different rotation angles after brazing.

HIGH POWER TEST SETUP

High-power test of the rotary joint has been conducted in Tsinghua University. The setup is shown in Fig. 5.

The power source of the high-power test was an X-band magnetron, followed by a four-port circulator to protect the magnetron. A water load was used to absorb the transmitted power at the end of the system. The directional coupler before the rotary joint was used to measure the incident power and the reflection power. And the transmitted power was measured by the directional coupler after the rotary joint. The system was operated under SF6 with a pressure of 0.18 MPa and no leaks was detected when rotating the joint.

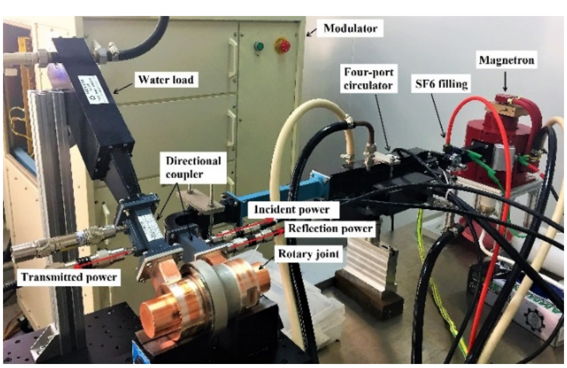

Figure 5: Setup of the high-power test of the rotary joint.

Before the test, the magnetron was tuned to the operating frequency of 9.3 GHz. The cathode voltage of the magnetron was increased from 34.9 kV to 36.6 kV to find the best working condition of the magnetron and the maximum power that can be input into the rotary joint, as reported in Table 1. The final working condition used in the high-power test is shown in Fig. 6.

Table 1: Working Condition of Test Bench

Magnetron Cathode voltage [kV]	Magnetron Anode current [A]	Input power to the joint [MW]
34.9	55.6	0.94
35.2	60.9	1.03
35.4	67.2	1.11
35.6	72.4	1.20
36.0	78.8	1.29
36.3	84.4	1.42
36.6	92.0	1.55

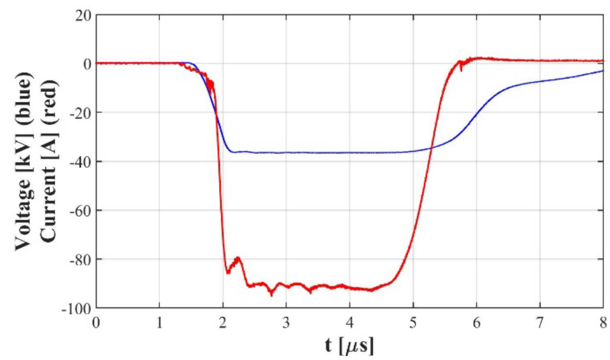

Figure 6: Waveforms of the magnetron voltage and current.

The powers from directional couplers were damped by attenuators and coaxial cables, and measured by an RF power sensor. All the components used in power measurement were calibrated before the high-power test.

HIGH POWER TEST RESULTS

The performance of the rotary joint was tested with different rotation angles from 0 degree to 180 degree with a step of 45 degree. The input power was kept at 1.55 MW during the high-power test. Figure 7 shows the results of high-power test.

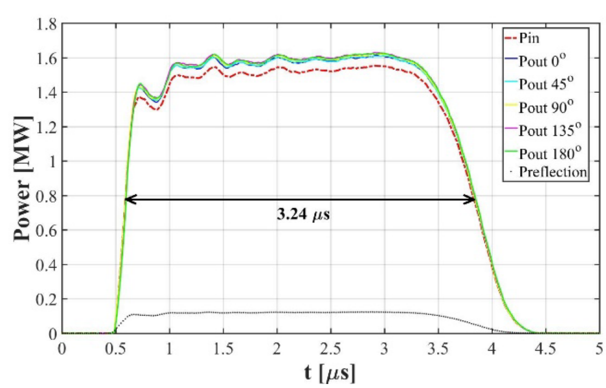

Figure 7: High-power test results of the rotary joint.

The shapes of the output power kept almost the same with that of the input power, which means the transmission

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characteristics of the rotary joint kept stable in the different rotation angles when the peak power was 1.6 MW and the pulse width was 3.24 μs with 100 pps (pulse per second). No RF breakdown was observed in the high-power test over one day.

However, the incident power measured was lower than the transmitted powers, which probably due to the different performance of the directional couplers under the condition of the lower-power calibration and the high-power test. Moreover, the result of the reflection was unsatisfied due to the bad matching of the water load, which had a reflection about -15 dB.

CONCLUSION

A compact X-band RF rotary joint has been designed, fabricated and tested in Tsinghua University. The RF measurement of the rotary joint showed good results: the maximum reflection was below -25 dB, the insertion loss was less than 0.1 dB, and the variance of output phase shifts was below 0.2 degree in different rotation angles. In the high-power test, the transmission performance of the rotary joint kept stable when the peak input power was 1.6 MW and the pulse width was 3.24 μs with 100 pps, which is in good agreement with the simulation and lower power measurement results.

The rotary joint will be applied in a 6-MeV X-band linac system to realize the movement of the accelerator tube.

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