DEVELOPMENT OF A HIGH-POWER X-BAND RF ROTARY JOINT

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Abstract

RF rotary joints allow the independent movement between the RF power source and the accelerating tube of a linear accelerator (linac). In this paper, the design of a compact X-band (9.3 GHz) high-power RF rotary joint is presented. Simulation results illustrate that RF parameters (the scattering matrix) of this rotary joint keep stable in the arbitrary rotation angle. The maximum return loss is about -30 dB, the insert loss is less than 0.11 dB, and the variance of output phase shifts is below 1 degree while rotating the joint. RF measurement on the rotary joint using Vector-Network analyser is also conducted and presented in this paper.

INTRODUCTION

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 linac system. Compared to S-band and C-band accelerators, X-band ones are more compact. They are more suitable for portable devices and for higher position accuracy in medical linacs due to the obvious advantages on the mobility of the accelerator devices. Therefore, it is essential to develop an X-band rotary joint.

Various X-band rotary joints have been reported in [1-3]. However, most of the commercial rotary joints are designed for radars, which focus on the average power rather than the peak power. An X-band rotary joint working at high peak power is needed in application of particle accelerators.

This paper describes the design of a new compact high-peak power (~MW) X-band rotary joint working at the frequency of 9.3 GHz and the peak power of 1.5 MW. The RF design, manufacture, and low-power RF measurement have been carried out and will be introduced in following sections.

DESIGN PROCEDURE

In this section, the detailed design of the X-band rotary joint is shown in both electromagnetic and mechanical aspects.

RF Design

The coaxial rotary joint is unsuitable for the high-power requirement. The input and output ports of this rotary joint are connected with WR-112 waveguides. The diameter of the circular waveguide (see Fig. 2) is equal to the broad side of WR-112 rectangular waveguide (28.499 mm).

The mode converter is the key component of the rotary joint. TM_{01} mode, the lowest axially symmetric mode, is chosen as the propagating mode in the circular waveguide to get the stable reflection and transmission characteristics regardless of the rotation angle. It is necessary to excite TM_{01} mode with a minimum of TE_{11} mode in the circular waveguide, as TE_{11} mode is the lowest mode in the circular waveguide. A design is shown in Fig. 1 [4]. The microwave is fed into the circular waveguide by side coupling and the length between the end of the circular waveguide and the central of the rectangular waveguide is typically matched for TM_{01} mode but open for TE_{11} mode. In our design, L is approximately 32.3 mm. In order to restrain the TE_{11} mode further, a section of rectangular waveguide is added opposite to the input and output rectangular waveguide to increase the symmetry of the model. The final mode converter is shown in Fig. 2. The mode separation result is reported in Fig. 3.

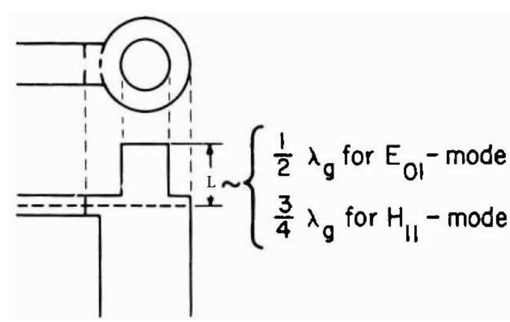

Figure 1: Stub-Matched Rectangular-to-Circular Waveguide Transition [4].

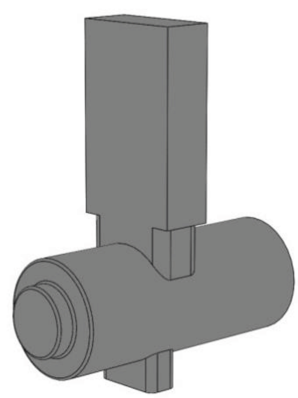

Figure 2: RF design of the mode converter.

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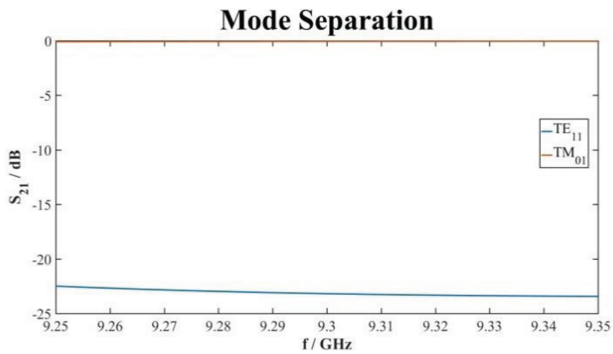

Figure 3: Mode separation between TM_{01} and TE_{11}.

A bearing system is introduced to the rotary joint to realize the rotation between the two ports. Consequently, an RF choke is essential for combining the two ports, which takes the mechanical joint between the two parts out of the electromagnetic field region. Quarter wavelength structures are added around the circular waveguide as the choke, as shown in Fig. 4. The maximum electric field on the surface of the choke is 2.76 MV/m, and the maximum magnetic field is 6.77 kA/m at 1.5 MW transmitted RF power.

The final RF design is shown in Fig. 5.

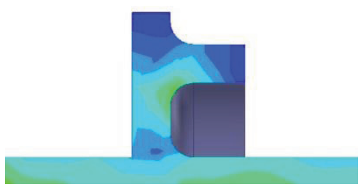

Figure 4: Field inside the choke.

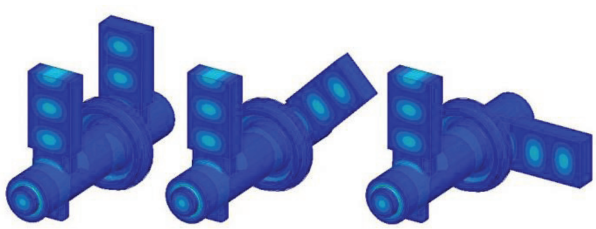

Figure 5: RF design of the rotary joint.

Mechanical Design

The whole body of the rotary joint is shown in Fig. 6. The rectangular waveguides, circular waveguides, and the mode converters are made of oxygen-free copper (OFC). The sections for supporting and fixing the bearing and two o-rings are made of stainless steel. The bearing provides the model with rotation ability and the vacuum tightness of the full assembly is ensured by two FKM o-rings. The final assembly is weighted about 3.5kg with a length of 157 mm and a diameter of 90 mm. The rotary joint is designed to be operated with insulating gas filled, such as SF_6.

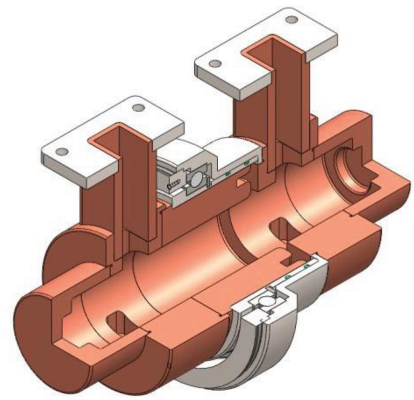

Figure 6: Mechanical design of the rotary joint.

LOW POWER RF MEASUREMENTS

The RF characteristics of the rotary joint have been tested at low power with Vector-Network analyser. Complex scattering parameters have been measured at different rotation angles from 0 degree to 180 degree with the step of 45 degree, as shown in Fig. 7.

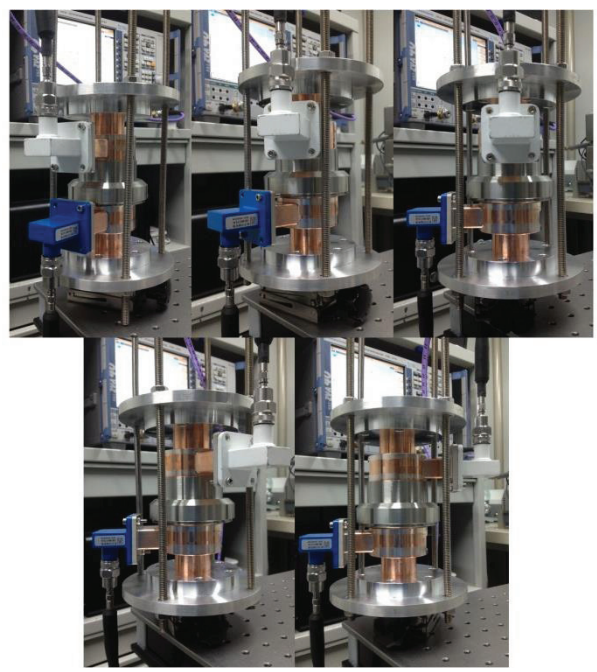

Figure 7: RF measurement setup of the rotary joint.

The results of the return loss, characterized by the amplitude of the S_{11} parameter, are reported in Fig. 9. The measured return loss maintains lower than -30 dB over 15.6-MHz bandwidth and lower than -20 dB over 66.2-MHz bandwidth. And this result agrees well with the simulation results, which are shown in Fig. 8.

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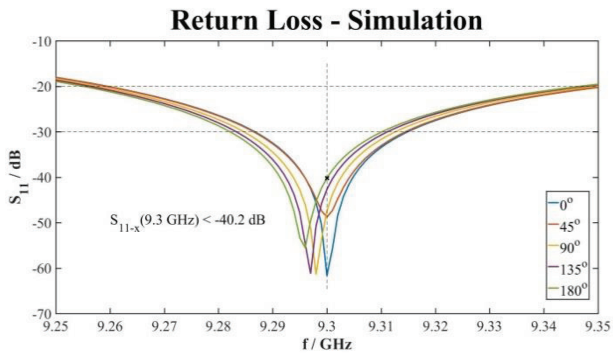

Figure 8: Simulation results of the amplitude of S_{11} parameters for the different rotation angles.

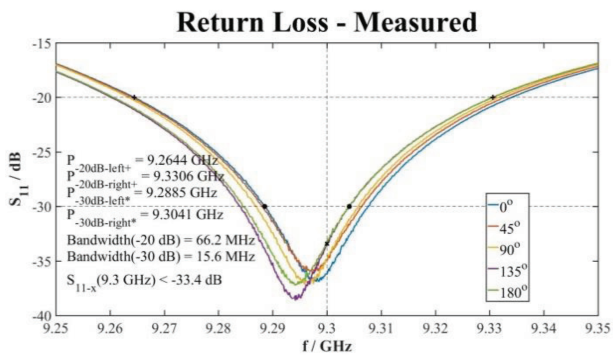

Figure 9: Measured results of the amplitude of S_{11} parameters for the different rotation angles.

The results of the insertion loss, characterized by the amplitude of the S_{21} parameter, are reported in Fig. 10. And it is better than 0.11 dB for all angles.

As for the drift phase, the phase of S_{21} parameter is shown in Fig. 11. The deviation of the phase varies within 1 degree under different rotation angles at the central frequency of 9.3 GHz.

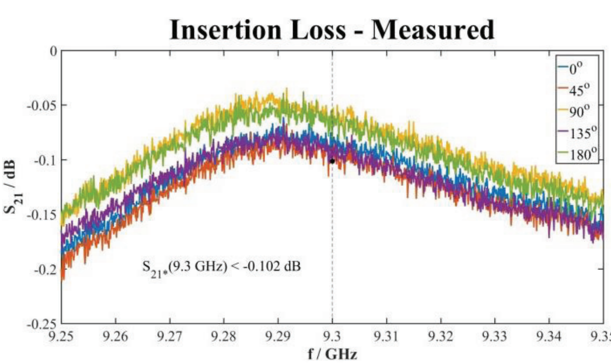

Figure 10: Measured results of the amplitude of S_{21} parameters for the different rotation angles.

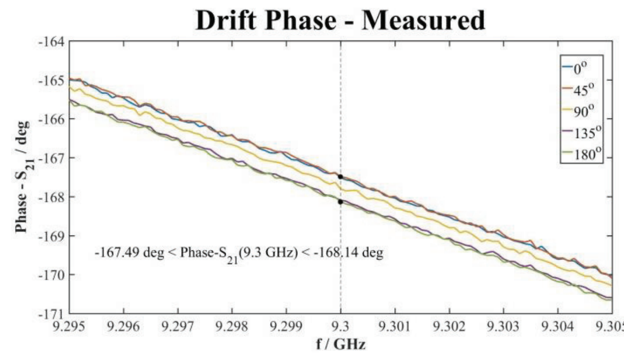

Figure 11: Measured results of the phase of S_{21} parameters for the different rotation angles.

CONCLUSION

A new compact X-band rotary joint has been designed, simulated, manufactured, and RF measured at low power. The RF measured results are in good agreement with the simulations, as shown in Fig. 8-11. It has a low return loss (below -30 dB) and a low insertion loss (better than 0.11 dB). And the deviation of the drift phase varies within 1 degree. High-power test using X-band magnetron is under preparing.

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