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STATUS OF THE POWER COUPLERS FOR THE CSNS DTL*

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Abstract

There are four Drift Tube Linac (DTL) tanks in China Spallation Neutron Source (CSNS) Project. Each DTL tank requires a power coupler with a peak power of 2 MW and a duty cycle of 1.5% for beam operation. After approximately two years machining, all four couplers were already installed in the tunnel before year 2017. Up to now, the first phase of beam tuning has been completed, the maximum transmission power of the coupler exceeds 1.7 MW with a pulse width of 650 μs and a repetition rate of 25 Hz, meanwhile, the vacuum is maintained on the order of 10^{-6} Pa during the operation and no breakdown was observed. This paper describes the architecture, the fabrication, the low power test results and the high power conditioning process of the coupler. Some problems encountered are also presented.

INTRODUCTION

The Accelerator system of China Spallation Neutron Source (CSNS) Project contains a 50 keV H^- Ion Source, a 3 MeV Radio Frequency Quadrupole (RFQ), a 80 MeV Drift Tube Linac (DTL) and a 1.6 GeV Rapid-cycling Synchrotron (RCS) successfully passed the technology acceptance test with a beam power over 10 kW in March 2018. The DTL section is 34.67 m long and is divided into 4 physical tanks. Each DTL tank has a similar design and is equipped with the same size power coupler in the center position. The type of half-height WR2300 ridge waveguide power coupler is chosen for DTL, design parameters of the coupler are shown in Table 1. Preliminary design of the coupler was quite early before 2012, and a cold model was manufactured to determine the dimension of the coupler. Measurement of the cold model was made in 2015, and some dimensions were modified to optimize the coupling coefficient. Finish machining, installation and high power conditioning of the power couplers were executed between December 2015 and March 2017. The coupler has been in operation for most of the time since April 2017.

Table 1: Parameters of the Coupler

Type	Waveguide
Frequency	324 MHz
Peak RF power	2 MW
Average RF power	30.2 kW
Pulse width	650 μs
Repetition rate	25 Hz
Maximum duty factor	1.625%
Coupling coefficient	1.3±0.1

DESIGN AND SIMULATION OF THE COUPLER

Preliminary design of the power coupler draws on the successful experience of America Spallation Neutron Source (SNS) and Korea Proton Engineering Frontier Project (PEFP). It uses a dog-bone shaped coupler iris to connect the tapered ridge waveguide with a constant ridge width and the DTL cavity. The size near the side of the ceramic window is designed to be the size of half-height WR2300 waveguide, the size close to the cavity side is given by optimizing the return loss (s11). To improve the simulation efficiency, a simplified model-a pillbox loaded with two symmetrical dog-bone shaped couplers is used. According to the simulation, the size of the hole diameter is determined to be 25.5 mm [1].

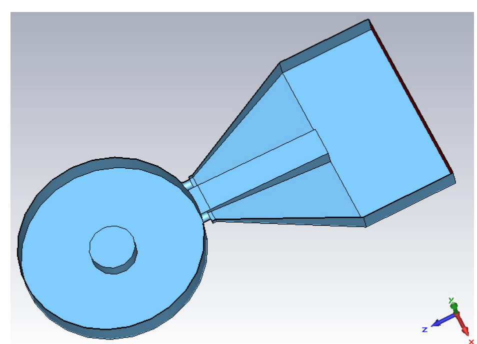

Figure 1: A cutplane of the new simulation model.

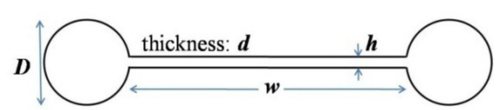

Figure 2a: Geometry of the dog-bone shaped aperture.

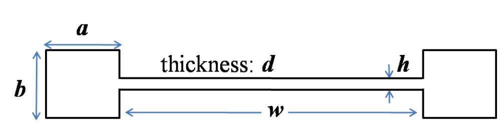

Figure 2b: Geometry of the modified dog-bone shaped aperture.

On the basis of preliminary design, a cold model is manufactured. Measurement of the cold model was taken in August 2015, and the results were far from the simulation. Considering that the dimensions of the hole diameter and ridge waveguide have an impact on matching, a new simulation model closer to the real situation is proposed,

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as shown in Figure 1. First, the simulation results using ensure the applicability, and a scaling factor of 0.8 is used here to correct the difference between the simulation (lossless) and measurement (loss). Secondly, the influence of main parameters on the coupling coefficient is analyzed. Finally, limited by the size of the coupler, the dog-bone shaped iris consist of a narrow slot with two cylindrical holes is modified to a narrow slot with two rectangular holes, as can be seen in Figure 2. Meanwhile, the angle between the two ridges is increased by increasing the distance between the two ridges near the ceramic window. The coupling coefficient of DTL1 is optimized to 1.35 at last, and all four couplers will use this design size [2].

MANUFACTURE OF THE COUPLER

Manufacture of the coupler is very complicated, it needs dozens of process and the accuracy requirements are relatively high. A cold model is required to determine the size of the iris and four formal ridge waveguides are required for operation. There is no need to consider the effect of vacuum in cold model manufacturing, so it eliminates the process of welding, leak detection and ultimate vacuum test. However, iris size of the cold model should be easy to change, so a split design is used. The cold model is made of aluminum, it consists of half waveguide A, half waveguide B and a transition part, as shown in Figure 3. This structure allows us to install and disassemble the transition part easily, thus facilitating the efficiency of measurement.

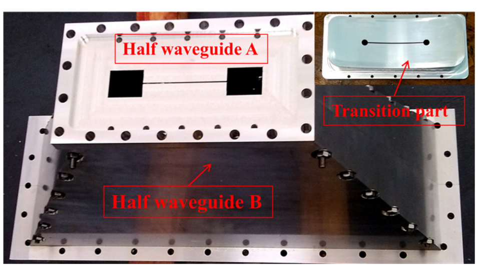

Figure 3: Split design of the cold model.

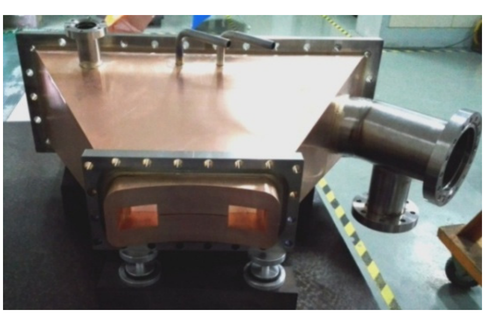
Figure 4: The formal model that has been welded.

The formal model (Figure 4) is mainly made of oxygen-free copper material, considering the high vacuum requirements, every model needs two vacuum brazing processes, one is to weld two copper halves, the other is this model are compared to the measurement results to to weld the copper body with different flanges and cooled pipes, and vacuum leak detection is taken after each brazing process to ensure the welding quality. After all of this, a 5×24 hours vacuum baking is also performed, and the vacuum of the ionic pump port of all four formal models is better than 1e-6 pa.

RF TEST RESULTS

Low power measurement of the cold model is taken as soon as the end of DTL1 field tuning in the tunnel. Detailed results can be found in Ref [2]. Each formal model is also measured on the corresponding DTL cavity in the tunnel. Figure 5 shows the setup of the measurement, it consist of the DTL cavity, the power coupler, the ceramic window, the WR2300 to N transformer and the N5221A Network analyzer. The low power test of the power coupler must be made after each DTL cavity field tuning, because the field distribution will greatly influence the measurement results. Measurement results of the couplers

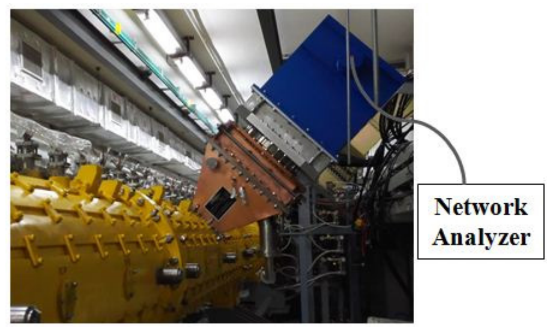

Figure 5: Setup of the measurement.

are listed in Table 2. Results of the DTL1 power coupler are the results of re-measurement after high power conditioning, and the coupling coefficient of the DTL1 coupler is almost the same to the simulation value 1.35. Frequency shift is also observed, the resonant frequency in atmosphere is shifted by 0.00197% after evacuation to vacuum. This value is quite consistent with the humidity-effect nomograph given in Ref [3] with a measurement temperature of 25 ºC and relative humidity of 50% [4]. The measurement results of the other three couplers are the results of non-conditioning.

Table 2: Low Power Test Results of the Couplers

Coupler	Coupling coefficient	Resonant frequency/MHz
DTL1(atmosphere)	1.32	323.99285
DTL1(vacuum)	1.33	323.99932
DTL2	1.33	323.89277
DTL3	1.27	323.88747
DTL4	1.20	323.89248

A direction coupler is placed between the ceramic window and the circulator to measure the positive and reflected power before ceramic window. Thus the coupling

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coefficient can be calculated by the data obtained by it. Table 3 lists the coupling coefficient of each coupler when the beam with a peak current of 5.5 mA, a repetition rate of 25 Hz and a pulse width of 115 μs is accelerated, accordingly, the peak power through the coupler is 1.7 MW and the pulse width of it is 400 μs. These data are samples at a particular monument and the actually coupling coefficients fluctuate over time in a small range depend on the state of the cavity. The resonant frequency of all DTL tanks is 324MHz. Comparing the coupling coefficient in beam range (β_{beam}) and the coupling coefficient in non-beam range ($\beta_{non\text{-}beam}$), shifts are observed due to the beam loading, different shift values may be caused by the system error and different power loss of each cavity. Comparing the low power test results of the coupling coefficient and the operation status of the coupling coefficient, we found that the coupling coefficient of all couplers have different degrees of increase. Reasons can be considered as follows: (1) Measurement error of the direction coupler. (2) The state of DTL cavities has changed. There are two movable tuners for each DTL cavity and the initial insertion depth of them is 50 mm during the low power RF test. However, the insertion depth of all movable tuners is changed during the operation for frequency compensation. This will change the field distribution in DTL cavity and affect the coupling coefficient. In addition, the temperature rise of cavities and drift tubes also have some influence on the coupling coefficient when high power is fed. (3) Non-conditioning of the coupler, ceramic window and DTL cavity. Although the coupling coefficient has some increase, the power transmission efficiency of the coupler at current beam is greater than 97.2%. It fully meets the operational requirements.

Table 3: Coupling Coefficient of the Couplers when Beam is Accelerated

Coupler	β_{beam}	$\beta_{non\text{-}beam}$	$\beta_{non\text{-}beam}$-β_{beam}
DTL1	1.40	1.52	0.12
DTL2	1.33	1.43	0.10
DTL3	1.36	1.46	0.10
DTL4	1.24	1.32	0.08

HIGH POWER CONDITIONING AND OPERATION

High power conditioning of the coupler and ceramic window are together with the conditioning of DTL cavity due to the progress of CSNS. Figure 6 shows the power transmitted by the coupler, the vacuum of the coupler and the vacuum of the DTL2 cavity as a function of time. At first, the input power with a max duty factor was less than 15 kW and was almost fully reflected due to the non-conditioning of the ceramic window and power coupler. At the same time, vacuum of the coupler fluctuated significantly. 15-20 hours later, most of the input power was fed into DTL cavity and we gradually increased the power level to 1MW. In this stage, violent outgassing occurred in both the cavity and the coupler and window, but the outgassing of the coupler and window was more frequent. After the power exceeded 1 MW, the main outgassing position was transferred from coupler to DTL2 cavity. But due to the short time of power conditioning, obvious degassing in the coupler and window could still be seen during each power increase. After more than one year of operation, the coupler can work stable with little degassing, as shown in Figure 7. The conditioning process of the other three couplers is similar to that of DTL2 coupler, and all four couplers are conditioned to the max power of 1.7 MW with a pulse width of 650 μs and a repetition rate of 25 Hz. In addition, the vacuum of the coupler is better than that of DTL cavity for most of the time during the operation.

Figure 6: High power conditioning process.

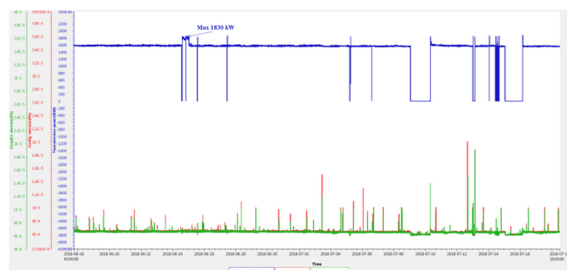

Figure 7: Operation status.

CONCLUSION

The whole process of design, manufacture, low power RF test and high power conditioning of the power couplers for the CSNS DTL is described in this paper. All four couplers have entirely gone through the RF conditioning and beam commissioning process with no breakdown. Now, they are operating steadily with a pulse width of 400 μs and a repetition rate of 25 Hz when a beam with pulse width of 115μs and repetition rate of 25 Hz is accelerated. As the current beam power is relatively low, more observation would be taken on the couplers with the increase of beam power.

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