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DEVELOPMENT OF A 1.5GHz HIGH-POWER CW MAGNETRON FOR SRF ACCELERATOR

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Abstract

An 1.5 GHz, 13.5 KW CW high-power magnetron for a superconducting RF accelerator has been developed by Andesun Technology Group Co., Ltd. with Nanjing Sanle Electronic Information Industry Group Co., Ltd., in order to replace the klystron, that could reduce the power source cost to about one-third. The cavity, output power antenna and coupling door-nob have been optimized by using CST Studio. Testing results have shown that the resonance frequency and output power have met the requirements, and the efficiency of the magnetron is higher that 78.45%.

INTRODUCTION

At present, the microwave energy of the RF superconducting accelerator is mainly provided by the klystron internationally. However, the klystron as a microwave source is characterized by low efficiency and high cost, which increases operating costs of the entire accelerator system. So the magnetron with a cost of one-third of the klystron is the best choice for the replacement of the original SRF accelerator microwave source. In order to meet the urgent need of microwave sources for SRF accelerator, a 1.5 GHz、13.5 kW CW magnetron for SRF accelerator is researched and developed by Andesun Technology Group Co., Ltd. with Nanjing Sanle Electronic Information Industry Group Co., Ltd.

The development of this magnetron is based on the 2450 MHz magnetron. First, the frequency of magnetron is reduced from 2450 MHz to 1500 MHz by increasing the radius of the cavity and so on. The CST Studio is used to optimize the coupling output part of the magnetron and gets the best parameter of the coupled antenna [1]. The electronic simulation of the magnetron is completed by the Particle-in-cell solver, which gains a general understanding of the performance of the magnetron [2]. The prototype measurement shows that the output power of the magnetron reached the requirement, the whole tube efficiency is 78.45%, and the tuning range is 10 MHz.

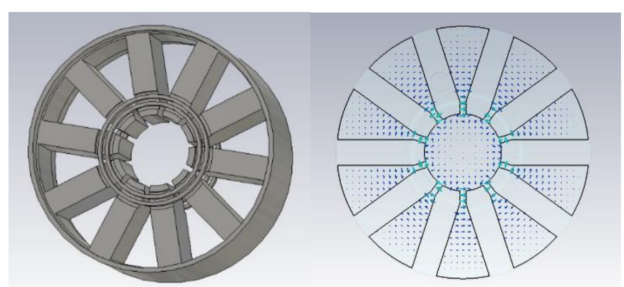
DESIGN OF THE MAGNETRON

According to the working parameters of the SRF accelerator, the performance parameters of this magnetron are as follows:

(1) Working frequency: 1.5 GHz
(2) Average output power: 13.5 kW
(3) Peak power: 17 kW
(4) Efficiency: ≥70%
(5) VSWR: ＜1.4
(6) Way of working: CW

Cavity Design

The anode cavity of the magnetron adopts a fan-slot type co-cavity resonance system with a diaphragm belt. A total of 10 cavities were used and the blade-to-slot ratio is 3.01. Figure 1 shows the simulation model and the electric field distribution of the π mode which is the magnetron operating mode. Cavity simulation with strips gains that the mode separation is 84.6%.



(a) (b)

Figure 1: (a) The simulation model. (b) The electric field distribution of the π mode.

Output Structure Design

The magnetron uses an axial energy extraction device. The design of the excitation cavity is based on the WR-650 standard waveguide. The semi-cylindrical short-circuit surface is used, and the output part of the antenna is designed as a bullet type. The parameters of the bullet antenna are decided by simulation with the excitation cavity. The simulation result shows that the S_{11} curve is lower than -70 dB at 1.5 GHz and lower than -40 dB within 20 MHz bandwidth. Figure 2 shows the simulation curve of S_{11}. Figures 3 shows the finished excitation chamber and output coupling antenna.

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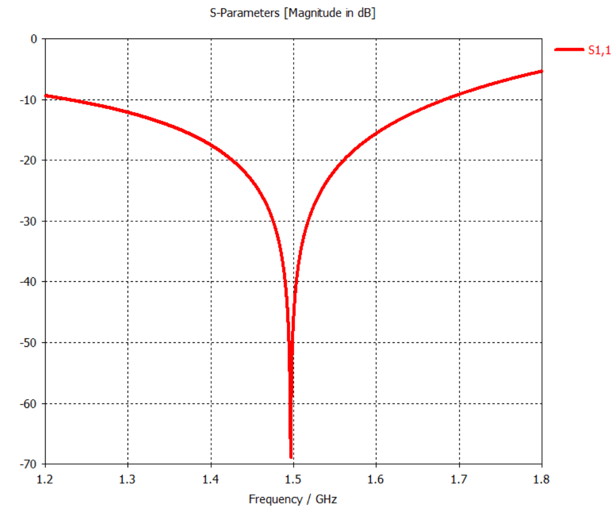

Figure 2: S_{11} of output structure.

(a) (b)

Figure 3: (a)The finished excitation chamber. (b)The finished output coupling antenna.

Whole Magnetron Simulation

After completing the design of each size of the magnetron, the magnetron is thermally simulated by Particle-in-cell solver. When we apply a voltage of 12,100 V and magnetic field of 2100 Gs, the simulation achieves optimal output performance. Figure 4 is a distribution image of electrons, which can clearly see the five electron spokes in the interaction space of magnetron. Figure 5 shows the output signal of the magnetron. The output power is obtained from the Fig. 5 according to the formula $\mathrm{P} = {280^2}/_{2}339200$ W [3]. Through the Fourier transform of the output signal, we get the output frequency of 1.527 GHz, and we can accept the difference of 30 MHz within the error range of the simulation.

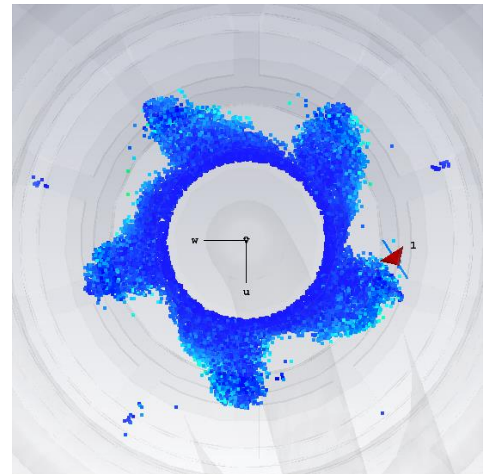

Figure 4: The electron distribution in the interaction space.

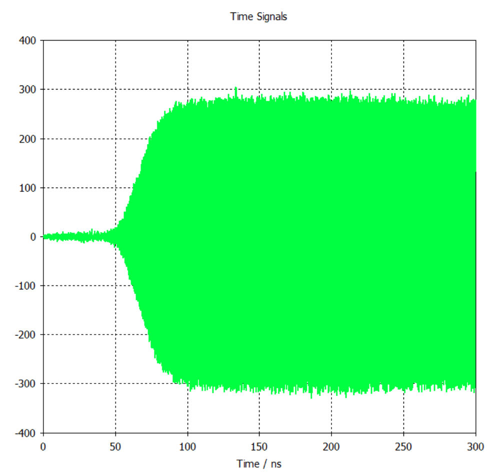

Figure 5: The output signal of the magnetron.

TESTING SYSTEM

The finished magnetron is shown in Fig. 6. The permanent magnet is used to generate an applied magnetic field, and the cavity is cooled by water.

(a) (b)

Figure 6: (a)The finished cavity. (b)The protype of 1.5 GHz CW magnetron.

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The schematic diagram of the power test of the magnetron is shown in the Fig. 7. The black frame circle represents the main test system, and the orange and yellow colors represent the power test section and the water cooling system, respectively. The microwave generator controls the voltage and current applied to the magnetron, then the microwave energy generated by the magnetron is coupled into the excitation chamber, and the output energy from the magnetron and the reflected energy of testing system are measured through the coupler. After passing through a three-port circulator, the power is eventually absorbed by the water load. The isolation of the three-port circulator is 20 dB. The actual test platform is completed as shown in Fig. 8.

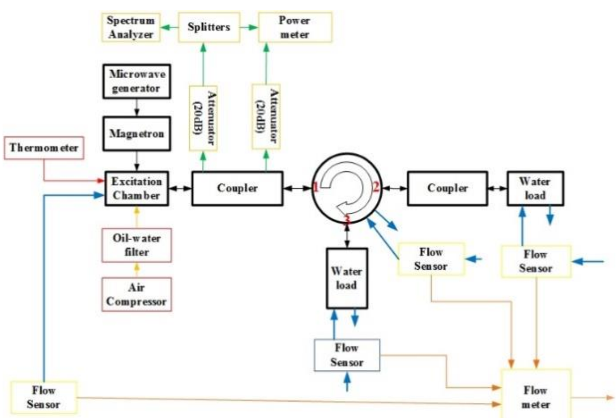

Figure 7: The schematic diagram of the power test of the magnetron.

Figure 8: The test platform of magnetron.

TESTING RESULT

After preheating the cathode for 30s under the voltage and current of 3.5 V, 28 A, the voltage and current of cathode are gradually reduced to 0.2 V, 6 A to keep the magnetron working normally, and the working power of cathode is 1.2W. Figure 9 shows the curves that the applied anode voltage and current as the function of time. The final test results are shown in the Fig. 10. When the magnetron is operated at 1.49779 GHz, the output power reaches 14.23 kW, which exceeds the expected power of 13.5 kW, and the voltage applied at this time is 10,670 V, the magnetic field is 2100 Gs. The overall working efficiency exceeds 78.45%.

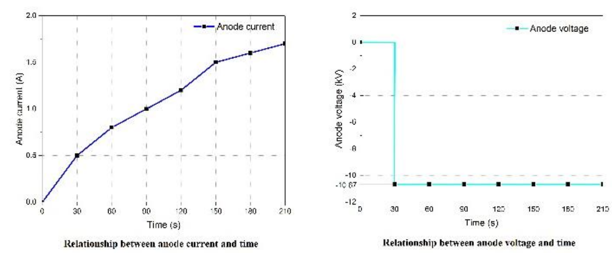

Figure 9: Curves of applied anode voltage and current as the function of time.

Figure 10: Testing results of 1.5 GHz CW magnetron.

CONCLUSIONS

A 1.5GHz high-power CW magnetron for SRF accelerator is successfully developed by Andesun Technology Group Co., Ltd. with Nanjing Sanle Electronic Information Industry Group Co., Ltd. The test results show that the 1.5GHz magnetron meets the design requirements and can meet the application requirements of SRF accelerator.

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