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C-BAND RF SYSTEM FOR THE SAPS TEST BENCH

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Abstract

This work describes a C-band RF system for the SAPS (Southern Advanced Photon Source of China) test bench linear accelerator. SAPS' RF testing system comprises of a photocathode electron gun and a 2-metre-long equal gradient acceleration device. The klystron power source delivers energy to the photocathode electron gun and the travelling wave acceleration structure, respectively. Test the photocathode electron gun first, followed by the travelling wave acceleration structure. We investigated a short-pulse C-band spherical pulse compressor. The photocathode electron gun's preliminary high-power testing is now complete.

INTRODUCTION

To improve the beam quality of photocathode microwave electron guns, increase the gradient inside the electron gun to lower heat and space charge emissivity. The photocathode electron gun cavity is designed to achieve an acceleration gradient of 150 MV/m.A 2-meter-long travelling wave acceleration structure is put at the back end of the photocathode electron gun to increase the energy and stabilise the emissivity of the electron beam emitted by the gun.

The RF system's function is to deliver enough power to the electron gun cavity to achieve a gradient of 150 MV/m, as well as RF power to the travelling wave acceleration structure to ensure that its gradient satisfies the design criteria. Figure 1 shows the layout design for the electron gun and accelerator tube.

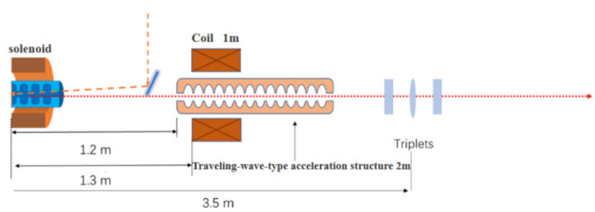

Figure 1: Layout of electron gun and accelerator tube.

RF SYSTEM

The components of the C-band RF system include a circulator, directional couplers, rectangular waveguides, a spherical pulse compressor, and more. Figure 2 display the C-band RF power source system's composition diagram. The klystron, circulator, and pulse compressor which are positioned in the system as seen in Fig. 3 are the most important parts of the RF power system.

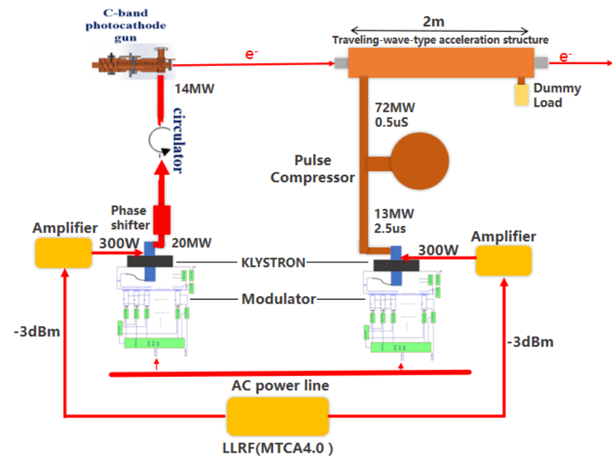

Figure 2: Composition of C-band RF power source.

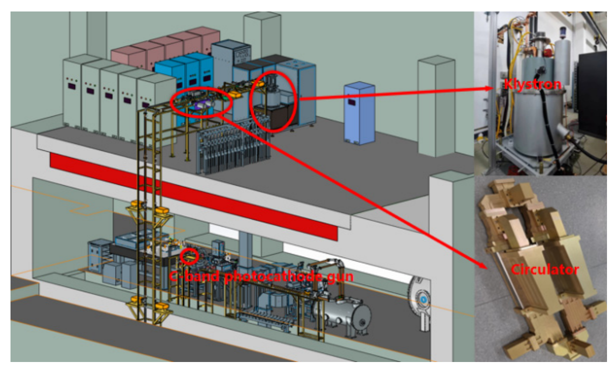

Figure 3: RF system schematic diagram.

Klystron

The traveling wave acceleration structure and the photocathode electron gun in the SAPS experimental device will each require one klystron with a 20 MW output power. High throughput electron optical system, highly dependable microwave output system, and high-efficiency beam wave interaction system are all features of C-band klystron. The klystron mainly comprises an electron optics system, a beam-wave interaction section, and a collector [1]. The designed klystron, with a working frequency of 5712 MHz, peak power of 50 MW, repetition rate of 50 Hz, and pulse width of 2.5 μs, satisfies the performance criteria of high gradient acceleration devices. Operational stability was taken into account when testing the klystron, and an RF pulse width of 1.2 μs was employed.

When the klystron was tested with an RF pulse width of 1.2 μs and a repetition rate of 5 Hz, the output power reached 45 MW. Figure 4 shows the power display.

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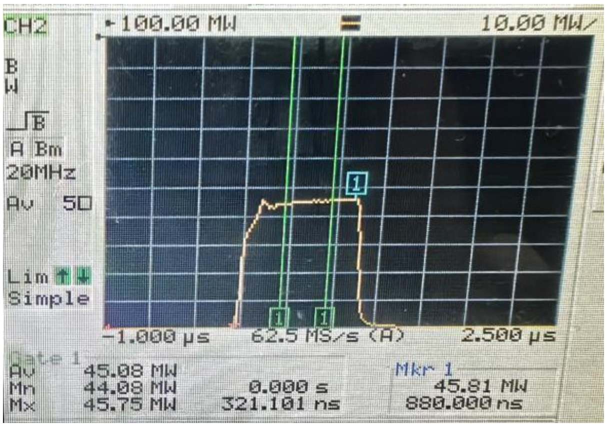

Figure 4: Klystron 45 MW power display.

Circulator

Before the field is established, there will be a substantial amount of reflection since the electron gun's microwave structure is a standing wave field. A ciculator is positioned between the cavity and the klystron to lessen the maximum reflection between the structure and the klystron, protecting the important component klystron. The magic T, phase-shifting section, and 3 dB bridge are the three main components that make up the circulator, which is essentially a four port device. Magic T primarily divides input signals into equal amplitude power divisions (3dB power divisions),which lowers the power entering the circulator and lowers the likelihood that the circulator would strike an arc. Two sets of differential phase shift make up the phase shifting portion, and they combine to provide a fixed 90-degree phase difference. Two sets of differential phase shifters make up the phase shifting section, and between the two differential phase shifts, a fixed 90 degree phase difference is generated. The synthesis and breakdown functions of microwave signals are primarily realized by the 3 dB bridge. Figure 5 displays the diagram illustrating the functioning concept.

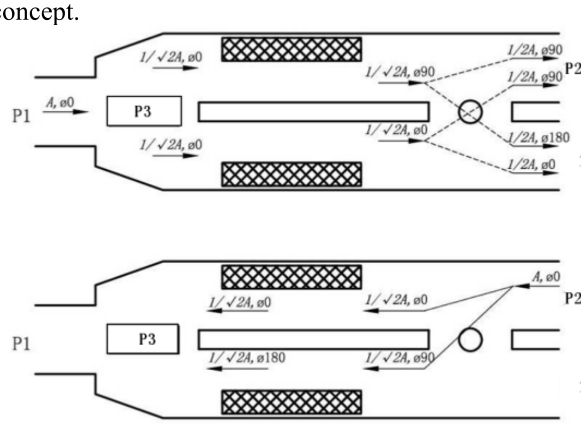

Figure 5: Working principle diagram of the circulator.

Test results of the differential phase-shifting ciculator are shown in Fig. 6. Test results of the ciculator when input from port 1: Voltage standing wave ratio (VSWR) of Port 1: 1.05, VSWR of Port 2:1.04. Insertion loss S21 of port 1→2: -0.12 dB. Isolation of Port 2→1 S12: -34.7 dB. Working bandwidth: ± 50 MHz.

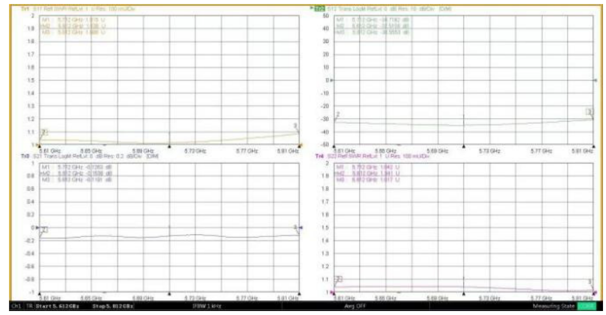

Figure 6: Circulator test results.

Pulse Compressor

SAPS was designed with a spherical pulse compressor. The wide pulse width and low power output of the klystron will be passed through the spherical pulse compressor to produce a narrow pulse width and high power RF wave. This RF wave will be fed into the traveling wave acceleration structure [2]. Using the theory, designed a spherical pulse compressor. Table 1 shows the technical parameters of the traveling wave acceleration structure, which were taken into account during the design process. When the traveling wave acceleration structure runs at a gradient of 40 MV/m, it requires 64 MW of input power. The pulse compressor's charge time is 2 μs, indicating a phase reversal. Reversed 0.5 μs is utilized to fill the acceleration tube with energy.

Table 1: Traveling Wave Acceleration Structure Design Parameters

Parameter	Value	UNIT
Frequency	5712	MHz
Mode	2Pi/3	
Length	2	m
Q0	10371	
tF	372	ns
τ	0.645	
Gradient	40	MV/m
Power	64	MW

Determine the greatest energy multiplication factor that may be attained using the relationship between the pulse compressor's coupling factor βand the energy multiplication factor M. When β=3.5, M reaches the maximum of 1.74. To reach a power output of 64 MW, a 10% transmission loss must be included, and the pulse compressor must produce at least 72 MW. So, when the output power of the klystron is 20 MW, the power gain of the pulse compressor reaches at least 3.6. Select TE112 as the pulse compressor's working mode.

Substitute the input signal into the partial differential equation, as stated in Eq. (1) and Eq. (2). Simulate the output waveform of a spherical pulse compressor in this operating condition, and following phase reversal, the energy multiplier's output power achieves its maximum, with a peak power gain of around 5.6 times, as illustrated in Fig. 7.

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$$E_k = \begin{cases} 1 & 0 \le t < t_1 \\ -1 & t_1 \le t < t_2. \\ 0 & t > t_2 \end{cases} \quad (1)$$

$$Tc\frac{dE_e}{dt} + E_e = -\alpha E_k. \quad (2)$$

There, E_k is the pulse compresor input signal, T_C is the cavity filling time, E_e is the cavity radiation field, and $\alpha = (2\beta)/(1+\beta)$,$\beta$ is the cavity coupling factor.

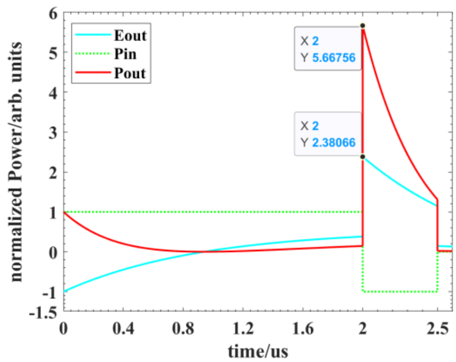

Figure 7: Output waveform of spherical pulse compressor.

The RF design for the C-band Spherical Pulse Compressor was created using 3D electromagnetic simulation software. The simulation results are given in Fig. 8.The operating mode's resonant frequency is 5711.9 MHz, and the coupling condition is overcoupled (coupling factor = 4).

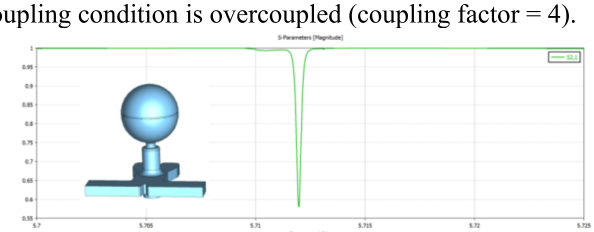

Figure 8: Simulation results of pulse compressor.

HIGH POWER TESTING

Because the test bench only has one RF power source, we can only test the photocathode electron gun first, followed by the traveling wave acceleration structure. Currently, the high-power preliminary test of the photocathode electron gun has completed. Under the parameters of high voltage pulse width of 3 µs, repetition rate of 5 Hz, and voltage of 335 kV in the klystron's cathode modulator, the output power of the klystron is 18 MW, and the RF power input into the electron gun is 14 MW. The power and waveform displays are displayed in Fig. 9.

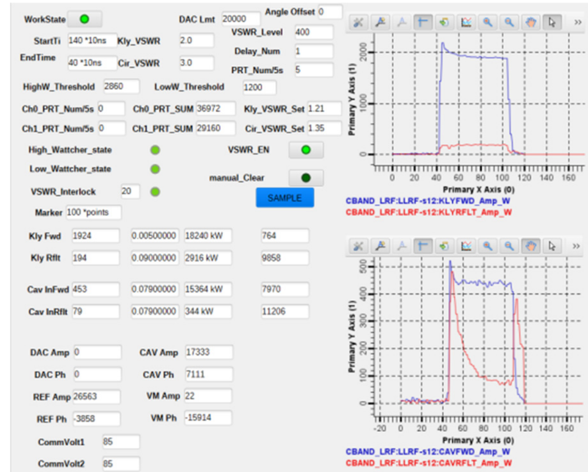

Figure 9: Power display and waveform display.

The photocathode electron gun is prone to arcing at high power, as illustrated in Fig. 10. When the breakdowns occurs, it also removes the amplitude signal transmitted by the pick up. The photocathode electron gun's amplitude signal is represented by the red curve, the phase signal by the green curve, and the vacuum by the blue curve. It can be seen that the vacuum change inside the photocathode electron gun corresponds to the pickup signal change. The input power is 14 MW, the gradient is 150 MV/m, and the acceleration gradient of the photocathode electron gun fulfills design specifications.

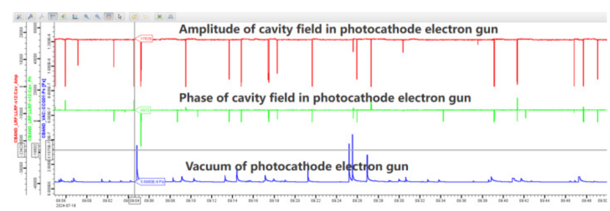

Figure 10: Test curve of photocathode electron gun.

CONCLUSION

Preliminary testing for the C-band RF system yielded some critical data and findings. The klystron's output power meets system requirements, and there is no breakdown in the circulator at 18 MW of RF power. The photocathode electron gun has met its operating aim, but at this power, there is more arcing, therefore the next step is to proceed with the aging test.

REFERENCES

[1] Y. Yu, Y. Jinghe, *et al.*,"Physical Design of High Power Klystron for C-band Industrial Linear Accelerator", *Atomic Energy Science and Technology* , vol. 57, issue z1, pp. 289-296, 2023.

[2] W. Fang *et al.*, "RF System for SXFEL: C-band, X-band and S-band", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 4446-4448. doi:10.18429/JACoW-IPAC2018-THPMK064