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RF Power Test and Conditioning of the New Accelerating Structures for the BEPC Ⅱ-Linac *

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Abstract The Beijing Electron Positron Collider Upgrade Project (BEPC Ⅱ) requires its injector linac to upgrade the beam energy and current. Thus the accelerating structures in the positron production region must be newly designed and constructed to meet the high gradient demand. These new structures must be tested and conditioned with the high RF power before their installation into the linac tunnel. This paper describes the design and construction of the high power RF test stand, the tuning of the RF power source, the progress and the final results of the RF test and conditioning.

Key words accelerating structure, high RF power, test, conditioning

1 Introduction

The Beijing Electron Positron Collider Upgrade Project (BEPC Ⅱ) requires its injector linac to increase the beam energy from 1.30GeV—1.55GeV to 1.89 GeV, and to increase the positron beam current from 3mA to 37mA, that is about 10 times higher[1]. Thus the accelerating structures in the positron production region must be newly designed and constructed to meet the high gradient demand, and to endure higher RF power and eliminate hidden trouble in the existing structures due to the past long-term operation. For example, in order to increase positron yield, the bombarding electron beam energy on the positron target is increased from 150MeV to 250MeV by upgrading the klystron output power from 30MW to 50MW and accelerator gradient from the current 10MeV/m to 20MeV/m. In addition, to obtain the high positron capture efficiency, the 3 accelerating structures (3.05m long each, at working frequency of 2856MHz) just downstream the target must be surrounded by solenoid with high focusing magnetic field of 0.5 Tesla. As a result, these accelerating structures' exterior size (including the input and output couplers) must be redesigned and the input and output cooling water contactors moved from the mid-structure to one end of each structure. At the same time, according to our experience on the structure's tuning, the inside cavities' size (2b) in the original design leaves a too big tolerance. In order to save the tuning workload and improve the structure performance after tuning, we use SUPERFISH[2]—— code to reduce the 2b tolerance by 10—15μm but keep all dimensions of the structure constant. It makes the structure more uniform after tuning and thus helps to increase the accelerating gradient. These new structures must be tested and conditioned with the high RF power before their installation into the linac tunnel. This paper describes the design and construction of the high RF power test stand, the tuning of the RF power source (klystron), the progress and the final results of the RF test and conditioning.

2 The design and constuction of the test stand

A layout of the high power test stand is shown in Fig.1 (side view) and Fig.2 (top view). It includes the vacuum system, the constant temperature cooling water system, the power supply system with the input and output waveguide and the RF transmission system. The power supply is a domestic 30 MW HK-01 type klystron with its new barium tungsten

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cathode made in USA and the highest output peak power is 32.4 MW. To protect the accelerating structure, the klystron output window and the waveguide system from sparking, a high vacuum degree of above 1.33×10^{-5} Pa is needed when its peak power is over 10MW. Therefore the test stand has 3 ion pumps (deflation rate 70l/s), installed at the klystron output, the accelerating structure input and dry load at the end of the structure, respectively. The accelerating structure is cooled down by water at the constant temperature of 45.2℃. To guarantee the work environment safety, the testing structure is placed in a small chamber that has enough wall thickness for radiation protection. Two sets of radiation dose meters are locateda 1m away from the klystron and 1m away from the testing structure, respectively. The surplus RF power is absorbed by dry load at the end of the structure.

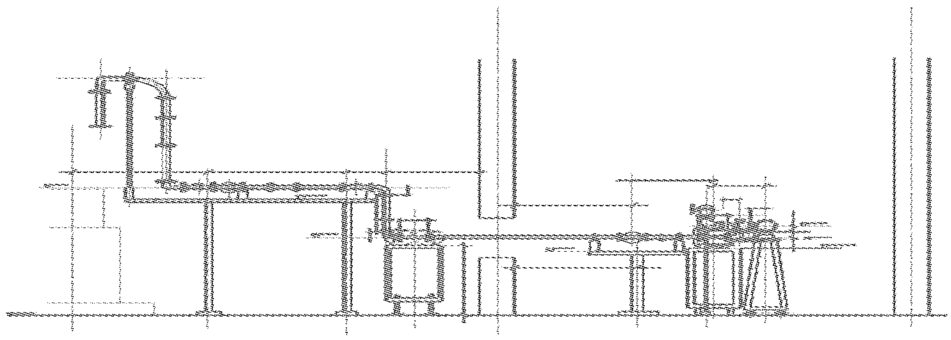

Fig.1. Side view of the test stand.

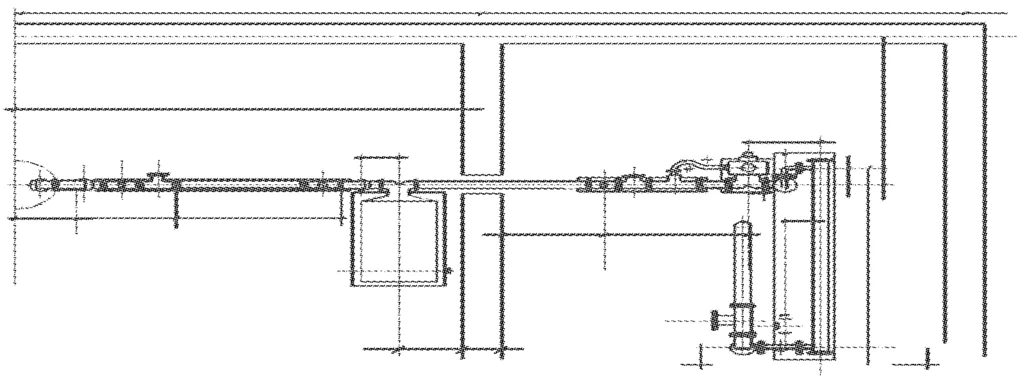

Fig.2. Top view of the test stand.

3 High power test result

3.1 Conditioning power measurement

Since it is a new test stand, it must have the arcing gas from the new waveguide at the beginning of the conditioning. Taking the first accelerating structure conditioning as an example, the relation between the conditioning test power and the modulator voltage is shown in Table 1. The klystron output RF power is measured by water load and checked with measuring the RF power absorbed by dry load at the end of the structure.

Table 1. The relation between the conditioning test power and the modulator voltage variety.

modulator voltage/kV		140	168	196	224	252
KLY. output power /MW	dry load absorption	2.0	6	12	19	26.6
	water load absorption	2.5	7.2	13.9	21.5	27.8

3.2 Radiation dosage measurement

At the condition of modulator voltage V_{DC} = 238kV and the klystron peak output power P_{out} = 26MW, the radiation dose measurements at the different locations away from the accelerating structure are shown in Table 2. The lead brick is placed at the end of the structure and a lead screen is placed at klystron 1m away for radiation shielding.

Table 2. The radiation dose rate around klystron and structure.

	around klystron (μSV/h)	around structure/(μSV/h)			
		outside 1m	away the end 1m	away the end 2m	away the end 3m
no lead brick	10.25	20	150	90	1.50
lead brick	1.60	6.5	20	10	1.3

The measured radiation dose rate around klystron is much less than that around the testing structure. From Table 2, one can see that the radiation dosage primarily comes from the testing accelerating structure. It is seriously increased with the RF power without lead brick shielding around the structure end. Therefore the lead brick is absolutely needed in the RF testing and conditioning.

3.3 Establishment and studying on the klystron stability

In the testing process, the self-oscillation phenomenon happened in the klystron operation at some modulator voltages and seriously affected the RF testing and conditioning. The self-oscillation made the klystron output power and wave form unsteady, as shown in Fig.3 and Fig.4 at the modulator voltage 160kV and the klystron output power 0.8MW and 1.6MW, respectively. CH1 means forward waveform line at the klystron exit inside the diagrams.

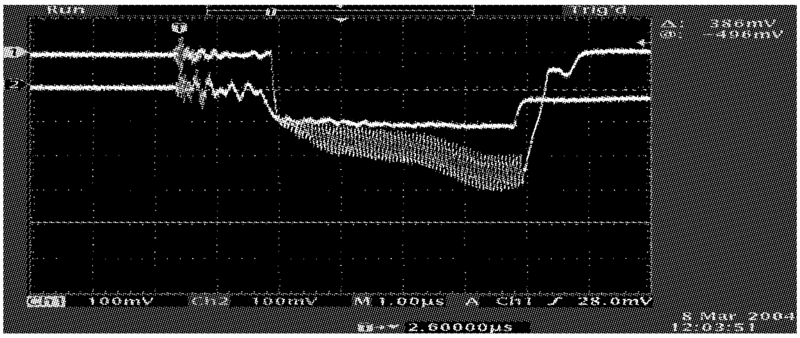

Fig.3. Self-oscillation waveform at modulator voltage 160kV and klystron output 0.8MW.

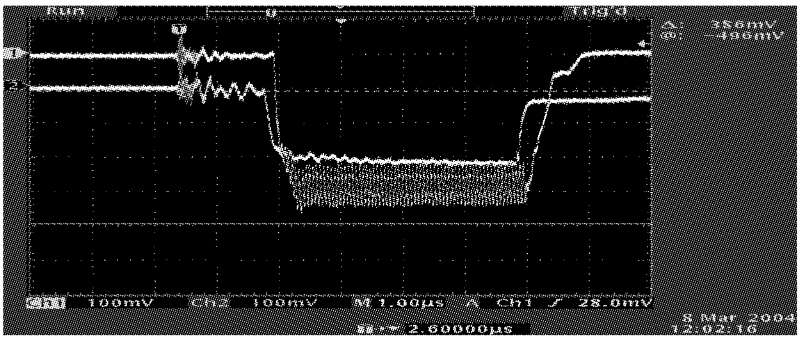

Fig.4. Self-oscillation waveform at modulator voltage 160kV and klystron output 1.6MW.

After careful research with the klystron self-oscillation phenomenon, the self-oscillation's central frequency was measured to be 2871MHz by the spectrometer, which is very close to the resonance frequency of the third cavity (2870MHz) of the klystron. Therefore, it was necessary to adjust the focusing coil magnetic field around the third cavity to eliminate the self-oscillation phenomenon. The focusing coil current values before and after adjustment are shown in Table 3.

Table 3. The klystron focusing magnet currents before and after adjustment.

		1	2	**3**	4	5	6
before adjustment	voltage /V	5.9	29.3	**63**	65	59.6	8.1
	current /A	5.1	4.2	**8.9**	8.9	8.9	2.1
after adjustment	voltage /V	5.4	28.3	**38**	56.5	48.4	8.3
	current /A	5.4	4.2	**5.6**	8.09	7.8	2.7

The third group in Table 3 shows that the voltage and current have great changes from 63V to 38V and from 8.9A to 5.6A, respectively, for the focusing coil surrounding the third resonance cavity. The self-oscillation phenomenon is greatly weakened after adjusting the third group focusing coil. Fig.5 shows the waveform without self-oscillation phenomenon at modulator voltage 160kV and klystron output power 1.6MW. CH1 means the forward wave form at the klystron exit.

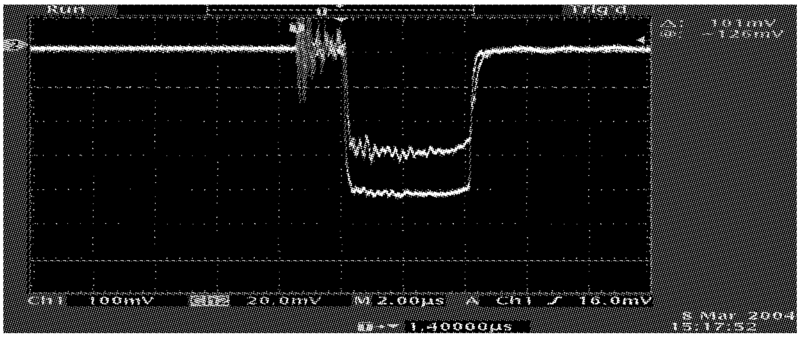

Fig.5. The normal wave form without self-oscillation at modulator voltage 160kV. and klystron output 1.6MW.

By eliminating the self-oscillation phenomenon, one can avoid the RF breakdown and protect the waveguide system from arcing gas frequently, and thus can steadily let the klystron output power completely into the testing structure leading a great improvement of the conditioning efficiency.

4 Conclusions

At the beginning of the conditioning, the waveguide system was conditioned first. In this period the serious arcing gas and RF breakdown were frequently appeared. The vacuum was controlled under 1.33×10^{-5}Pa to protect the klystron output window when the output power was over 10MW. The vacuum protection threshold was 1×10^{-4}Pa when the output power was fairly low to improve the conditioning efficiency.

The test and conditioning for each new accelerating structure need about 10 days including 72 hours for that klystron output power over 20MW and the structure's dynamic vacuum is steadily under 2×10^{-6}Pa. The four structures were completely well conditioned with high RF power. The test and conditioning of the forth structure used the ED (Energy Doublers) which upgraded the peak power by a factor of 5. The acceleration gradient was about 25MV/m until the vacuum degree improved to about 2×10^{-6} Pa at the end of conditioning. These new accelerating structures are being installed in the linac tunnel this summer.

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BEPCⅡ直线注入器新加速管的高功率测试和老练*

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摘要　BEPCⅡ(北京正负电子对撞机重大改进工程)要求其直线注入器提供更高的能量和流强,为此必须改进正电子产生靶前后的加速管,以提高加速梯度,并消除原有加速管因长期运行后性能有所下降的隐患.本文叙述了新加速管的高功率测试,包括测试装置的设计、建立,微波功率源(速调管)的调试和加速管高功率测试结果及其分析.

关键词　加速管　高功率　测试　老练

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