HIGH POWER TEST OF A C-BAND 6 MeV STANDING-WAVE LINEAR ACCELERATOR*

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Abstract

A C-band 6MeV standing-wave bi-periodic on-axis coupled linear accelerator has been developed at the accelerator laboratory of Tsinghua University [1,2]. In the recent high power RF test, the capture ratio, the energy spectrum, the spot size and the dose rate of this accelerator have been measured. With a 2.07-MW input power, the peak current is 130mA and the output spot root-mean-square diameter is about 0.8mm. The output kinetic energy is 6.0MeV with a spectrum FWHM of 7.5%. In this paper, the setup and detailed results of the high power RF test are presented.

INTRODUTION

Compact structure is one of the development trends of accelerators for medical and industrial applications. During the last two years, the accelerator laboratory of Tsinghua University has developed a compact C-band standing-wave linear accelerator. The bi-periodic on-axis coupled accelerating structure, is operated on π/2 mode at 5712MHz. The design goal is to achieve 100mA peak pulse current with kinetic energy of ~6.2MeV (total beam current ~130mA), under 2.2WM input RF power. Besides, the length of the accelerating structure is restricted to be less than 300mm.

This accelerator numbered 1# was designed, fabricated and cold tested in our laboratory. The results of cold RF test show a good agreement with the simulation. Recently, high power RF test has been carried out to measure properties of the accelerator, including capture ratio, energy spectrum, output beam spot size and dose rate.

In the high power RF test, we've found that the maximum input power for the accelerating structure could only reach 2.07MW due to the instability of the magnetron. Performance of our accelerator is slightly affected consequently. For this reason, we have modified the original design by adding another cell for accelerating. A structure numbered 2# with this new design has been fabricated and is ready for subsequent tests.

ACCELERATOR REVIEW

In the design process, we used SUPERFISH and PARMELA for 2D cavity geometry optimization and beam dynamics study, respectively. A MATLAB code was also applied to speed up the whole process. We finished full 3D design by CST Microwave Studio to determine the coupling between the cells and the coupler.

The optimized accelerating structure 1# consists of three different bunching cells and nine normal cells. The detailed parameters of the accelerating structure are shown in Table 1.

Table 1: Parameters of Accelerating Structure 1#

Parameter	Value
Operating frequency	5712MHz
Length	288mm
Accelerating gradient#	27MV/m
Efficient shunt impedance*	117MΩ/m
Quality factor*	10500
Inter coupling factor*	2.4%
Coupling, β	1.7

#Values for 2.2MW input power
*Values for normal cell in cold test

The structure is equipped with a 60mm.mrad-emittance thermal-cathode gun. To measure beam properties, the output end is sealed with a 50μm-thick titanium window instead of a heavy-metal bulk target. The accelerating structure is cooled by water jacket.

HIGH POWER TEST SETUP

A C-band magnetron, followed by a four-port circulator, provides input power for the accelerating structure. Two directional couplers are installed between the circulator and the accelerator to monitor the incident and reflected power.

Before the test, a high power water load was used for input power calibration. It was found that the maximum stable input power can only reach 2.07MW. Frequent breakdowns of the magnetron occurred when the input power to the accelerating structure was pushed higher than 2.07MW. Therefore, the maximum input power was kept to be 2.07MW instead of original design value 2.2MW to protect our magnetron.

A Faraday cup with integral circuit was used for the capture ratio measurement. The Faraday cup signals saved by oscilloscope were filtered to eliminate noise from the imperfect ground.

To measure the output energy spectrum, a magnetic analyzer was connected to the accelerating structure. By scanning magnetic field strength, electron with different energy can pass through side-way of the magnetic analyzer sequentially and hit a fluorescent screen. The

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energy spectrum can then be calculated by the relative brightness of the screen. In the test, we also installed a 38mm long, 0.2mm wide slit at the entrance of the analyzer to limit the beam size. The energy resolution can be promoted to less than 1%[3,4].

The spot size of the output beam can be measured by the optical transition radiation emitted at the boundary of vacuum and the titanium window of the accelerator. Light from the titanium window was reflected by a mirror which was placed at 45^0 to the beam line. A CCD camera equipped with a focusing lens was applied to capture the image. The resolution of the CCD camera was about 50μm/pixel. As the brightness of optical transition radiation is proportional to the number of incident particles, the root-mean-square diameter of the beam can be easily calculated from the brightness distribution of the image.

The high power RF test area is shown in Fig. 1 (only include the devices for measurement of energy spectrum).

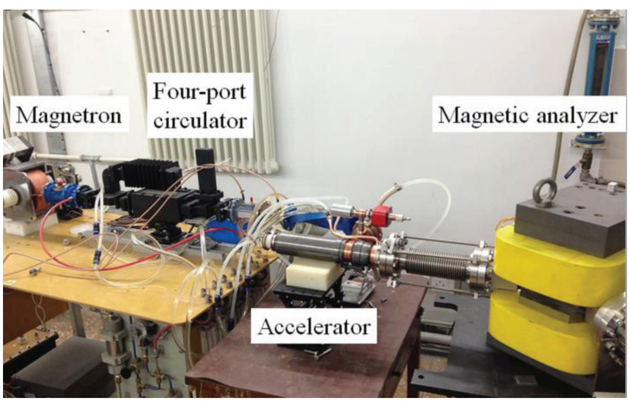

Figure 1: High power RF test area.

HIGH POWER TEST RESULTS

In high power RF test, the operating SWR, the capture ratio, the energy spectrum, the output beam spot size and the dose rate were measured.

Operating SWR

Two matched Agilent 423B low-barrier schottky diode detectors, together with two low-loss cables were applied to detect the incident and reflected wave from the directional couplers. After careful calibration, the detected signals could be used to calculate the reflection and standing-wave ratio (SWR) of the accelerator.

A typical waveform, including the anode current of the magnetron, the incident and reflected wave, is shown in Fig. 2. By tuning the magnetron when operating, the SWR could reach below 1.2, representing less than 1% of the input power reflected by the structure. The SWR without beam loading was measured to be 1.7, which agreed well with the cold test result and our design value.

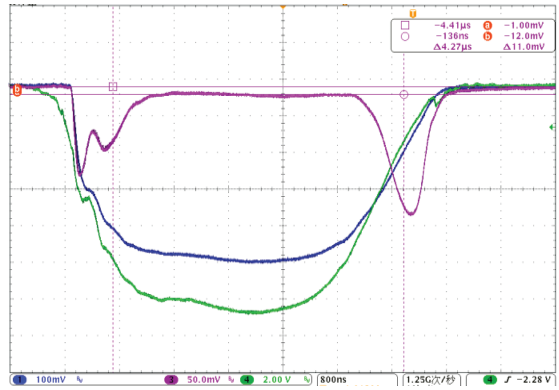

Figure 2: Anode current of the magnetron (green), incident wave (blue) and reflected wave (purple).

Capture ratio

The plot of capture ratio vs. input power is shown in Fig. 3. For different input power, the gun voltage was changed to fix accelerating pulse beam current at 130mA. A higher capture ratio is expected for 2.2MW input power.

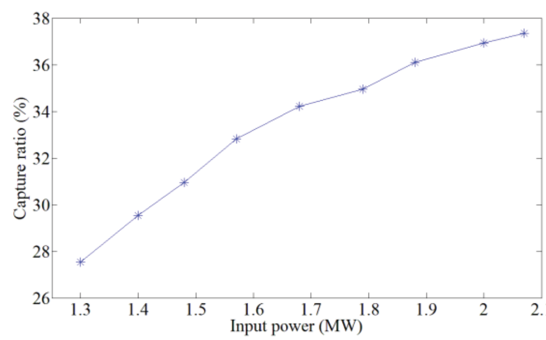

Figure 3: Capture ratio vs. input power.

Energy spectrum

With accelerating pulse beam current at 130mA, the energy spectrums of the output beam with different input power are shown in Fig. 4. For 2.07MW input power, the FWHM of the energy spectrum is about 7.5%.

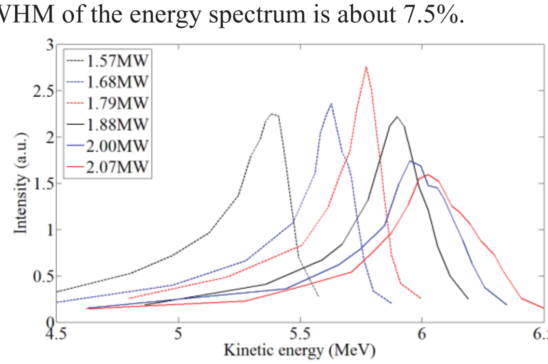

Figure 4: Energy spectrum for different input power (beam current fixed at 130mA).

The peak kinetic energy of output beam for different input power can be extracted from Fig. 4, as shown in

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Fig. 5 (added with three points for lower input power). The peak energy is proportional to the square root of input power.

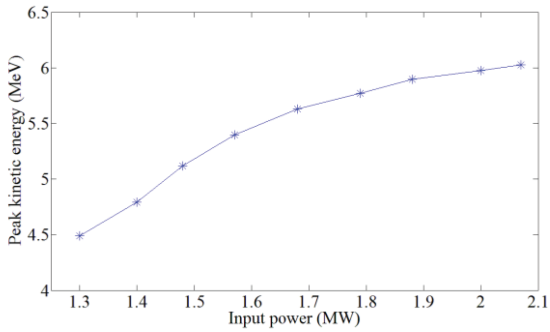

Figure 5: Peak kinetic energy vs. input power (beam current fixed at 130mA).

For the maximum stable input power 2.07MW, the pulse beam current was changed from 90mA to 140mA. The relevant energy spectrum is shown in Fig. 6.

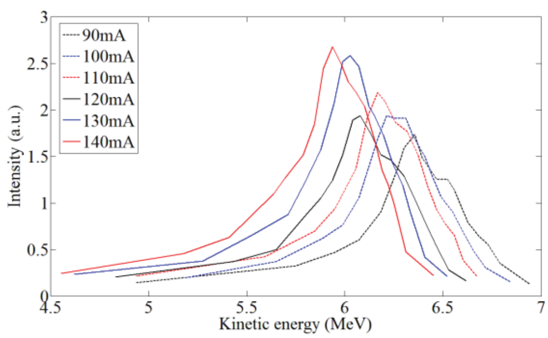

Figure 6: Energy spectrum for different beam current (input power fixed at 2.07MW).

The peak kinetic energy of output beam for different pulse beam current can be extracted from Fig. 6, as shown in Fig. 7. The peak energy is inversely proportional to beam current.

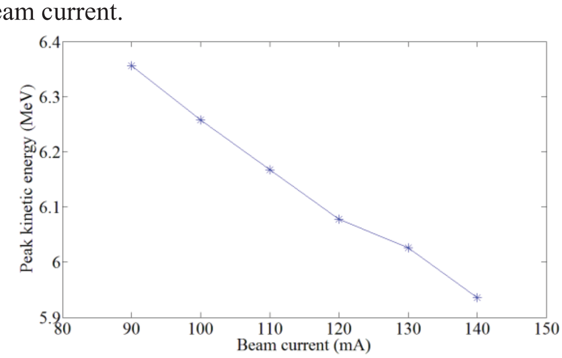

Figure 7: Peak kinetic energy vs. pulse beam current (input power fixed at 2.07MW).

Spot size

For 2.07MW input power and 130mA pulse beam current, the beam spot image captured by the CCD camera and its distribution along the red dash line are shown in Fig. 8. The root-mean-square diameter of the beam spot is about 0.8mm.

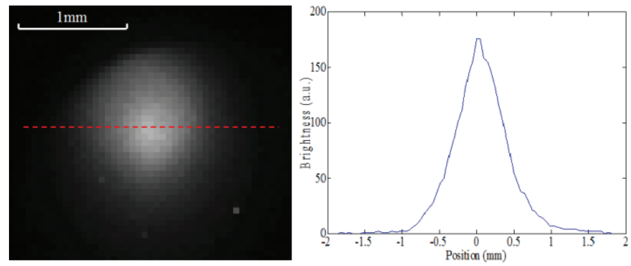

Figure 8: Beam spot and distribution along the dash line.

Dose rate

Tungsten target was appended at the exit of the accelerating structure and the X-ray dose rate was measured. With 2.07MW input power and 130mA pulse beam current, the dose rate measured one meter away from the target reached 1000rad/min (1‰ duty factor).

CONCLUSION AND OUTLOOK

High power RF tests have been carried out on a C-band 6MeV standing-wave linear accelerator developed at the accelerator laboratory of Tsinghua University. In the high power test, the capture ratio, the energy spectrum, the beam spot size as well as the dose rate were measured.

With 2.07 MW input power, the peak current is 130mA and the output spot root-mean-square diameter is about 0.8mm. The output kinetic energy is 6.0MeV with a spectrum width of 7.5%. For tungsten target, the dose rate can reach 1000rad/min (1m from the target, 1‰ duty factor).

The results of the high power RF test show good performance of this accelerator. However, it's still a little below our expectation due to insufficient input RF power. A modified vision with another accelerating cell has been designed and fabricated recently. This new prototype requires less input power and now is ready for high power test. We expect better performance on it.

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