RESEARCH ON A 16MEV BACKWARD TRAVELING WAVE (BTW) ELECTRON LINAC*

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Abstract

A 16MeV BTW electron linac, with a main accelerating tube and a buncher linked together as a single accelerating section, was built at the Tsinghua Accelerator Lab and tested from 1996 ~ 2002. The accelerator design, the results of a cold test, its commissioning, and the beam performance are described in this paper. Experimental performance proved the feasibility of the single section BTW structure.

1 INTRODUCTION

The BTW structure combines the advantages of the traveling wave (TW) and standing wave (SW) structure. The forward TW electrically on-axis coupled structure is remarkable for its good adaptation and shorter filling time. The SW magnetically off-axis coupled structure is remarkable for its high shunt impedance. Since the RF input is near the beam exit and the buncher is near the RF exit, the field level of the buncher depends on the line attenuation of the structure and on the beam loading [1] [2] [3], which has a slight effect on the capture coefficient of the buncher.

Recently, electron linacs have become widely used in China. Tsinghua University's accelerator laboratory has developed a single-section 16MeV Backward Traveling Wave (BTW) accelerating structure. Experiments have demonstrated that this BTW accelerating structure shows great promise.

2 $3\pi/4$ BACKWARD TW STRUCTURE DESIGN

2.1 General Description

The designed electron beam energy of the BTW structure is 16MeV, and the structure consists of 6 buncher cells and 34 uniform cavities plus input and output couplers (Figure 1). The input coupler is located at the beam exit for the backward TW structure. The working frequency is 2856MHz. The waveguide is a 1.6m single section, which operates in $3\pi/4$ mode. A 5MW S-band klystron serves as its microwave power source.

The cavity configuration has to be carefully optimized to obtain high shunt impedance. The optimized shunt impedance is 122 $M\Omega/m$; experience shows that the practical impedance is at most 85% of the theoretical value.

*Supported by the National Natural Science Foundation of China (10135040)
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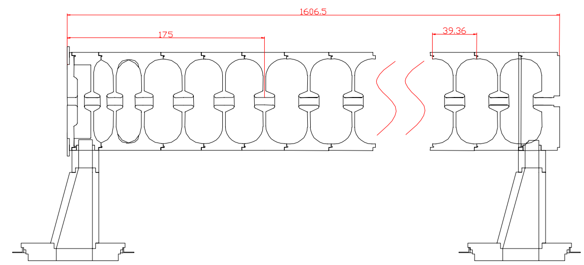

Fig.1 BTW structure

2.2 Physical Design

In order to apply the BTW structure to low energy fields, a study on beam dynamics of BTW structures was carried out. An APD computer code [8] was compiled specifically for disk-load wave-guides, BTWs, and standing wave accelerating structures. Combined with other electromagnetic field computer codes, the APD code could also be used for accelerator physics design of these three accelerating structures, for structure tuning, and for coupler matching.

The physics design of the 16MeV BTW electron linac showed that using 4.5MW microwave power, the accelerator could accelerate a 115mA electron beam to 16MeV in 1.6 meters. Under the action of a focusing magnetic field of 500 Gauss, the beam transverse envelope is in 3mm and the output beam spot diameter was less than 2mm.

Table 1 Summary of the design characteristics and parameters for the 16MeV BTW Linac [7] [8].

coupling pattern	magnetic coupling
operating pattern	traveling wave
Energy	16MeV
input power	4.5MW
beam current	115mA
operating frequency	2856MHz
operating mode	$3\pi/4$
shunt impedance	122 $M\Omega/m$
coupling coefficient	1%
Q factor	15800
group velocity	8.2‰ C
attenuation factor	0.3 $/m$
total length	1.6 m
buncher length	17.5 cm
buncher cavity number	6
capture factor	40%
peak field	15.7 MV/m
average field	10 MV/m

The radial beam envelope is shown in Figure 2, and Figure 3 gives the phase oscillations curves.

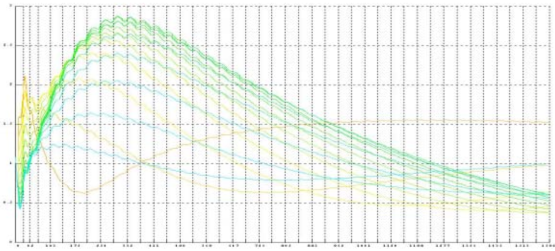

Fig.2 BTW accelerator tube radial beam envelope

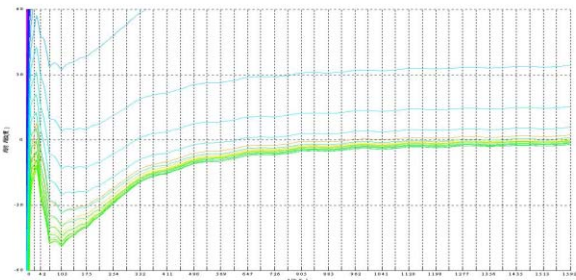

Fig.3 BTW accelerator tube phase oscillation

3 TUNING AND MATCHING

The first step of the tuning procedure was to adjust the phase shift in every cavity to the design value. A uniform cavity chain was achieved by tuning each cavity in the $\pi/2$ mode at a frequency of 2866MHz. This allowed cavities to operate at a frequency of 2856MHz in the $3\pi/4$ mode. For the buncher, in addition to tuning the frequencies of various cavities, it was also necessary to adjust the k value, where k is the cell-to-cell coupling factor and it determines the electrical field distribution on-axis.

Matching was done by adjusting the dimensions of the coupler cavities to insure a low standing-wave ratio at the input and output of the structure. The aim of tuning the couplers was to let the RF power couple to the structure from the rectangular waveguide through an input aperture in the first cavity without reflection. The final step was to find a way to carefully determine the dimensions of the coupling aperture while keeping the operating frequency of this coupler. The basic ideas were based on Kyhl's method presented in a SLAC note [4], and Chanudet's method which was used at LAL [5].

4 COLD TEST

4.1 $\rho \sim f$ curve

It is well-known that the $\rho \sim f$ curve in a TW accelerating tube is much flatter than in a SW accelerating tube, especially in the region near f_0, where ρ usually is 1.02~1.10. The frequency range of VSWR below 1.2 should be 2~4 MHz, with a minimum VSWR approximately equal to 1.0. For this BTW accelerating tube, the measured minimum VSWR was 1.02, and the frequency range of VSWR below 1.2 was 2MHz (Figure 4).

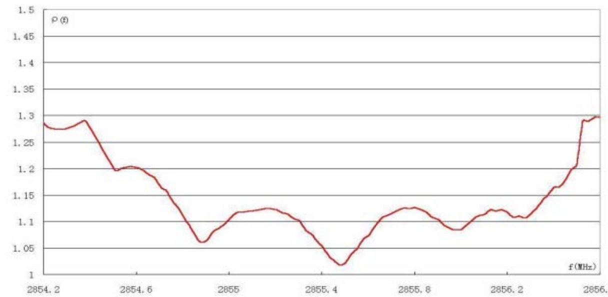

Fig.4 $\rho \sim f$ curve of the BTW accelerator tube

4.2 TW field distribution

The electrical field and the shunt impedance of the total BTW tube were measured using the bead-pull technique. The field distribution of the 1.6m-long accelerating structure was measured in 3 minutes with a precision of 0.1kHz and a step size of 0.5mm. Fig.5 shows the measured and the theoretical results of the electric field distribution along the beam axis. The measured attenuation coefficient is A=0.48Np.

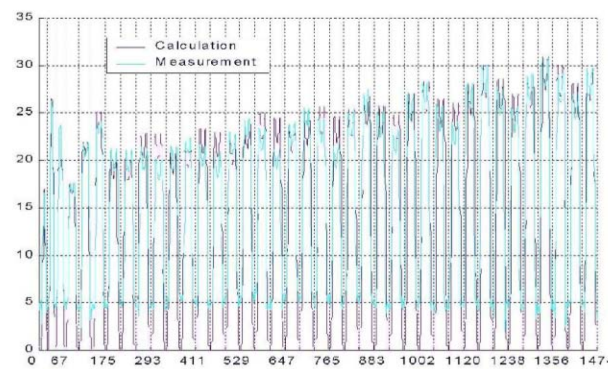

Fig.5 Electrical field distribution of BTW structure along the beam axis.

4.3 Other microwave parameters

Table 2 gives a comparison of the measurement data with the design values[6].

Table 2 Comparison of measured data with design values.

	Calculated Values	Measurement results
Shunt impedance	122 $M\Omega/m$	104 $M\Omega/m$
group velocity	8.2‰ c	8.1‰c
Q value	15800	14000
coupling coefficient	1%	1.01%
attenuation coefficient	0.286 $/m$	0.329 $/m$

5 HIGH POWER TEST

Figure 6 shows a view of the 16MeV BTW electron linac under commissioning.

Fig. 6 A 16MeV BTW electron linac under commissioning in Tsinghua Accelerator Lab

Table 3 gives the comparison of the calculated result and the measured beam characteristics.

Beam	Calculated	Measured
Energy/MeV	16	16
Current/mA	115	120
Spot size/mm	$\leq \phi 2$	$\leq \phi 2$

The beam energy was measured using the aluminum absorption method. The beam current was measured using a Faraday cup and beam transformer. The measured beam spot size was less than 1.8x2.0mm after the beam passed through a 1.6m accelerating waveguide. The 16MeV BTW electron linac was capable of emiting a very strong X-ray, with a dose rate exceeding 120Gy/min.m (Figure 7). The results of commissioning showed that the backward TW accelerating waveguide provides a 120mA electron beam with 16MeV energy, thus satisfying the design requirement (Figure 8).

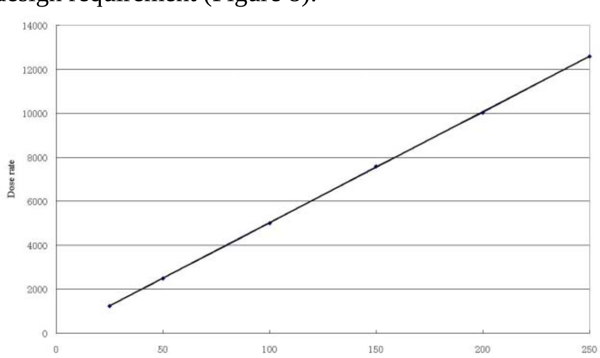

Fig. 7 Dose rate versus PPS

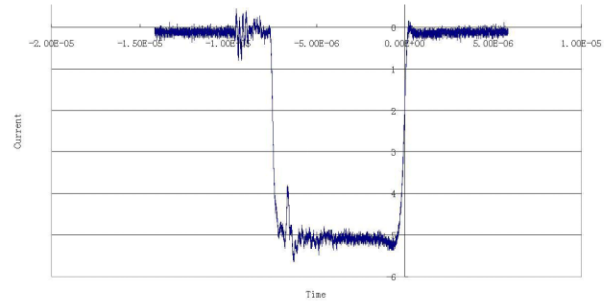

Fig. 8 Accelerated beam current waveforms

6 CONCLUSION

The accelerating waveguide presented in this paper used a backward traveling wave structure to bunch and accelerate electrons. The BTW structure has several advantages. The BTW structure shunt impedance is higher than that of a disk loaded waveguide. In addition, the BTW is a backward wave structure, which is beneficial for efficiently using microwave power.

Results of this research suggest that the backward traveling wave accelerating structure is preferable for certain applications, because the BTW structure has a higher effective shunt impedance, a shorter filling time and is more stable to operate. A 16MeV BTW accelerating tube operating in the $3\pi/4$ mode was successfully developed to be used as a radiation source for various applications.

7 REFERENCE

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