DEVELOPMENT OF A C-BAND 4/8 MeV DUAL-ENERGY ACCELERATOR FOR CARGO INSPECTION SYSTEM

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Abstract

Modern cargo inspection system applies dual-energy X-ray for material discrimination. Based on the compact C-band 6 MeV standing-wave accelerating structures developed at Tsinghua University, a compact C-band 4/8 MeV dual-energy accelerator has been proposed, fabricated and tested. Compared with that of the conventional S-band 3/6 MeV dual-energy accelerator at Tsinghua University, the volume and the weight of the C-band one has been reduced by ~40% and ~30%, respectively. Detailed review of this C-band dual-energy accelerator is present in the paper.

INTRODUCTION

Nowadays, cargo inspection system is essential for homeland security and customs control. Dual-energy X-ray is necessary for effectively discrimination of materials with similar atomic numbers [1]. Over the last decade, dual-energy accelerators within the energy range of 1-10 MeV have been developed by various research groups [1-6].

Most of these accelerators are operated at S-band (2856 or 2998 MHz). Accelerators operated at higher frequency such as C-band (5712 MHz) and X-band (9300 MHz) are preferable when space is limited and accurate positioning is required [7]. Compared with X-band ones, C-band accelerators require less production precision and are less likely to detune after brazing [7]. Recently, the research of C-band accelerators for medical and industrial applications is of high interest and many prototypes have been developed [7-12].

Two prototypes of C-band 6 MeV standing-wave biperiodic on-axis coupled linear accelerating structure have been developed at Tsinghua University [7]. A compact 4/8 MeV dual-energy accelerator has been developed based on the prototypes by adjusting the input power as well as the beam loading.

ACCELERATING STRUCTURE

The prototypes of C-band 6 MeV standing-wave linear accelerating structure have a compact size with a narrow spectrum and a small spot size that can be used for medical and industrial applications.

The two prototypes share nearly the same design for the bunching cells and normal cell. Compared with the prototype I, the prototype II has one more normal cell to lower the required input power to achieve the same acceleration. The main parameters of the accelerating structure prototype II are listed in Table 1.

In Table 1, the length of the accelerating structure excludes the thermal-cathode gun and the flange at the exit for test. P_m is the required input pulsed power to accelerate 130 mA beam to the nominal 6 MeV. E_a is the corresponding accelerating gradient of the normal cell.

Table 1: Parameters of the C-band 6 MeV Accelerating Structure Prototype II

Parameter	Value
Frequency (MHz)	5712
Number of bunching cells	3
Number of normal cells	10
Length (cm)	~31
Quality factor	10000
External coupling factor	1.6
P_m (MW)	1.95
E_a (MV/m)	24

The accelerating structure is cooled by a water jacket. The prototype II after fabrication is shown in Fig. 1.

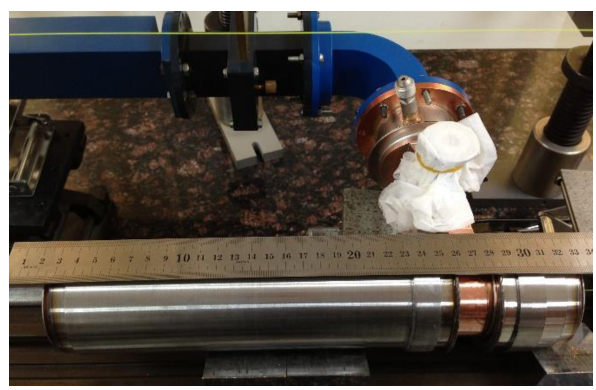

Figure 1: The C-band 6 MeV accelerating structure prototype II.

DUAL-ENERGY ACCELERATOR

The compact C-band 4/8 MeV dual-energy standing-wave accelerator has been developed based on the accelerating structure prototype II, as shown in Fig. 2.

The power source of the accelerator is the VMC3109 magnetron from CPI and it's fed by a domestic solid state modulator. The maximum pulsed and average power are 2.5 MW and 2.5 kW, respectively. Taking the attenuation of the waveguide system between the magnetron and accelerator to be 0.5 dB, the maximum pulsed input power available for the accelerator is ~2.23 MW.

The energy variation has been achieved by adjusting the input power as well as the beam loading.

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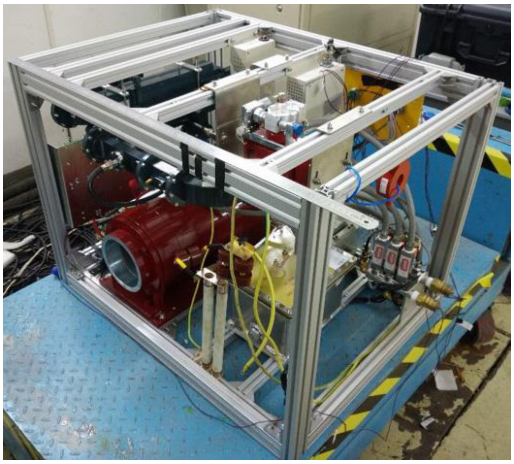

Figure 2: The C-band 4/8 MeV dual-energy accelerator.

The pulsed current at the gun exit I_{exit} with different input power and emitting current from the gun I_{gun} is illustrated in Fig. 3. The capture ratio of the accelerator is measured to be 15-35%.

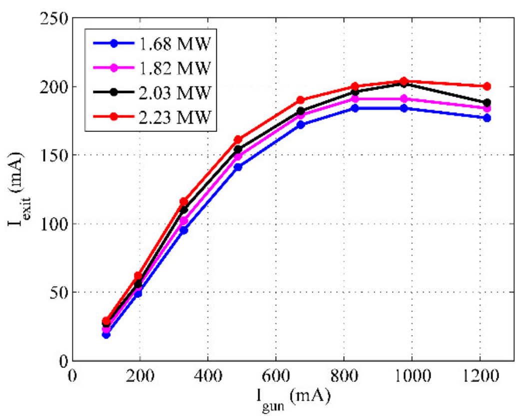

Figure 3: The pulsed current at the gun exit in the high power test.

The average energy gain of the accelerated beam with different input power and I_{gun} is illustrated in Fig. 4. The range of the average energy gain in high power test is 3.6-8.5 MeV. This is limited by the adjustable range of the input power and the emitting current from the thermal-cathode gun.

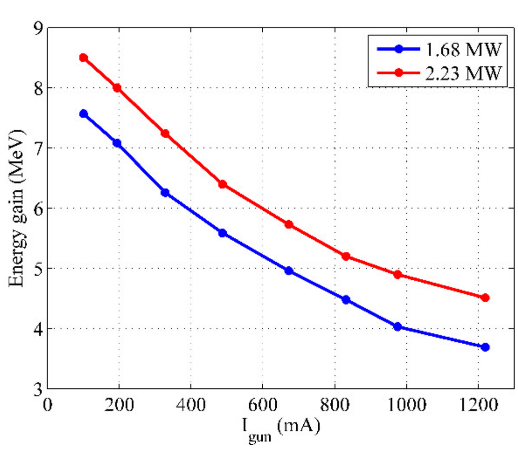

Figure 4: The average energy gain in the high power test.

Based on the high power test results, 1.68 MW input power and 1220 mA emitting current have been set for the low energy end of the dual-energy accelerator. Meanwhile, 2.23 MW input power and 100 mA emitting current has been set for the high energy end.

At these two settings, the beam spot at the gun exit has been measured to be smaller than 1.5 mm in diameter.

The stability of the dose rate when the accelerator is operated at dual-energy mode is better than ±1.5%. With a thin W-Au target and a duty factor of 1‰, the highest dose rate at 1 m away from the exit is measured to be higher than 1200 R/min when the accelerator is operated at single-energy mode.

Limited by the transfer time of the control system and the modulator, the highest repetition of the accelerator is 2×80 Hz.

A comparison of the C-band accelerator and the conventional S-band dual-energy accelerator developed at Tsinghua University is listed in Table 2.

Table 2: Main Parameters of the C-band and S-band Dual-energy Accelerator

Parameter	C-band	S-band
Accelerating structure length (cm)	~31	~29
Dual-energy (MeV)	4/8	3/6
Spot diameter (mm)	<1.5	<2
Accelerator size (m)	0.95×0.7×0.7	1.3×0.8×0.8
Weight (T)	<1	1.5

Compared with the S-band accelerator, the C-band one has merits of larger energy range and smaller spot size which will benefit the imaging quality. The volume and weight of the C-band accelerator have been reduced by ~40% and ~30% respectively which makes it more suitable for compact application.

CONCLUSION

A compact C-band 4/8 MeV dual-energy accelerator has been developed for cargo inspection system. It has remarkable improvement over the conventional S-band one in terms of energy range, spot size, volume, and weight. High power test results show good performance of the accelerator. The imaging experiment is undergoing to demonstrate the material discrimination.

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