A PORTABLE X-BAND ON-AXIS STANDING WAVE LINAC STRUCTURE

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Abstract

A portable X-band on-axis standing wave electron linear accelerating structure has been developed that is suitable for portable radiation therapy and radiography. The phase-focusing technique is used. The design parameters of a 2 MeV, X-band, on-axis coupled, SW accelerating guide operated in the $\pi/2$ mode is described. A prototype 150 mm long structure has been machined, brazed and sealed, and the experimental data of the cold tests and beam tests are presented.

INTRODUCTION

The many advantages of using higher RF frequencies for electron linear accelerators include higher shunt impedance, higher breakdown threshold level, smaller size and short fill time. In addition, increasing the RF frequency increases the accelerated beam energy for a fixed input RF power [1][2]. An extremely small accelerator structure with high shunt impedance is needed for medical and industrial applications. The Accelerator Laboratory at Tsinghua University, which has extensive experience with S-band electron linacs, having studied X-band SW electron linacs since 1991, is currently developing a prototype 2 MeV, X-band SW accelerating guide. One objective is to study the fabrication and tuning techniques of X-band accelerating structures. Work is also proceeding on the development of a portable 6 MeV X-band SW accelerating structure for medical electron linacs.

STRUCTURE OPTIMIZATION

Three types of X-band accelerator structures have been developed, the disc-loaded structure[1], the side-coupled structure[1], and the coaxially coupled structure[2][3]. However, the Accelerator Laboratory prefers the on-axis structure for X-band SW linac based on our experience of fabricating S-band structures. This structure has advantages similar to the coaxially coupled structure which offers a significantly smaller diameter than the side-coupled structure. In addition to small size and less weight, the cylindrical symmetry structure is simpler to machine and braze.

The two important limits that influence the effective shunt impedance are the beam aperture radius and the thickness of the copper web between the accelerating cavities. Decreasing the beam aperture radius and the thickness of the copper web increases the effective shunt impedance. However, the size of the beam hole is limited by the beam transverse transmission. Our dynamic simulation calculations showed that the beam aperture diameter should be 4.0 mm. The web thickness is related to the coupling cavity which must be inserted between the two accelerating cavities in the on-axis coupled structure and to thermal conductivity requirements. The web thickness was chosen to be 2.8 mm and the coupling cell length was chosen to be 1.0 mm.

As shown in Table 1, the on-axis structure offers about the same shunt impedance and outer diameter as the coaxial structure. Although the theoretical effective shunt impedance of the on-axis structure is less than for the side-coupled structure, our experience shows that the actual shunt impedance of both structures are similar with S-band linacs.

Table 1. Parameters for X-band (9300 MHz) Accelerator Structures

Structure	Disc-loaded	Side-coupled	Coaxial	On-axis
Type of Operation	TW	SW	SW	SW
Mode of Operation	$2\pi/3$	$\pi/2$	$\pi/2$	$\pi/2$
Effective Diameter (cm)	3.2	5.3	3.2	3.2
Effective Shunt Impedance(MΩ/m)	80	145	130	133
Beam Aperture Diameter (mm)	8.0	4.0	4.0	4.0

PHYSICAL DESIGN

A 2 MeV X-band on-axis SW accelerator was designed with a guide that is approximately 150 mm long and with 11 accelerating cells and 10 on-axis coupling cells. It uses 5 accelerating cavities as a buncher. The structure is operated in the $\pi/2$ mode with an average effective shunt impedance of 121.4 MΩ/m. The RF power is supplied by a tunable coaxial magnetron of 1.0 MW peak power at X-band (9305 to 9325 MHz). The pulse coaxial magnetron was developed by BIEVT.

To minimize the size and weight of the structure and to improve the beam spot as well as the transmission, the phase-focusing technique was used without a bulky, external magnetic focusing device[1][2][4]. It is well known in alternating phase focusing, that the electrons alternate between ahead of the accelerating crest where they are

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longitudinally focused and behind the crest where they are radially focused. By choosing the right phase velocity taper and by tapering the magnitude of the buncher field levels from cavity to cavity, the RF field in the buncher region provides transverse focusing as well as longitudinal bunching and acceleration. An injection voltage of 16 kV is used with a converging injection beam. The electron beam focal spot size is less than 1.0 mm and the pulsed beam current is 75 mA with 0.6 MW input RF power. The capture efficiency is about 30% . Some performance data for the guide is shown in Fig. 1 to Fig. 4.

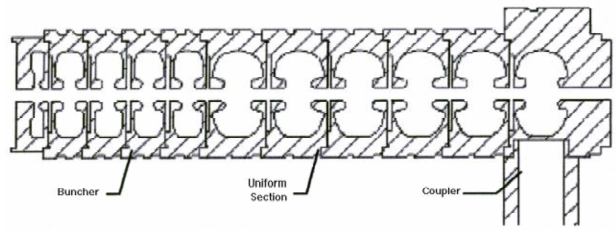

Fig. 1. Schematic Illustration for On-axis Structure

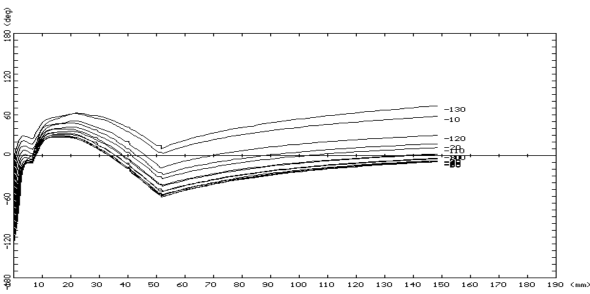

Fig. 2. Longitudinal Orbits for Various Input Phases

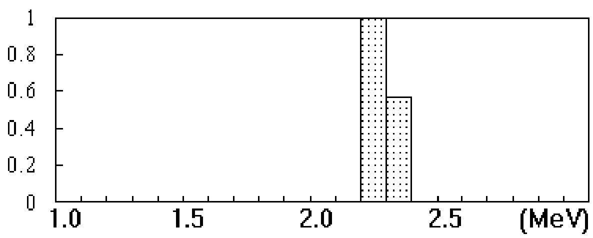

Fig. 3. Energy Spectra

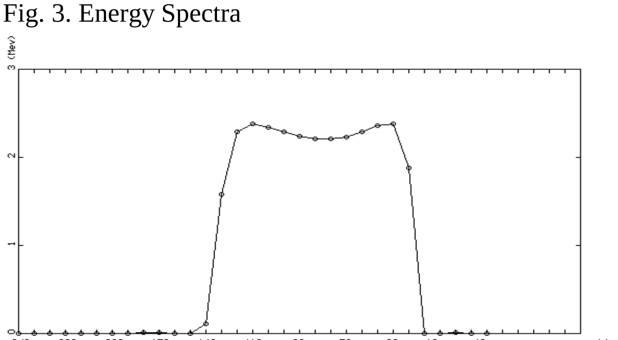

Fig. 4. Energy Spectra as a Function of Input Phase

TUNING AND LOW POWER TESTS

After careful machining, the cavities were assembled and tuned. The fabrication and tuning of the prototype X-band structure were strongly interrelated and must progress carefully due to the high operating frequency. The frequencies were measured using a HP8757D network analyzer. Both accelerating and coupling cavities were isolated and measured by inserting two probes into the cavity drift tubes one by one. The two probes serve to short out adjacent cavities as well as the RF transmission. The tuning was iteratively repeated since the states of adjacent cavities has some effect on these measurements. The position and size of the probes greatly influences the measurements; therefore, the probe optimization is very important.

The guide tuning results are: The frequency uniformity is ±1.5 MHz for the accelerating cavities and ±2.0 MHz for the coupling cavities. The stop band is less than 2.0 MHz. The nearest neighbor coupling, k_1 for accelerating section, is 3.7%. The nearest neighbor coupling factors for the buncher section were adjusted to meet the field configuration. The bead pull data is shown in Fig. 5. The passband characteristic of the guide is shown in Fig. 6. Before brazing, the measured Q of the guide was 6050. The coupling factor of the waveguide coupler, β, is 2.12 at zero beam loading.

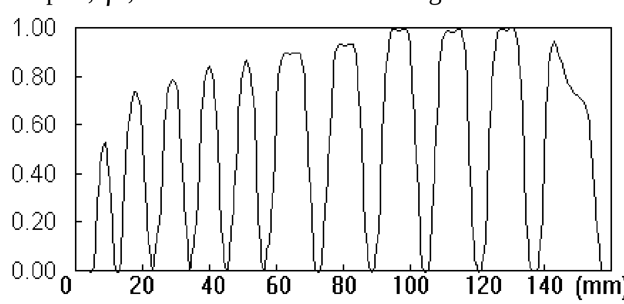

Fig. 5 On axis Bead Drop Data

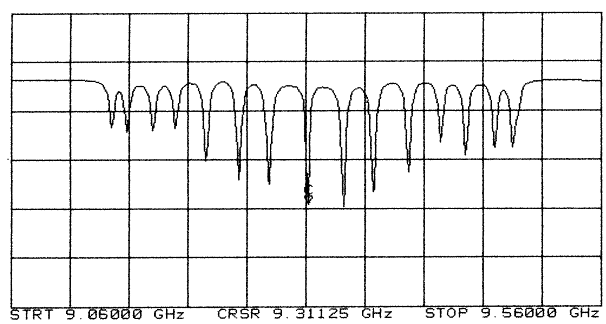

Fig. 6 Modules of Complex Reflection vs. Frequency

The brazing was done in collaboration with BIEVT. The electron gun, RF waveguide, RF window, glass window and ion pump were designed and fabricated at BIEVT. The overall structure was then brazed, evacuated and sealed. No post-braze tuning of the guide was done. The dispersion curves for the guide are shown in Fig. 7.

The final measured Q for the guide is 7100 with a β of 2.24. The average shunt impedance for the whole guide is about 105.0 MΩ/m. Fig. 8 is a photograph of the 2 MeV On-axis SW Guide.

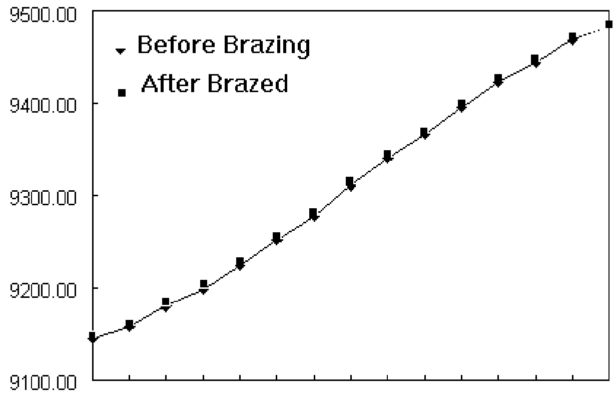

Fig. 7 Dispersion Curve for On-axis Coupled SW Accelerator Structure

Fig. 8. 2 MeV On-axis SW Guide Braze Assembly

BEAM TESTS

The structure beam tests have been completed in Tsinghua University Accelerator Laboratory in collaboration with BIEVT and the China Institute of Atomic Energy. The design parameters and the experimental data of the beam tests are shown in Table 2.

Table 2. System specifications

	Theory	Experiment
Electron Energy (MeV)	2.3	2.4
Electrical Length (mm)	148.5	148.5
RF Frequency (MHz)	9300.0	9316.5
RF Peak Input Power (MW)	0.60	0.68
Injection Voltage (kV)	16	17
Capture Efficiency	30%	30%
Peak Beam Current (mA)	75	>90
Target Spot Size (mm diameter)	<1.0	<0.7

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