14MeV SINGLE-SECTION SW GUIDE FOR MEDICAL ACCELERATORS[1]

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Abstract

A 14MeV, on-axis coupled, S-band waveguide for medical accelerators was built and tested between 1993 and 1995. The accelerator design, the results of cold and hot tests and the beam performance are given in this paper.

INTRODUCTION

Recently electron linacs are widely used in China and low energy medical electron linacs with energies of from 4 to 10 MeV can be manufactured by several organizations in China. However, new medium and high energy electron linacs must be developed to meet the demand in radiotherapy. There is also evidence that certain tumors can be more effectively treated with a combination of low- and high- energy photons or of photons and electrons. As a result, a single machine that can produce both low and high energy x-rays together with a wide range of electron energies would be very useful. Such multi-energy accelerators are currently offered by foreign companies. Based on our past works, we began development of multi-energy electron linac structures for the domestic market in 1991. A single-section 14 MeV standing-wave accelerating structure providing two X-ray modes and several electron modes was the first one developed for medical use in China.

GENERAL DESCRIPTION

The guide was designed for X-ray energies of 6 or 15MV and electron beam energies of from 6 to 14MeV. The guide has a single 1.45m long section, operated in the $\pi/2$ mode at 2998MHz. Its microwave of power source is a S-band magnetron, MG5260, whose output power can be adjusted to a maximum peak power of 2.6MW. The beam energy is varied by changing the input RF power, injection voltage and injected current.

The cavity configuration must be carefully optimized to obtain 14MeV beam energy within a 1.45m long accelerating guide. The optimized shunt impedance is as high as 105 MΩ/M but our experience shows that the practical impedance is at most 85% of the theoretical value.

The guide contains 30 accelerating cells with 29 coupling cells, divided into three homogeneous regions with distinctive phase velocities and field configurations. These regions respectively contain 1, 3 and 26 accelerating cells.

The electron gun has a triode structure with a 8mm diameter cathode. The gun emits up to 1A of beam current over a voltage range of 7 to 15KV. A 270° deflection system was adopted for achromaticity and small beam spot size.

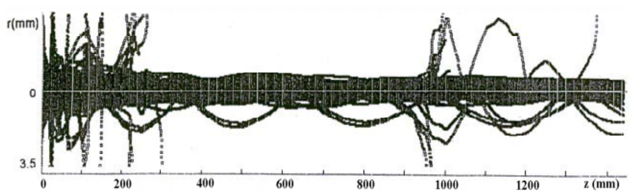


Fig.1 Radial multiparticle track for 15MV X-ray mode without any focusing solenoid

PHYSICAL DESIGN

The design of the buncher and the selection of the operating parameters are compromises between the two X-ray energy modes and are meant to optimize the spectrum sharpness at 12MeV. As a result, the capture efficiency for the 6MV mode is relatively low. For the 6MV mode, the input power was reduced and the beam loading was increased while maintaining the rf phase focusing.

The longitudinal and transverse beam dynamics were calculated using the LONGN and TRSVN [1] codes. The result was checked using a multiparticle trace code. Fig.1 shows the radial multiparticle track for the 15MV X-ray mode without any focusing solenoid.

Tables 1 and 2 summarize the design characteristics and parameters for each operating mode.

Table 1. Design characteristics

length	1.45 m
frequency	2998 MHz
power	2.6 MW
coupling	1.7 fixed
shunt impedance	89 MΩ / m
injection voltage	7~15 kV
coupling coefficient k	3.3%

[1] Supported by the Major Research Project of the Eighth-Five Plan (1991~1995) of China

Table 2. Design parameters for each operating mode

parameter	x-ray mode		electron mode				
Beam energy(MeV)	6	13.5	6	8	10	12	14
Injection voltage(kV)	15	7	10	10	10	10	7
Injected current(mA)	900	130	45	36	26	17	17
Peak power(MW)	1.80	2.20	0.9	1.0	1.1	1.5	2.2
Beam current(mA)	120	35	5	5	5	5	5

TUNING AND COLD TEST

The mode spacing of the coupled cavity chain for the π/2 mode can be expressed as kπ/2N, where k is the cell-to-cell coupling factor and N is the total number of cells in the chain. For a long cavity chain with 59 cells, the coupling factor k should be large enough so as to ensure stability of operation. However, increasing k can cause a decrease in the figure of merit, Q_0, for the entire tube, thus causing the shunt impedance, ZT^2, to decrease. The coupling factor was experimentally determined to be slightly more than 3%, which would not cause a decrease in ZT^2. Also, the dispersion diagram shows that the group velocity for the guide is as high as 0.04, which is enough for phase stability and to meet the tolerance requirement.

The location of the coupler affects the passband performance. The PPDW code was used to analyze and calculate the passband characteristic of the input coupler when placed in different cells. The PPDW code which is based on equivalent circuit theory, was developed to analyze microwave characteristics of arbitrarily composed, coupled cavity chains. Figs. 2 and 3 show the modules of complex reflection as a function of frequency for the coupler located in the 1st and the 21st cavities respectively. Locating the coupler in the 21st cavity suppresses the modes immediately adjacent to the π/2 mode. The coupler was adjusted for overcoupling of 1.78 at zero beam loading as a compromise between the two x-ray modes.

The guide design has the field configuration of the guide separated into three steps. Therefor the coupling factors , k , of the coupling cell to both accelerating cells to the coupling should vary at the location of the field configuration variation. The coupling factors were varied by modifying the coupling apertures on both webs of the second and eighth on-axis coupling cells.

The shunt impedance and the field flatness of the entire guide were measured using the bead-pull technique. An automated phase-lock frequency tracking system and a precise and accurate computerized data acquisition system were developed for the measurement. The field distribution of a 1.45m long accelerating structure was measured in 3 minutes with a precision of 0.1 KHz and a step size of 0.5mm. Fig.4 shows the measurement system schematic drawing. Fig. 5 shows the measured and the theoretical results for the electric field distribution along the beam axis of the guide.

The tuning results for the guide are: the stop band is less than 20KHz; the frequency uniformity of various cavities is better than 200KHZ; the shunt impedance of the entire guide is 89 MΩ/M; and the field flatness in the accelerating section is better than 3%.

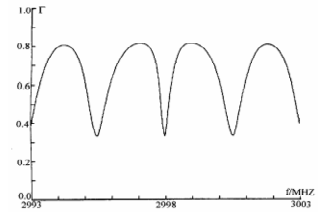


Fig.2 Rf power fed into the A_0 cavity

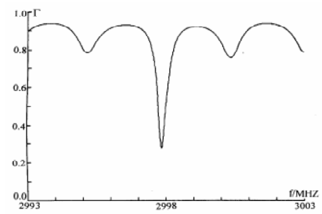


Fig.3 Rf power fed into the A_{22} cavity.

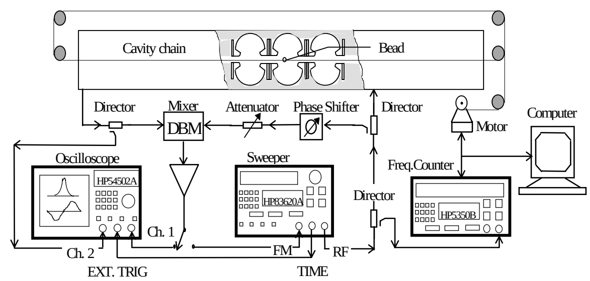
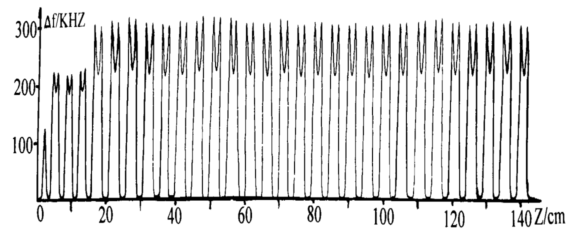
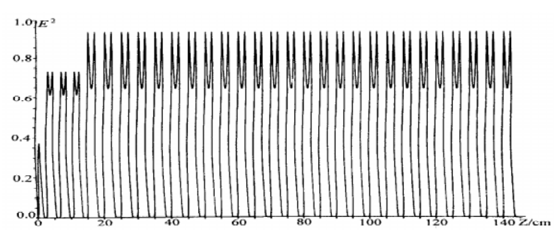


Fig.4 Bead-pull measurement system



(a) Measured



(b) Calculated

Fig.5 Electric field distribution along the beam axis of the guide

MECHANICAL DESCRIPTION

Since our brazing technology can control frequency errors to within ±0.3MHz, the guide did not need further tuning after brazing. Fig.6 shows the entire guide after brazing.

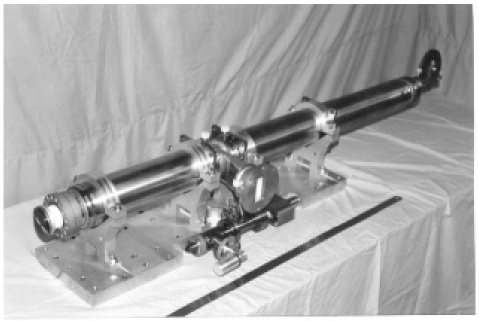


Fig.6 The brazing guide

The rf horn assembly is a short section of standard OFHC S-Band waveguide brazed into the coupler. The rf assembly has a vacuum port cut into the side and a ceramic rf window braze assembly welded to it.

The final assembly of the guide includes an electron gun, a rf window, a 2 l/s vacuum pump, a vacuum envelope for beam transport through the 270° bending magnet, support tubing, and an anti-dark current solenoid near the buncher end.

The structure was designed to be baked-out and sealed-off; however, several bakeable flanges were also used at the gun, the 270° deflection system, and the pinch-off. The guide was baked-out and pinched-off initially. Any component that fails can be easily replaced. After baking out a cold vacuum of 1x 10^{-6} Pa is typically achieved.

HIGH POWER TEST

Table 3 compares the calculated result and the measured beam characteristics.

Table 3

beam	beam energy/MeV		beam current/mA	
	calculated	measured	calculated	measured
X-ray	6	6.2	120	160
Electron-beam	14	15	5.0	28

The beam energy was measured using the aluminum absorption method. The beam current was measured using a Faraday cup and a beam transformer. The guide was shown to provide a 15MeV electron beam, thus satisfying the design requirement.

The measured beam spot size was less than 1.2x1.8cm after the beam passed through a 1.45m long accelerator guide and a 270° deflection system without any focusing solenoid. The focus is the result of rf phase focusing, an asymmetrical first bunching cavity and converging beam injection.

Commissioning tests of two 14MeV SW guides have been completed in two domestic medical linacs. One of them is being installed at a hospital in Beijing by the Beijing Medical Equipment Institute.

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