AN X-BAND COAXIAL STANDING-WAVE LINEAR ACCELERATOR STRUCTURE

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Abstract

A new high efficiency X-Band, standing-wave linear accelerator cavity structure has been developed. It utilizes a shaped coaxial cavity as the coupling cavity between accelerating cavities for π/2 mode operation, hence the overall diameter is extremely small while maintaining a very high shunt impedance. The coupling cavity and accelerating cavity are easily machined on opposite sides of a single cell, eliminating any subassembly steps. Cavity geometries were developed using the computer codes LACC & LALA. Prototype 1.5 MeV and 4.0 MeV, 20 cm long accelerators are now under development. The accelerators employ a stepped field focusing technique to keep the beam focused at low field levels. The beam dynamics code PARMELA was used to optimize the longitudinal bunching and transverse beam characteristics. The accelerator design parameters, as well as experimental results, are presented.

Introduction

Microwave electron linear accelerators with energies up to 50 MeV have been widely used for radiation therapy and radiography. Most of these accelerators use an S-Band microwave frequency around 3 GHz, since high power RF sources (magnetrons and klystrons) are readily available at this frequency range and the size of the accelerators is reasonably compact. A few attempts to develop accelerators at X-Band frequencies have been made in the past. But due to: 1) the lack of a high power source at X-Band frequencies, and 2) the complexity of machining and tight mechanical tolerances and alignments, the accelerators remained mostly at the R & D level.

Recently, there has been new interest in electron accelerators operating at higher frequencies for high energy physics research (linear collider) and new industrial applications (bore hole investigation and portable radiographic applications), which has lead to renewed R & D activities with X-Band accelerators.[1, 2]

There are various advantages of using higher microwave frequencies for electron accelerators, i.e.:

1) Smaller size

2) Higher shunt impedance (shorter length for given power to obtain a certain energy gain)

3) Higher breakdown threshold level

4) Shorter fill time

It is of interest to develop an extremely small X-Band accelerator structure with high shunt impedance for future applications.

The side-coupling standing-wave linear accelerator has many advantages. Among those, the high shunt impedance and high stability are extremely important factors for medical and industrial applications. However, the overall diameter of the structure is much larger than the accelerating cavity diameter due to the side cavities. Moreover, a great number of machining and assembly steps are required.

For most X-Band accelerator applications where space limitation, the machining process, and tuning are of concern, the side-coupling structure may become unsuitable. Figure 1 shows the schematic cross section of a new coaxially coupled, standing-wave accelerator design reported earlier, which utilizes the shaped coaxial cavity as the coupling cavity for π/2 mode operation.[3] Table I summarizes typical parameters for X-Band accelerating cavities, comparing traveling-wave, side-coupled standing-wave and the new structure.

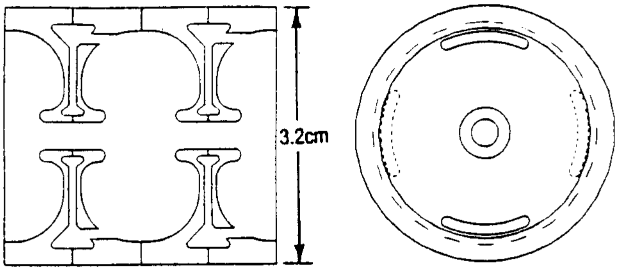

Fig. 1 Schematic Illustration of New Coaxially Coupled X-Band Standing-Wave Linear Accelerator Structure

TABLE I TYPICAL PARAMETERS FOR X-BAND (9300MHz) ACCELERATOR STRUCTURES

Structure	Disc-Loaded	Side-Coupled	Coaxial
Type of Operation	TW	SW	SW
Mode of Operation	2π/3	π/2	π/2
Effective Diameter	3.2cm	5.3cm	3.2cm
Beam Hole Diameter	8mm	4mm	4mm
Nearest Neighbor Coupling	2%	3%	8%
Effective Shunt Impedance	80 MΩ/m	145 MΩ/m	130MΩ/m

As shown in the table, the new structure offers significantly smaller diameter than the side-coupled structure, while maintaining a high shunt impedance and nearest neighbor coupling.

In this paper, a new X-band coaxial coupled accelerator structure is presented along with the cavity and accelerator structure optimizations. Also, a beam focusing technique without use of a solenoid or quadrupole magnet is discussed.

Cavity Optimization and Low Power Test

In order to reduce the overall guide diameter and to simplify machining and assembly, the X-Band coaxial cavity structure was developed similar to a previously reported S-Band structure. In the TM010-like mode of operation used, the open regions at the inner and outer diameters of the coupling cavity have strong magnetic field components, while the electric field component is concentrated in the capacitive region in between. Consequently, the frequency responds sharply to changes in the capacitive gap and outer diameter. These parameters are used to bring the cavity within the desired frequency range.

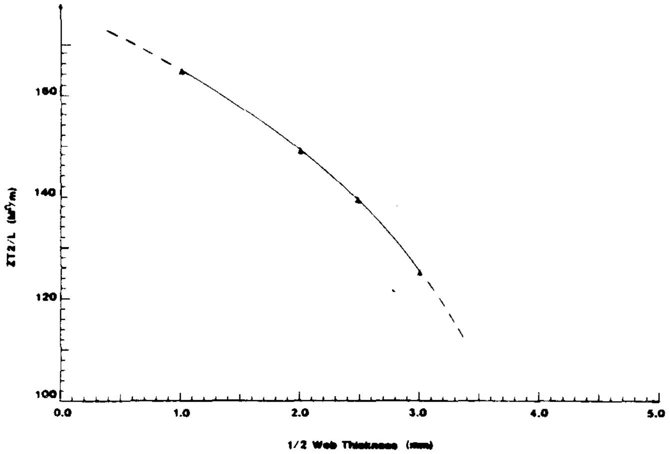

Fig. 2 Shunt Impedance vs Web Thickness At X-Band Frequencies

The optimization of the two cavities, one for shunt impedance, the other for ease of machining and tuning, were closely linked. Figure 2 shows the relationship between the thickness of the copper web between accelerating cavities (where the coupling cavity is located) and the theoretical shunt impedance per unit length at 9300 MHz. Unfortunately, the thickness of the web, which is inversely proportional to the effective shunt impedance, is limited by 1) a practical geometry for the coupling cavity, and 2) thermal conductivity requirements. Further, the diameters of the two cavities should be well-matched in order to ensure strong magnetic coupling through slots cut along the outer diameter of the accelerator cavity. The cavity code LALA was used to develop the accelerating cavity, while the code LACC was used to develop the coupling cavity. Selection was based on the ease with which each code was used for the particular geometry.

The accelerating cavity was first optimized for maximum shunt impedance, then small modifications in diameter and contour were made to match the evolving coupling cavity. Initial calculations indicated that a minimum web of 5 mm would be required to obtain a readily machined, matched, 9300 MHz coupling cavity. The final coupling cavity diameter exceeded the accelerating cavity diameter by 8%, which was determined to allow for sufficient magnetic coupling through 60^o to 75^o slots cut at the outer diameter of the accelerating cavity. Although the capacitive gap is quite small (1.15 mm), tight machining tolerances (± .0025 mm), the unexcited state of the coupling cavity during normal operation, and a higher than previously thought breakdown level eliminate any concern.

These cavities have been easily machined by skilled machinists with a first cut frequency variation of ± 12 MHz for the coupling cavity and ± 1 MHz for the accelerating cavity. Second cuts can place the frequencies within ± 5 MHz and 0.5 MHz respectively. This should provide sufficiently accurate tuning for stable, efficient operation of guide, without loss of efficiency. Because of the dimensions and geometry, no post-braze tuning will be attempted. The nearest neighbor coupling constant, K_1, for the cavities has been measured at 8%, while the next nearest neighbor constant, K_2, is less than .05%. The low K_2 is obtained by rotating adjacent cavities by 90^o.

TABLE II X-BAND COAXIAL STANDING-WAVE LINEAR ACCELERATOR DESIGN PARAMETERS

Accelerator Structure	Type I	Type II
Electron Energy (MeV)	1.5	4.0
Accelerator Length (cm)	20	22
Number of Cavities	14½	14½
Effective Shunt Impedance (MΩ)	22	26
Available Peak Power (MW)	0.2	1.5
Average RF Power (KW)	0.2	1.5
RF Pulse Width (μsec)	2.5	4.0
Peak Beam Current (mA)	80	200
Beam Pulse Width (μsec)	2.1	3.6
Beam Unloaded Coupling Factor	2.0	2.0
Load Line (MeV)	2.1—6.7i	6.2—7.3i
Radiation Output at 1m (Rad/min)	25	750

Accelerator Development and Low Power Test

Both a 1.5 MeV and 4.0 MeV X-Band accelerator were designed with the new coaxial cavity geometry. Table II summarizes the accelerator design parameters. The 1.5 MeV accelerator will be powered by a 230 KW pulsed coaxial magnetron (Varian SFD-349 HS), while the 4 MeV accelerator will use a 1.7 MW pulsed coaxial magnetron (Varian SFD-303B). Both guides are approximately 20 cm in length. The initial layouts of the guides were determined using a simple, one dimensional model. Although longitudinal bunching was readily obtained using a three stage, graded configuration, it was anticipated that the low field levels, especially for the 1.5 MeV accelerator, would result in sharp radial losses of the beam within the 4 mm beam tunnel. To refine the radial beam characteristics of the initial designs, the beam optics code PARMELA was used. Beginning with an idealized injection beam of "quasi-electrons" distributed randomly over a representative phase space ellipse, the momentum, position, and phase coordinates of the quasi-electrons are followed down the length of the guide. Figure 3 shows a sketch of the initial one dimensional designs and the resultant beam spot profile and transmission to the end of the guide. To improve the beam spot and transmission, it was decided to try a combination of a lower field in the input cavity, and a step in the field near the midsection of the guide. This technique was found to provide effective focusing from previous studies and is fundamentally a phase-focusing technique. Figure 3, of the beam spot size down the length of the guide, indicates that a likely location is the 4th or 5th cavity for the 1.5 MeV guide. Because of the higher field level, which contributes to radial focusing, the 4 MeV guide did not require any modification

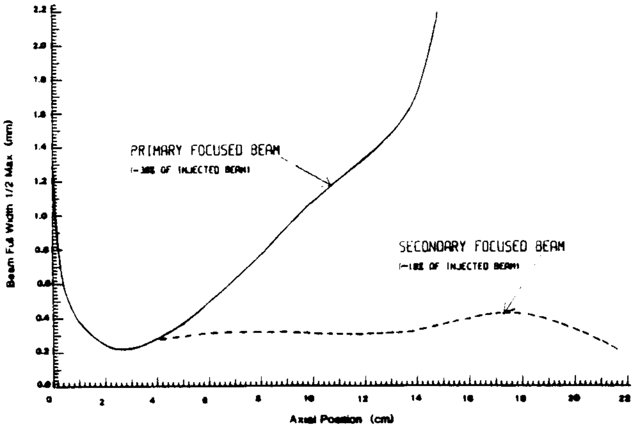

Fig. 3 1.5 MeV Beam Profile Without Focusing By Stepped Accelerating Field

beyond a lower input field. Figure 4 shows the final configurations, resulting beam spot profiles, and transmission values for the two guides. The 1.5 MeV field configuration is clearly not optimum for the shunt impedance of the accelerator. The obtainable accelerating efficiency is reduced by approximately 2%. An alternate design was examined, with a two step field in the buncher region, and a slightly higher (10%) field level in the accelerating region. Although radial focusing is not as effective, further testing may prove this design to have adequate beam characteristics, and in light of higher shunt impedance, to be more desirable.

Although a complete guide has not yet been assembled, some low power tests of partial sections have been made. A partial dispersion curve is shown in Figure 5.

Conclusion

A novel coaxial X-band cavity structure was presented, as well as the current development status of two accelerators employing the structure (1.5 MeV and 4.0 MeV). The accelerators have a small diameter, are compact, and retain a high efficiency. In addition to small size and less weight, the new design offers: 1) simplicity in machining and assembly, 2) high K_1 and low K_2, and 3) requires no post-assembly tuning. A stepped accelerating field in the buncher region provides transverse beam focusing as well as longitudinal bunching.

References

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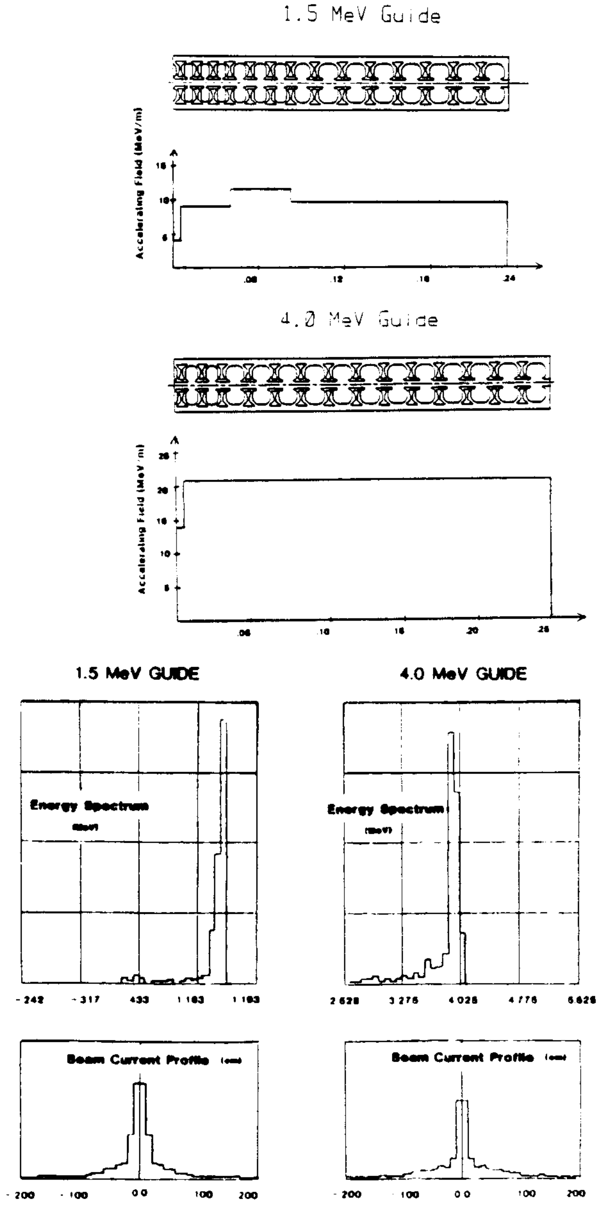

Fig. 4 Final Configurations, Energy Spectra, and Beam Current Profiles

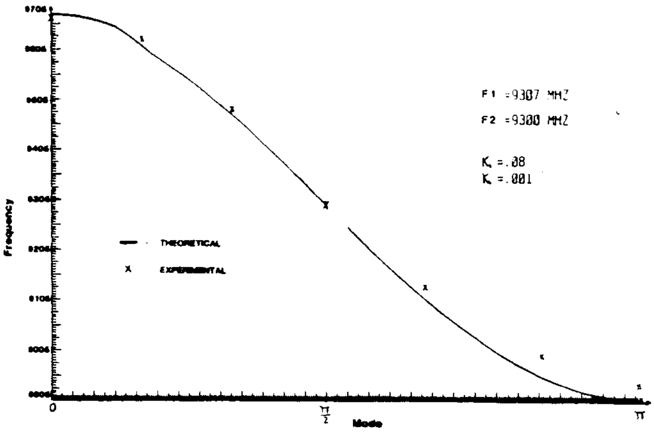

Fig. 5 Comparison of Theoretical Dispersion Curve With Measured Values