DEVELOPMENT OF AN X-BAND HYBRID DIELECTRIC-IRIS-LOADED ACCELERATOR*

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Abstract

A compact x-band hybrid dielectric-iris-loaded travelling-wave linac with constant impendence structure has been designed. By adjusting the values of β_ϕ and the numbers of cells, the beam energy of 33 MeV, the capture efficiency about 50% and the energy spread about $\pm 3\%$ with the beam current being 70 mA and the electron gun voltage being 50KeV are obtained through longitudinal dynamics calculation. The length of accelerator tube is 1.48m. The maximum accelerating gradient is less than 45MV/m. By using electromagnetic code such as MAFIA, the attenuation per unit length of structure α, the shunt impedance Z_s, the quality factor Q, the group velocity β_g and the phase velocity β_ϕ are got by optimizing the dimensions of the cavities.

INTRODUCTION

X-band high-gradient accelerator has been progressed greatly in recent years, motivated by the need for the future linear colliders in high energy physics research and for the industrial and medical application. By developing X-band high gradient accelerating structure, one can use a shorter length for a given power to achieve certain electron beam energy. There are obvious advantages for using X-band range than S-band one. First, the shunt impedance per unit length of X-band is higher than that of S-band. Second, the maximum permissible electric field strength is also higher.

One disadvantage of conventional iris-loaded accelerating structures is the high ratio of the peak surface electric field to the peak axial electric field. Typically this ratio of Es/Ea is more than 2. The high surface electric field relative to the accelerating gradient may prove to be a limitation for realizing technologies for very high gradient accelerators. A hybrid dielectric and iris loaded periodic structure can reduce *Es/Ea* to near unity, while maintaining high acceleration efficiency as measured by *r/Q* compare favourably with conventional metallic structures[1] and the r/Q values of dipole modes for the new accelerating structure are much lower than those for the iris-load accelerating structure[2]. The device is shown in figure 1.

This paper presents a design of an x-band (11.424GHz) hybrid dielectric and iris loaded travelling wave electron linear accelerator with beam energy of 33 MeV and beam current of 70 mA. The longitudinal dynamics for this accelerator and the RF parameters are calculated.

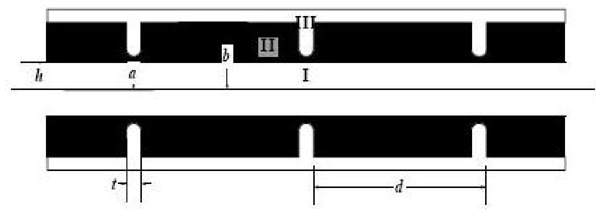

Figure 1: Sketch of regular accelerator cavities. In the figure, region I is vacuum; region II is ceramic with dielectric constant ε_r; region III is copper. *a* is the iris radius, *b* is the outer radius, and *h* is the beam hole radius. *t* is the thickness of the iris, and *d* is the length of one cell.

DESIGN OF THE NEW ACCELERATING STRUCTURE

Theory

The electron beam capture efficiency of the period structure with constant phase velocity β_ϕ is lower than the one of tapered β_ϕ and the efficiency of RF to beam conversion with constant impendence structure is lower than that of the constant gradient structure, however, a constant phase velocity and constant impendence structure are adopted in order to reduce the machining workload and simplify the microwave measurement.

The group velocity β_g of acceleration TM01 mode in a hybrid dielectric-iris-loaded structure is not only the function of beam hole radius, but also iris radius and dielectric constant. To constrain the emittance growth caused by short-range wakefields and keep higher accelerating efficiency, the group velocity is chose to be 0.03 with β_ϕ =1.

The equations about electric longitudinal dynamics along z axis for the accelerating structure are recalled here:

$$\frac{d\gamma}{dz} = \frac{eE}{mc^2}\cos\phi \qquad (1)$$

$$\frac{d\phi}{dz} = \frac{2\pi}{\lambda}\left[\frac{1}{\beta_\phi} - \frac{1}{\beta}\right] \qquad (2)$$

*Work supported by the National Nature Science Foundation of China, Grant No. 10375060, 10375061 and 10675116
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Here $\beta = \frac{1}{\gamma}\sqrt{\gamma^2 - 1}$, β is the relative velocity of electron, z is the longitudinal position, γ is the relative energy, E is the accelerating gradient, ϕ is the phase, c is the velocity of light, m is the mass of electron, β_ϕ is the phase velocity, λ is the wavelength.

The RF power distribution along the linac section and the accelerating electric field can be expressed by:

$$\frac{dP}{dz} = -2\alpha P - i_b\sqrt{2\alpha Z_s P} = -2\alpha P - i_b E \quad (3)$$

$$E = \sqrt{2\alpha Z_s P} \quad (4)$$

Here P is RF power, α is the attenuation per unit length of structure, Z_s is the shunt impedance, i_b is the beam current.

Based on the above equations, the phase velocity and numbers of cavities and the accelerating gradient of accelerator cavities can be optimized to gain high energy increase and high capture efficiency under the conditions of the given RF power input, voltage input of the electron gun and beam current, while the length of the accelerator is shorter.

Simulation and Calculation

First, we assume that the voltage input of the electron gun is 50kV, the RF power input is 20MW and the pulse beam current is 70mA. The values of optimized β_ϕ (0.5, 0.85, 1) and the numbers of cells (3, 5 and 162 respectively) for three sections are obtained by large numbers of optimized calculations. The distribution of β_ϕ along z axis is shown in figure2.

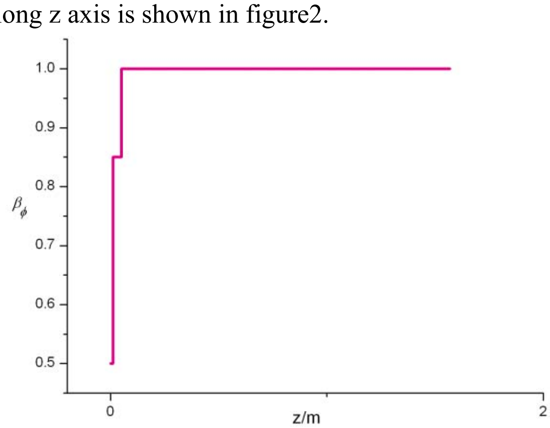

Figure 2: The distribution of β_ϕ along z axis.

By using electromagnetic code such as MAFIA [3], the attenuation per unit length of structure α , the shunt impedance Z_s , the quality factor Q, the group velocity β_g and the phase velocity β_ϕ are got by optimizing the dimensions of the cavities. The structure parameters and performance parameters for the three sections are given in table 1 and table 2.

Table 1: The Structure Parameters of Accelerator Cavities ($\varepsilon_r = 6$)

Type	*t/mm*	*a/mm*	*b/mm*	*d/mm*	*h/mm*
#1	1	4	5.839	4.374	2
#2	1	4	5.451	7.435	2
#3	1	3.23	5.226	8.747	2

Table 2: The Performance Parameters of Accelerator Cavities

Type	β_ϕ	α	***Rs*** (MΩ/m)	***Q***	β_g	***No.***
#1	0.5	0.444	15.14	3299.8	0.082	3
#2	0.85	0.275	56.09	4666.0	0.093	5
#3	1	0.907	56.73	4393.8	0.03	162

Using above equations and MATHEMATIC code, we can get the variations of residual power and the accelerating gradient along accelerator tube, which is shown in figure3 and figure4 respectively. The phase trajectory is shown in figure 5. The result by tracking 501 particles from -π to π shows that the capture efficiency is 49.7%. The energy increase is shown in figure 6. The beam energy is 33MeW and the energy spread about $\pm 3\%$. The relation of the energy increase vs. the beam current loading is shown in figure7. The relation of energy increase vs. input power is shown in figure 8.

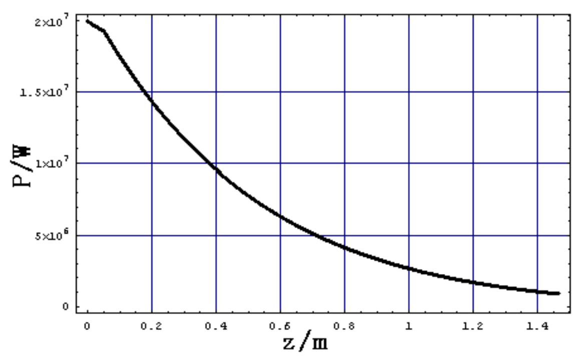

Figure 3: The residual power variation along z axis.

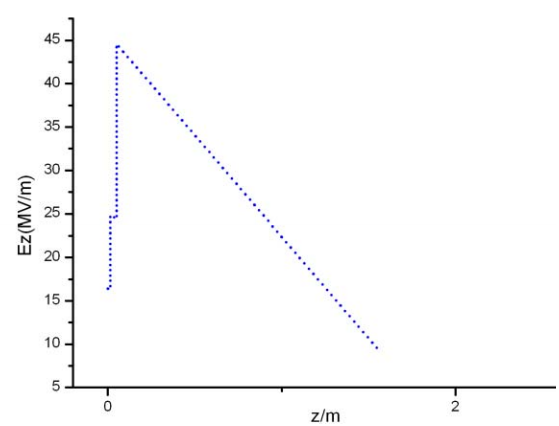

Figure 4: The accelerating gradient variation with beam loading along z axis.

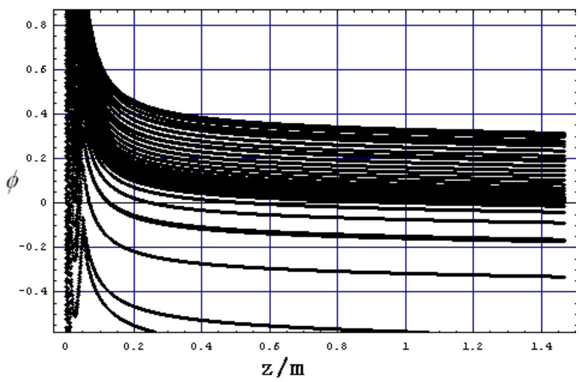

Figure 5: The phase trajectory along z axis.

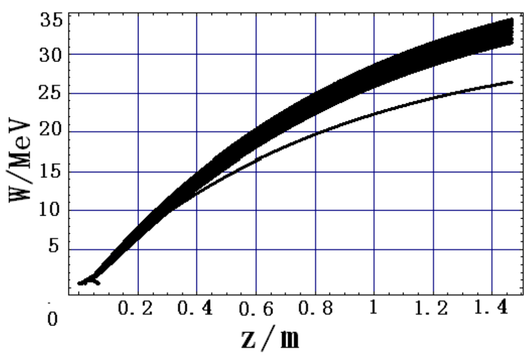

Figure 6: The energy increase curve along z axis.

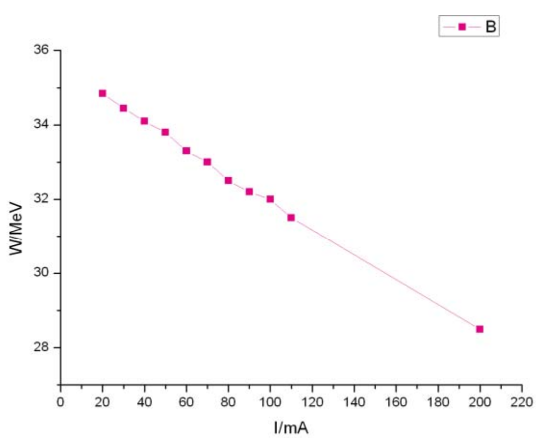

Figure 7: Curve of beam current loading (P_0=20MW).

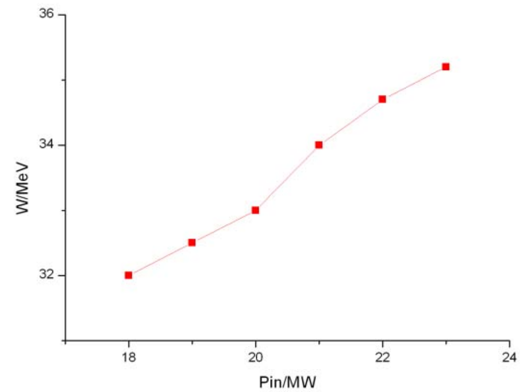

Figure 8: Energy vs. input RF power (I=70mA).

Based on the above results, the beam characteristics are shown in table 3.

Table 3: Critical Parameters of X-band 33MeV TW Accelerator

Main Parameters	***Designed Value***
Energy	33MeV
The length of accelerator tube	1.48m
Operation mode	$2\pi/3$
Structure type	Constant impedance
Input peak power	20MW
Operation frequency	11.424GHz
Input voltage of electron gun	50kV
Pulse beam current	70mA
Shunt impedance	56.73 MΩ/m
Q	4393.75
Capture efficiency	49.7%
Energy spread	±3%
Filling time	164.5ns

CONCLUSIONS

With the help of MAFIA code and MATHEMATIC code, a compact x-band (11.424GHz) hybrid dielectric and iris loaded travelling wave electron linear accelerator was designed. The beam energy is 33 MeV. The capture efficiency is about 50% and the energy spread is about ±3% with the beam current being 70 mA and the electron gun voltage being 50Kev. The length of accelerator tube is 1.48m

REFERENCES

[1] Zou, P., Xiao L., L., Sun X. et al. J.Appl. Phys., 2001, 90(4):2017-2023.

[2] Cong-feng Wu etc. Model cavity investigations and calculations on HOM for an x-band hybrid dielectric-iris-loaded accelerating structure, PAC07

[3] MAFIA, the MAFIA Collaboration, December 1996