RESEARCH OF L-BAND DISK-LOADED WAVEGUIDES TRAVELLING WAVE ACCELERATING STRUCTURES FOR A HIGH POWER LINAC

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Abstract

L-band Electron Accelerator has been widely utilized for industrial irradiation. In this paper, we designed a constant-impedance, disk-loaded structure which operates on 2π/3 mode. CST and SUPERFISH code were used for the design of bunching and accelerating cavities respectively. The geometrical parameters of the cavities were studied, and optimized RF parameters were obtained. We calculated the beam dynamics which presented that the electrons can be accelerated to 50 MeV. The model cavities have been fabricated and tested. Some valuable experimental results were obtained, which can provide a beneficial datum for the design and manufacture of L-band travelling-wave accelerating structures of 50 MeV LINAC.

INTRODUCTION

Electron linear accelerators have been widely used for industrial applications, such as cargo inspection, irradiation processing, food preservation sterilization and so on. [1] In order to meet the needs of the production of radioactive drugs via photonuclear reaction, it usually requires the accelerators to provide electron beams with higher energy and better stability. In order to get higher beam energy, L band travelling-wave accelerating structure is a good candidate which can also simplify the accelerating system.

In this paper, an L-band disk-loaded waveguides travelling wave accelerating structure for a high energy LINAC of 50 MeV was developed. SUPERFISH, a well-known RF design code [2], was used for the design of cavities and beam dynamics was simulated with MATLAB code. At the same time, model cavities have been fabricated and the experimental results were displayed.

DESIGN OF THE ACCELERATING STRUCTURE

We designed a constant-impedance structure which operates on 2π/3 mode and the operating frequency is 1.3 GHz. This structure consists of 3 bunching cavities and 63 uniform accelerating cavities. (Shown in Fig. 3) In order to accelerate the particles continuously, the length of each cavity must equal βλ/3 (λ refers the RF wavelength and β is electron traveling speed over light speed). The schematic diagram of the 1/4 section of the uniform accelerating cavity is shown in Fig. 1. In this figure, D refers the cycle length, 2a is beams aperture, t is the disk thickness, b is waveguide radius, d is disk interval and ρ is the disk hole edge radius. Subtle changes of the above dimension would affect the basic parameter of the accelerating structure. So, it's of great importance to get an accurate cavity dimension, which was calculated with two-dimensional SUPERFISH code.

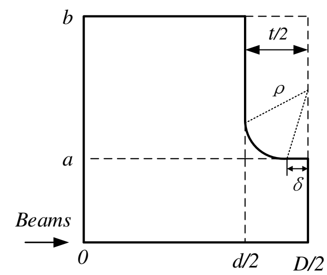

Figure 1: Schematic diagram of cavity dimension.

The dimensions of the uniform cavity was optimized in order to get better parameters of accelerating structure. The optimized dimensions are shown in Table 1 and the relevant basic parameters of the accelerating structure are listed in Table 2.

Table 1: The Accelerating Cavity Parameters

parameter	value(mm)
D	76.8699
d	69.8699
2a	40
2b	179.2242
t	7
ρ	3.6

Table 2: Basic Parameters of Accelerating Structure

parameter	value
Frequency（f_{rf}/GHz）	1.3
Quality factor (Q)	21333.0
Attenuation constant (α)	0.07802
Shunt impedance (R_s/MΩ·m^{-1})	51.58
Group velocity (v_g)	0.008216

In this paper, SUPERFISH code was used to calculated the effect of small changes in size of accelerating cavity dimension on basic parameters. It can be seen that the RF frequency changes linearly with the cavity dimension as the Fig. 2 shows and the changing rate were listed in Table 3. It can be seen that the waveguide radius b have the great influence on RF frequency and the effect of cycle length D and δ on f is relatively small in Table 3.

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Table 3: RF Frequency Changing Rate with Different Cavity Dimensions

Cavity dimension derivative	Changing rate (kHz/µm)	Standard error
$\partial f / \partial t$	0.69205	0.00142
$\partial f / \partial r$	-1.27936	0.00391
$\partial f / \partial a$	2.89212	0.00271
$\partial f / \partial \delta$	-0.33764	0.00801
$\partial f / \partial b$	-14.92903	0.00334
$\partial f / \partial D$	-0.27264	0.000302

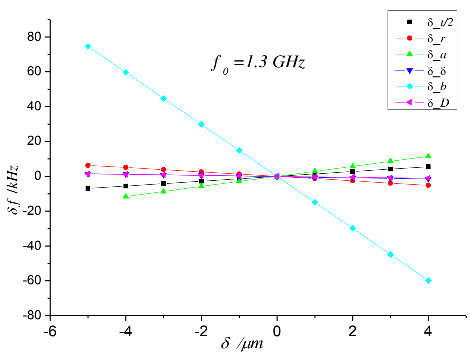

Figure 2: RF frequency changing rates with different cavity dimensions.

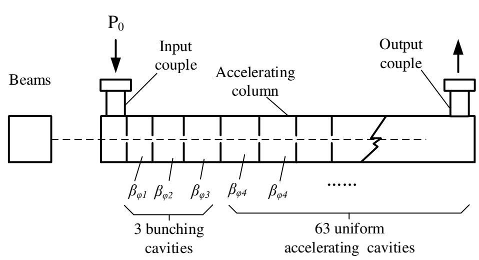

Figure 3: Schematic diagram of the accelerating tube.

BEAM DYNAMICS

CST code was used to calculate the bunching cavity size, shunt impedance and quality factor etc. under different phase velocities, which can be used to simulate the bunching cavity parameters.

Figure 3 shows the schematic diagram of the accelerating tube. The electron beam generated by the electron gun is accelerated in the tube. Different combination of β_φ in the bunching cavities can result in different parameters of beam dynamics. The beam loading effect was taken into account in the simulation of beam dynamics.

The voltage of the electron gun is 50 kV and the input Power from the coupler is 10 MW. The beam current is design to be 0.3 A. In this paper, the parameters of the three bunching cavities and uniform accelerating cavities were set as follows:

$\beta_{\varphi 1}$=0.56 (bunching 1), $\beta_{\varphi 2}$=0.68 (bunching 2)

$\beta_{\varphi 3}$=0.95 (bunching 3), $\beta_{\varphi 4}$=0.9999 (63 uniform cavities)

The beams dynamics was calculated with a self-developed program on MATLAB platform and the results are shown in Figs. 4 and 5. Figure 4 refers the phase orbits of electrons with different initial phase. Figure 5 refers the energy gain of electrons with different initial phase and it could reach 50 MeV and the relative energy spread is small, which meets our design requirements.

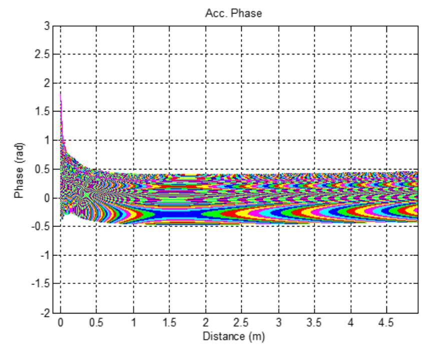

Figure 4: Phase along the accelerating cavity.

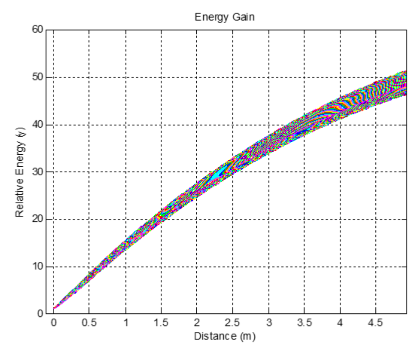

Figure 5: Energy gain along the accelerating cavity.

RF COLD TEST

Four complete cells model cavities and two half-cells model cavities were fabricated in NSRL workshop and both were made up with Aluminum. The two half-cells model cavities were placed at the left and right sides of test cavity (as 1 and 4 in Fig. 6). RF signal was fed into the cavity with a monopole antenna and the signal was analyzed with the network analyzer Agilent E5071C meanwhile. The monopole antenna and network analyzer was connected with N-type connector in this experiment.

Figure 6 gives a brief drawing of the whole experiment platform and the physical map are showed in Fig. 7.

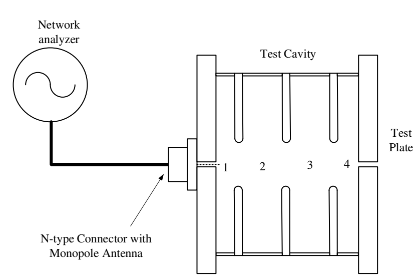

Figure 6: The experiment schematic drawing.

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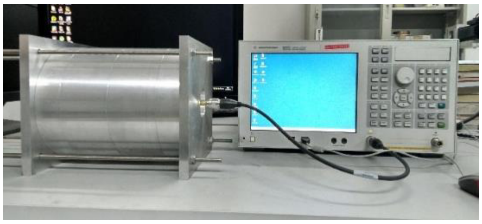

Figure 7: Physical drawing of the testing platform.

There exist π/ 2 model for one whole cavity and two half, π/ 3 and 2π/ 3 models for two whole cavities and two half cavities. At the same time, there are π/ 4, 2π/ 4, 3π/ 4 for three and two half cavities. π/ 5, 2π/ 5, 3π/ 5 and 4π/ 5 for four and two half cavities. Experimental test was performed under temperature 20°C and humidity 66% and the RF frequency results of different testing cavities (with different numbers of whole cavities) under this condition were showed in Fig. 8.

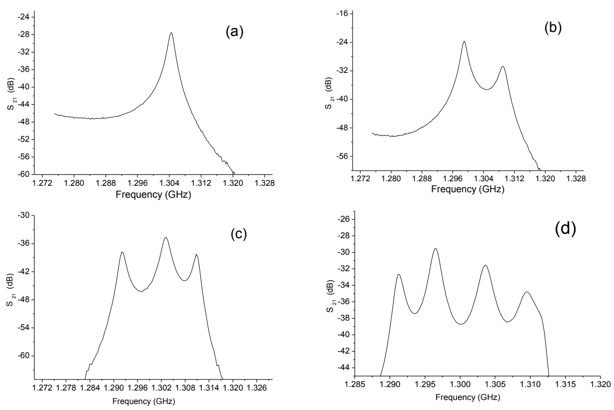

Figure 8: Testing result of cavities. (a) refers S_{21} curves of one and two half cavities; (b) refers two and two half cavities; (c) is three and two half cavities; (d) is four and two half cavities.

The cool test was conducted under atmosphere condition while the simulation was under the vacuum assumptions. The testing resonant frequency f_r and the vacuum resonant frequency f_0 was related in the following formula:

$$f_r = \frac{f_0 + \Delta f_T}{\sqrt{\varepsilon_r}} \quad (1)$$

The ε_r stands for the air relative permittivity which was defined as follows:

$$\varepsilon_r = 1 + 210\times10^{-6}\frac{P_d}{T} + 180\times10^{-6}\left(1+\frac{3580}{T}\right)\frac{P_W}{T} \quad (2)$$

P_d and P_w were the pressure (the unit was Torr) that the dry air and the water vapor provide. $P_w=P_s\times H$, $P_d=760-P_w$ and the Ps was the humidity related saturated vapor pressure. The Δf_T is the frequency difference resulting from the difference between testing and working temperature, which was defined as:

$$\Delta f_T = \frac{\partial f}{\partial T}\bullet\Delta T \quad (3)$$

The temperature affected coefficient measured was -40 kHz/°C. On this condition, the frequency difference Δf_P out of the pressure difference is -0.413 MHz. the testing frequency of the network analyzer is 20 MHz and the related measured resolution Δf_S is ±0.0125 MHz.

The directly testing frequency f_t is 1.29905 GHz. Considering the above errors, the experimental RF frequency equal:

$$\begin{aligned} f &= f_t - (f_P + f_s) \\ &= 1299.05 - (-0.413 + 0.0125) = 1299.4505\ \text{MHz} \end{aligned} \quad (4)$$

Table 4: Comparison of Calculated and Experimental RF Frequency Results

Model	Calculated results f_1/GHz	Testing results f_2/GHz	(f_1-f_2) /MHz	Relative deviation
2π/ 3	1.299 999 704	1.299 450 5	0.549 204	0.042%

In Table 4, it can been seen that the difference between the calculated and experimental RF frequency results is very little (about 0.042%). The present work demonstrates numerical simulation can provide a beneficial datum for the design and manufacture of L-band travelling-wave accelerating structures.

CONCLUSIONS

In this paper, the bunching and accelerating cavities was designed, some experimental model cavities were fabricated and tested. At the same time, beam dynamics was calculated and the simulation have a great agreement with the experiment. Designing the structures systematically, fabricating the model cavities and making tests can provide an integrated and systematic method for the research and design of an L-band accelerating structure and fabrication of the L-band LINAC.

REFERENCES

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[2] Halbach K, Holsinger R F, Jule W E et al., "Properties of the cylindrical RF cavity evaluation code SUPERFISH", in *Proc. of 1976 Proton Linac Conf.* 1976, p.122.