20MEV ELECTRON LINEAR ACCELERATOR IN NANJING UNIVERSITY

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1.Abstract

Characteristics (including the beam loading, injection, power and frequency characteristic) of the electron linear accelerator with RF-feedback under optimal coupling are described. The beam loading characteristic has a steep slope in the range of small beam currents and a slight slope in the range of large currents. The linac efficiency is maximal for each beam current. The frequency characteristic of the linac with RF-feedback is smoother than a usual linac.

The optimal coupling is realized by means of adjusting the phase shifter in the feedback loop and the variable directional coupler which is located between the main waveguide and the feedback loop. A three-dimensional figure shows that the power in the feedback loop has only one maximum when the phase shift and coupling changes. It is convenience to adjust the linac with RF-feedback by an adaptive optimal phase following system under frequency stabilization.

2.Description of the linac

We are constructing a 20 Mev electron linear accelerator with RF-feedback under optimal coupling.[1,2] Its scheme is shown in fig.1.

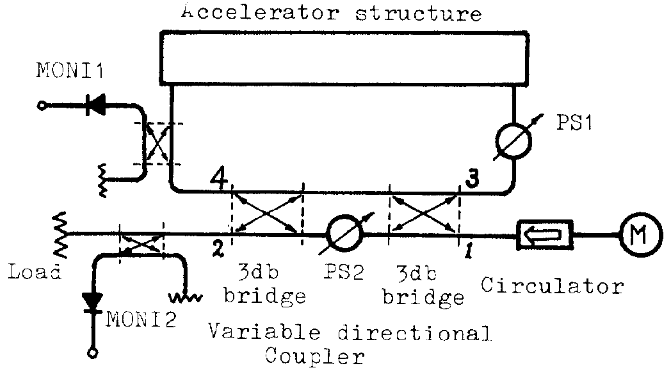

Fig.1. The scheme of the linac with feedback under optimal coupling.

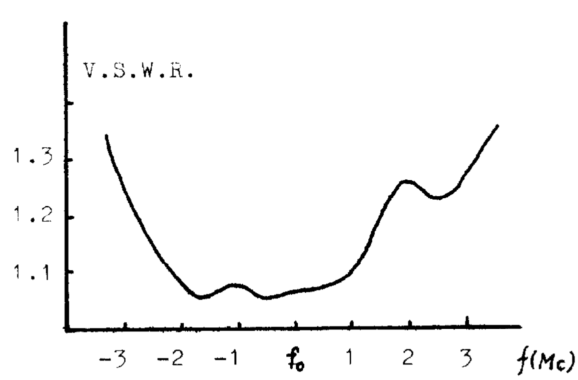

Fig.2. The band of the accelerator

The accelerator structure is a constant impedance structure. Its length is 2.57m. Its attenuation is 0.185 nepers. The band of the accelerator structure is shown in fig.2. The feedback loop consists of a phase shifter(PS1), a variable directional coupler which includes two 3db bridges and another phase shifter(PS2), a monitor(MONI1) and some waveguide components. The total attenuation of the feedback loop (including the accelerator structure) is 0.268 nepers. There is another monitor(MONI2) in front of the load. A 4.5MW magnetron is used as a power source. A circulator is inserted between the magnetron and the variable directional coupler.

3.Adjustment of the linac

It is well known that for a linac with RF-feedback there is a resonant phase, at which the power to the accelerator can be increased to a maximum. Suppose that P_1,P_2,P_3 and P_4 is the power at port 1, port 2, port 3 and port 4 respectively in fig.1. We can get

$$P_4/P_1=M^2 \tag{1}$$

$$M = \frac{C}{1-T\sqrt{1-C^2}\cos\varphi} \tag{2}$$

Where M is the field multiplication factor, T the transmission coefficient, $T=\exp(-\tau)$, τ is the total attenuation in the feedback loop (including beam loading), C the voltage coupling coefficient of the coupler and φ the phase of the feedback loop.

When $\varphi=2n\pi$ (n=0,1,2,······)

$$\cos\varphi=1$$

eq.(2) becomes

$$M = \frac{C}{1-T\sqrt{1-C^2}} \tag{3}$$

It is a resonant loop. M is a maximum for the linac with feedback under fixed coupling.

When we adjust the coupler to make it optimal coupling, i.e.

$$C=\sqrt{1-T^2}$$

it makes M supreme

$$M = \frac{1}{\sqrt{1-T^2}} \tag{4}$$

In our linac φ can be adjusted by PS1. $\varphi=\theta_0+\theta_1$, θ_0 is the phase of the loop for a given frequency, θ_1 the phase shift of PS1. C can be adjusted by PS2, $C=\cos(\theta_2/2)$. θ_2 is the phase shift of PS2. So we can adjust θ_1 and θ_2 to make M supreme. A three-dimensional figure is shown in fig.3.

In the same way, we can get

$$P_2/P_1=N^2 \tag{5}$$

$$N = \sqrt{1-C^2} - \frac{C^2T\cos\varphi}{1-T\sqrt{1-C^2}\cos\varphi} \tag{6}$$

Its three-dimensional figure is shown in fig.4. When $\cos\varphi=1$ and $C=\sqrt{1-T^2}$, i.e. M is supreme,

$$N = 0 \tag{7}$$

In this case we can get a microwave envelope from the monitor 1. It is shown in fig.5. Another microwave envelope from the monitor 2 is shown in fig.6.

For the given frequency and beam current, at first we can adjust the shifter 1 to make the loop resonant then adjust the shifter 2 to make it optimal coupling. In this case M is supreme.

When the frequency drifts or/and beam current changes we can use an adaptive optimal phase following system under frequency stabilization to make the linac with feedback resonant and optimal coupling all along.[3] The linac with RF-feedback has maximal efficiency.

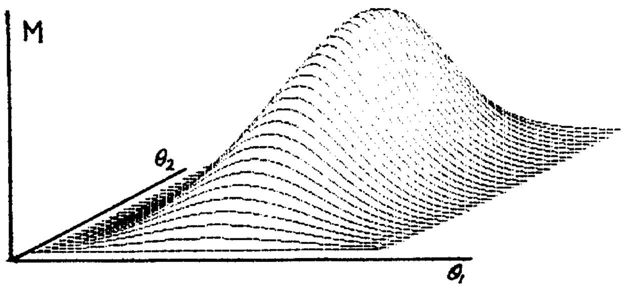

Fig.3. M versus θ_1 and θ_2

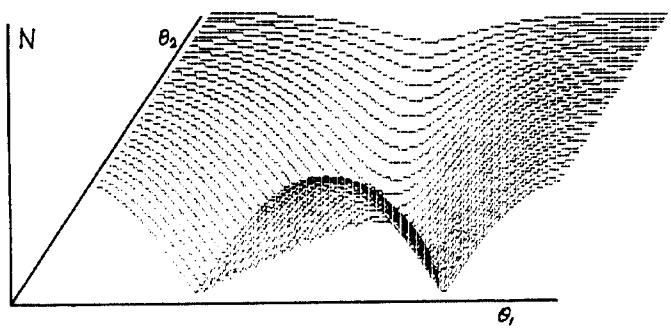

Fig.4. N versus θ_1 and θ_2

Fig.5. Microwave envelope from monitor 1.

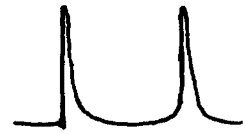

Fig.6. Microwave envelope from monitor 2.

4. Characteristics of the linac

According to the equations of longitudinal dynamics motion we calculate characteristics of the linac. The beam loading characteristic is shown in fig.7. It is a ideal beam loading characteristic. The linac has maximal efficiency for different beam current.

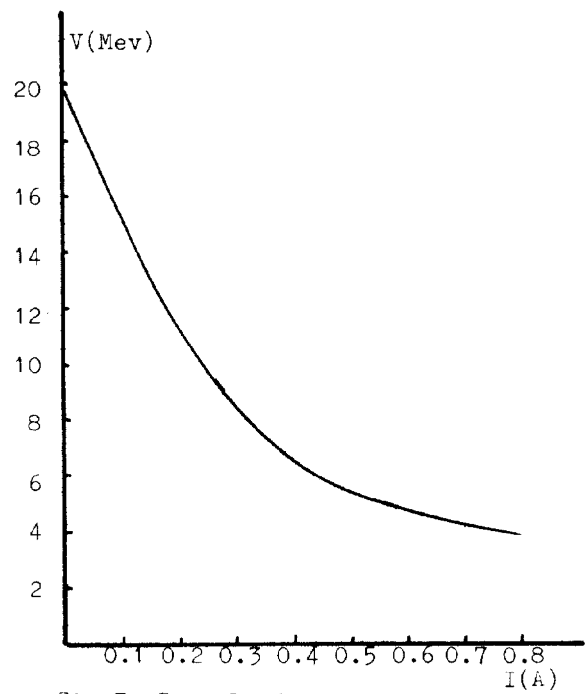

Fig.7. Beam loading characteristic

The frequency characteristic is shown in fig.8. The curve 1 is the frequency characteristic of the linac without an adaptive optimal phase following system, and the curve 2 with this system. The curve 2 is smoother than the curve 1. For a usual linac, the frequency drifting, parameters of the accelerator structure cnange due to its dispersion. They make the phase velocity of the wave and the strength of electric field vary, then make the electron energy vary. For our linac with feedback, besides above factor, there is another factor. When the frequency drifts the phase of the feedback loop changes too. It makes the loop detune, i.e. makes the field multiplication factor M decrease. In the end, the electron energy will descend. It is to be noted that in the linac with feedback the latter influences more severely than the former. When we use an adaptive optimal phase following system, the latter influence can be canceled.

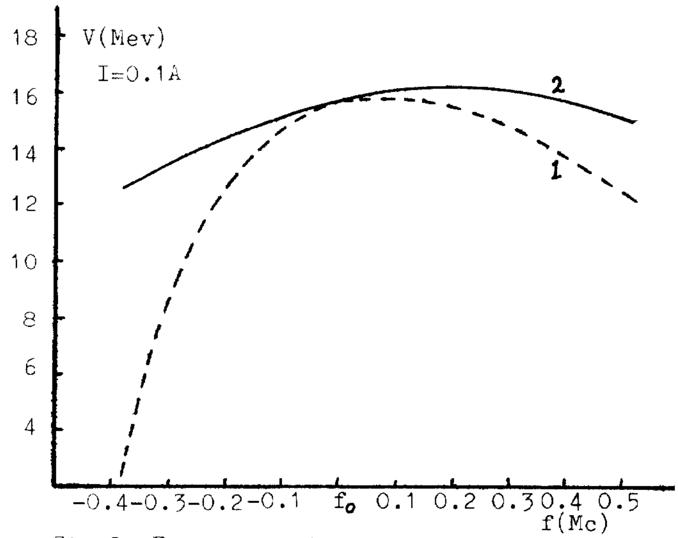

Fig.8, Frequency characteristic

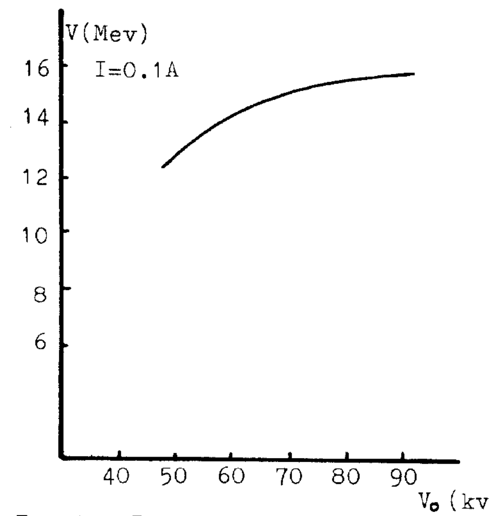

Fig.10. Injection characteristic.

Only the former factor influences electron energy. So its frequency characteristic is curve 2. In addition we can adopt large disk-hole diameter in the linac with feedback. It follows that its despersion is smaller than a usual linac which can attain the same energy. It will be seen from this that only if we use an adaptive optimal phase following system, the linac with feedback has the less restrictive frequency tolerance.

The power characteristic is shown in fig.9.

The injection characteristic is shown in fig.10.

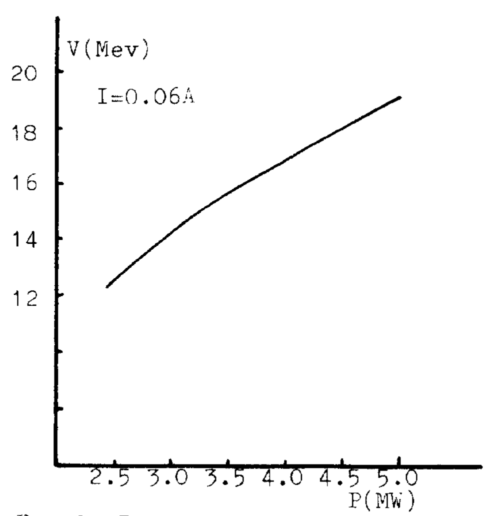

Fig.9. Power characteristic.

References

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2. Wang Yuan-ling, Lai Qi-ji, Journal of Nanjing University (Natural Sciences Edition) Vol.20, No.4, Dec. 1984, 675.
3. Xi De-xun, "an Adaptive optimal phase following system under frequency stabilization". (Presented at this conference. To be published.)