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A MONITOR HAVING LOTS OF FUNCTIONS FOR A LINAC WITH FEEDBACK

Wang Yuan ling, Lai Qi ji, Yao Nai guo

Department of Physics, University of Nanjing, Nanjing, China

Abstract

In our 20 Mev electron linear accelerator with feedback we use a detector in the feedback loop to observe a microwave envelope which includes a lot of information. Under the accelerator operating condition from the micro wave envelope we can monitor the frequency, power, phase and beam loading and calculate the attenuation constant, group velocity, filling time and the field multiplication factor. We can also observe some unstable phenomena.

1. Introduction

It is well known that some of parameters of the accelerator structure (such as attenuation constant, group velocity, filling time and so on) can only be measured under low power level condition in the general linac. However, not only can we monitor the frequency and power , but also we can measure those parameters under accelerator operating condition in our linac with feedback.[1] We use a disk-seal tube as a detector. It connects with a terminal of the directional coupler which is inserted in the feedback loop and placed in front of the accelerator structure. The sketch is shown in fig.1. A signal from the detector is sent to a ossilloscope. We can see a microwave envelope on the screen. The photograph of the microwave envelope is shown in fig.2. This envelope contains much information. Let us analyse one by one.

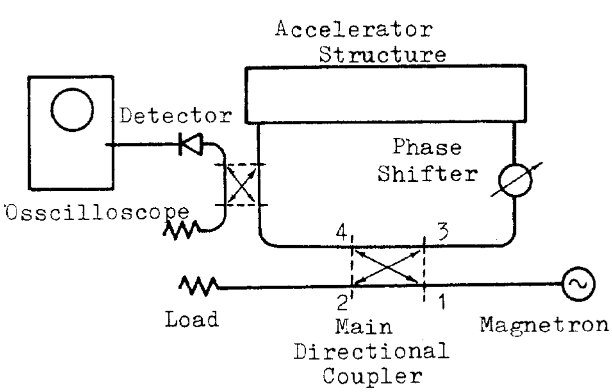

Fig.1

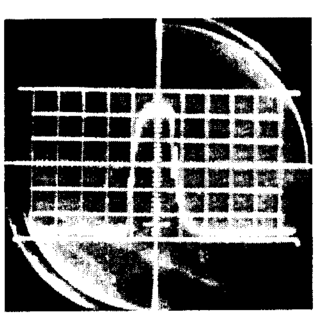

Fig.2

2. The monitor of the frequency and phase

In a constant impedance linac with feedback under zero beam loading condition the energy gain of electrons is given by:[2]

$$V = MoEoL\,\frac{1-e^{-\tau}}{\tau} \qquad (1)$$

and the field multiplication factor is

$$Mo = \frac{C}{1-e^{-(\tau+\tau')}\sqrt{1-c^2}\cos\theta} \qquad (2)$$

where Eo is accelerating field intensity in the accelerator, $Eo=\sqrt{2Po\alpha_o r_o}$, Po the power from the external power source, r_o the shunt impedance per unit length, α_o the attenuation in nepers per unit length, L the length of the accelerator structure, τ the attenuation of the accelerator structure , $\tau=\alpha_o L$, τ' the attenuation of the waveguide system and C the voltage coupling coefficient of the main directional coupler.

$$\theta = \frac{2\pi}{\lambda_{ga}} L + \frac{2\pi}{\lambda_{gw}} L_w \qquad (3)$$

where λ_{ga} is the waveguide wavelength of the accelerator structure, λ_{gw} the one of waveguide system and Lw the length of the waveguide system. Therefore, θ includes information of the frequency and phase.

In eq. (2) Mo attains its maximal value when $\theta=2n\pi(n=0,1,2\ \ )$. The height of the envelope is also maximal. It is called resonance. We refer to the frequency as fo and the phase as $\theta=0$. The height decreases with the change of θ or f. When $\theta=\pm\pi$, f=fo or $\theta=0$, $f=fo\pm\Delta f$ the Mo and the height of the envelope attain its minimal value. The changing of the frequency of $2\Delta f$ corresponds to the change of phase of 2π. Their microwave envelopes are shown in fig.3. So by means of observing the microwave envelope we can tune the resonance of the feedback loop and monitor the changing of the frequency or phase.

In our linac with feedback $2\Delta f$ is about 3MHz. We can monitor the changing of the frequency of 50KHz.

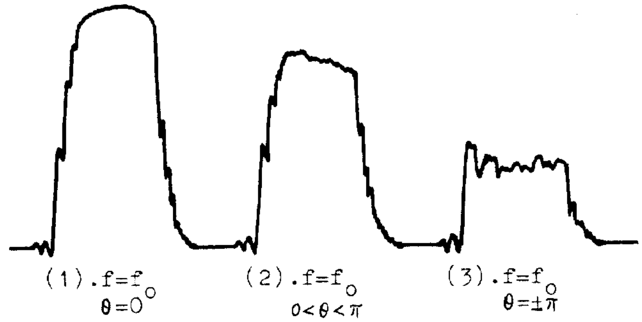

Fig.3

3. Measurement of the filling time and calculation of the group velocity

In the fig.2 we can see that the envelope has many steps which characterize the superposed process of the field step by step. The width of each step is time during which the microwave energy circulates once in the feedback loop. It includes two parts: one is time of the microwave passing through the accelerator structure; another is time through the waveguide system.

$$T = T_1 + T_2 \qquad (4)$$

According to the definition of the group velocity we can obtain:

$$T = \frac{L}{V_{ga}} + \frac{Lw}{V_{gw}} \qquad (5)$$

where Vga is the group velosity of waves in the accelerator structure and Vgw is one in the waveguide. The latter is known. So we can obtain

$$Vga = \frac{L}{T - \frac{Lw}{Vgw}} \qquad (6)$$

From fig.2 the measured value of the filling time is 0.3us. We obtain Vga=0.0292C (c is the velocity of the light). Our designing value is 0.0298C. It is satisfactory.

4. The field multiplication factor and the attenuation of the feedback loop

Under resonance condition we can calculate the total attenuation of the feedback loop from eq.(2) if we have obtained the field multiplication factor Mo. $\tau+\tau'$ can express in nepers as follows

$$\tau+\tau' = \ln \frac{\sqrt{1-c^2}}{1-\frac{c}{Mo}} \qquad (7)$$

In our linac with feedback the coupler is fixed and c=0.707. In order to obtain Mo let us analyse the process of the field building-up in the feedback loop. Assume first that the directional coupler is ideal and the detector has a linear law characteristic. When a wave E_1 enters the port 1 of the main directional coupler in fig.1, the wave transmitted past the coupling section to port 4 is CE_1. Then the wave CE_1 passed through the feedback loop becomes $CE_1 e^{-(\tau+\tau')}$ and arrives at port 3. Both the waves at port 1 and at port 3 transmit past the coupling section and superpose at port 4. They become $CE_1+CE_1\sqrt{1-c^2}\,e^{-(\tau+\tau')}$. With the wave superposing again and again, a stable value of $\frac{CE_1}{1-e^{-(\tau+\tau')}\sqrt{1-c^2}}$ is obtained at port 4 finally. So the field multiplication factor Mo is equal to $\frac{C}{1-e^{-(\tau+\tau')}\sqrt{1-c^2}}$. We assume that in the envelope the height of the first step is H_{f1}, one of the second step H_{f2} and the height of the total envelope is H. They are shown in fig.4. We can obtain

$$\left.\begin{aligned} H_{f1} &= CE_1 \\ H_{f2} &= CE_1 + CE_1\sqrt{1-c^2}\,e^{-(\tau+\tau')} \\ &\vdots \\ H &= \frac{CE_1}{1-e^{-(\tau+\tau')}\sqrt{1-c^2}} = M_oE_1 \end{aligned}\right\} \qquad (8)$$

therefore

$$M_o = \frac{H}{H_{f1}}C \qquad (9)$$

From eq.(9) we can attain Mo conveniently. Unfortunately, the detector we used has a non-linear low characteristic at the beginning part. It is the non-linearity that influences the height of H_{f1}. To eliminate the influence of the non-linearity let us analyse the back-porch of the microwave envelope. Assume that a stable value has arrived before the pulse ends. When the pulse ends the signal at port 1 is zero. The value at port 3 is $ME_1e^{-(\tau+\tau')}$. The height of the first step bounced is

$$H_{b1} = M_oE_1 - M_oE_1\sqrt{1-c^2}\,e^{-(\tau+\tau')} = CE_1 \qquad (10)$$

We have verified that $H_{b1}=H_{f1}$. We need not consider the influence of non-linearity oh the H_{b1}. So we can obtain

$$M_o = \frac{H-H_{f1}+H_{b1}}{H_{b1}}C \qquad (11)$$

In our linac with feedback under zero beam loading condition we get Mo=1.48, $\tau+\tau'$=2.63db. This measurement is satisfactory.

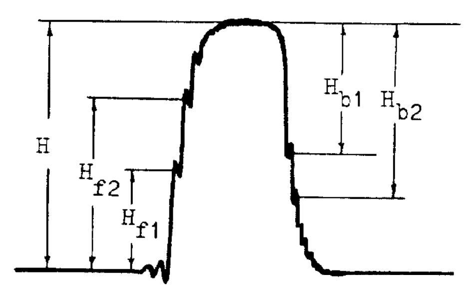

Fig.4

5. The measurement and monitor of the beam current

Under beam loading condition we can derive the field multiplication factor

$$Mb = \frac{C-\sqrt{1-c^2}\,i\,Y_o\,(1-e^{-\tau})e^{-\tau'}/E_o}{1-\sqrt{1-c^2}\,e^{-(\tau+\tau')}} \qquad (12)$$

Because Mb always is less then Mo (i=0), the top of the envelope with beam loading will descend. Its picture is shown in fig.5.

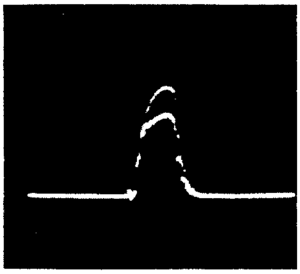

Fig.5. Upper envelope for i=0, lower envelope for i=150mA.

From fig.5 we can obtain the beam current

$$i = \frac{H_o - H_i}{H_o} \cdot \frac{C\sqrt{2P_o \alpha_o \gamma_o}}{\sqrt{1-c^2}\,\gamma_o (1-e^{-\tau})e^{-\tau'}} \qquad (13)$$

Where H_o is the height of the envelope without beam current under resonance condition and H_i is one with beam current.

Using this method we can also measure the intensity of beam current.

6. Observation of unstable phenonena

We can observe some unstable phenonena from the microwave envelope.

(1) When the deQing circuit is out of order in modulator, the top of envelope appears the jitter. It is shown in fig.6.

(2) When the electric breakdown in the waveguide the envelope will descend down. It is shown in fig.7.

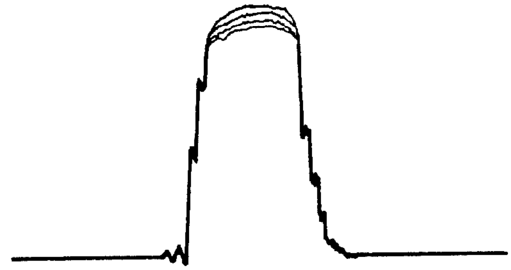

Fig.6

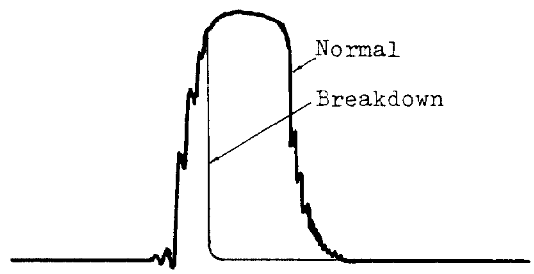

Fig.7

References

1.Linac Group of Nanjing University:"A 20 Mev medical electron linear accelerator." Proceedings of 1979 Accelerator conference P.149. (in Chinese)

2.Wang Yuan ling: IEEE Trans. Nucl. Sci. Vol. NS-28 (1981) 3526.