STUDY OF CHARACTERISTICS OF TRAVELING WAVE RESONANT RING FOR HIGH POWER CW ELECTRON LINEAR ACCELERATOR

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ABSTRACT

Some characteristics of a traveling wave resonant ring with a linac are presented. By introducing a beam loading factor it becomes easy to calculate the multiplication factor M with beam loading. Q value and phase characteristic are also described.

1, Introduction

A traveling wave resonant ring (TWRR) was adopted in development of a high power CW electron linear accelerator for the study to transmute radioactive wastes.

The linac is to be operated at a room temperture and is energized by two 1.2MW CW L-band klystrons to produce an electron beam with an energy of 10Mev and the maximum current of 100mA. The average beam power is 200kW-1MW depending on the duty factor 20%-100%. Fig.1 shows one unit of an accelerator section with a TWRR.

Because of the low accelerating electric field and the high average RF power TWRR can enhance the electric field M times (M is called multiplication factor) and improve the accelerator efficiency.

2, Calculation of multiplication factor M

For a simple TWRR, M can be calculated by following formula

$$M = \frac{b_4}{a_1} = \frac{jC}{1 - T\sqrt{1-C^2}\,\exp(-j\beta Lw)} \qquad (1)$$

where C is coupling coefficient, T is voltage transmission coefficient $T = \exp(-\alpha_w \cdot Lw)$, α_w is attenuation constant, β is phase constant and Lw is waveguide length of the resonant ring.

For the TWRR with a constant impedance accelerator under beam loading , M can be calculated by the formula (2)

$$Mb = \frac{\sqrt{\frac{I^2R^2}{E^2}(1-e^{-\tau_a})^2 e^{-\tau} + (1-e^{-2\tau})} - \frac{IR}{E}(1-e^{-\tau_a})\, e^{-\tau} e^{-\tau_{w/2}}}{1-\exp(-2\tau)} \qquad (2)$$

For the TWRR with a constant-gradient accelerator under beam loading, after introducing accelerator attenuation α_a and beam loading factor IR/E in to the T

$$T = \exp(-\alpha w \cdot Lw) \cdot \exp(-\alpha a \cdot La) \cdot \exp(-\alpha a \cdot La \cdot IR/E) \qquad (3)$$

we can directly use formula (1) to calculate M, where I is beam current, R is shunt impedance and E is electric field.

3, Phase characteristic

According to formula (1) the module $|M|$ and argument θ of M are given by Eqs. (4) and (5).

$$|M| = \frac{C}{(1+T^2(1-C^2)-2T\sqrt{1-C^2}\cos(\varphi))^{1/2}} \qquad (4)$$

$$\theta = \arg(M) = \frac{\pi}{2} - \arctan\left(\frac{T\sqrt{1-C^2}\cos(\varphi)}{1-T\sqrt{1-C^2}\cos(\varphi)}\right) \qquad (5)$$

the graphs of $|M|$ vs. φ and θ vs. φ are shown on Fig.2.

4, Reflection

Let's suppose that there is some reflection having a reflection coefficient $\Gamma e^{-j\theta_1}$ and a transmission coefficient $\sqrt{1-\Gamma^2}e^{-j\theta_2}$ where $\theta_1-\theta_2=\pm\pi/2$ in TWRR. The multiplication factor M is calculated by the following formula

$$M = \frac{Ce^{-j\psi_1} - CT\sqrt{1-C^2}\sqrt{1-\Gamma^2}e^{-j(\psi_1+\varphi+\psi_2+\theta_2)}}{1-2T\sqrt{1-C^2}\sqrt{1-\Gamma^2}e^{-j(\varphi+\psi_2+\theta_2)} + T^2(1-C^2)e^{-j(2\varphi+2\psi_2)}} \qquad (6)$$

The reflection from the input port is given by:

$$\Gamma_1 = \frac{b_1}{a_1} = \frac{-C^2T_1^2\Gamma e^{-j(2\psi_1+2\varphi_1+\theta_1)}}{1-2T\sqrt{1-C^2}\sqrt{1-\Gamma^2}e^{-j(\varphi+\psi_2+\theta_2)} + T^2(1-C^2)e^{-j(2\varphi+2\psi_2)}} \qquad (7)$$

Fig.3 shows the module of M vs. φ with different reflections Γ without beam loading (a) and with beam loading (b), respectively.

5, Q value

For the TWRR with a accelerator the loaded Q value is given by:

$$Q_L = \frac{f}{2df} = \frac{2\pi Nw\frac{\lambda_g^2}{\lambda_0^2} + 2\pi Na\frac{C}{Vga}}{2\arccos\left(\frac{4T\sqrt{1-C^2} - T^2(1-C^2)-1}{2T\sqrt{1-C^2}}\right)} \qquad (8)$$

where Na = La/ λ_o, Nw = Lw/ λ_g, λ_g is the waveguide wavelength, λ_o is the free space wavelength, C on the numerator is the velocity of the light, Vga is the group velocity in the accelerator.

Fig.4 shows M and θ vs. φ and Q value of measurements. The measured are in good agreement with those calculated indicated in Fig.2.

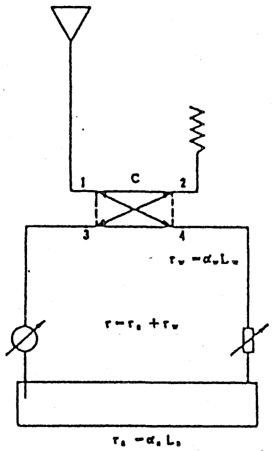


Fig. 1. The resonant ring with the linac.

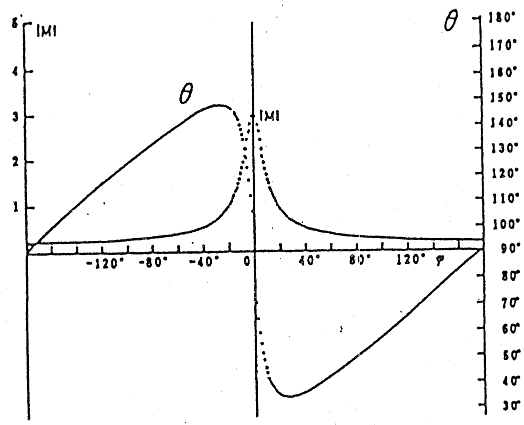
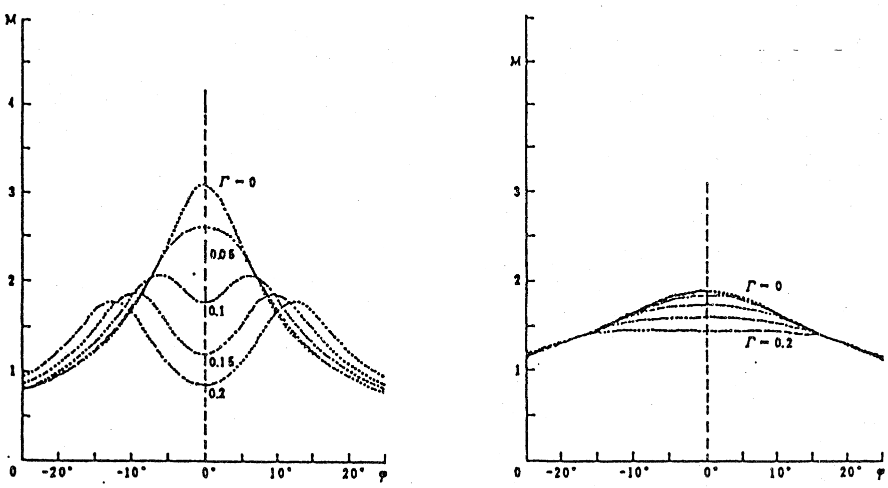


Fig. 2. The module and argument of the multiplication factor M vs. the phase of the resonant ring φ



a). the resonant ring with the linac without beam loading

b). the resonant ring with the linac with beam loading

Fig. 3. The multiplication factor M vs φ with different reflection Γ in the resonant ring

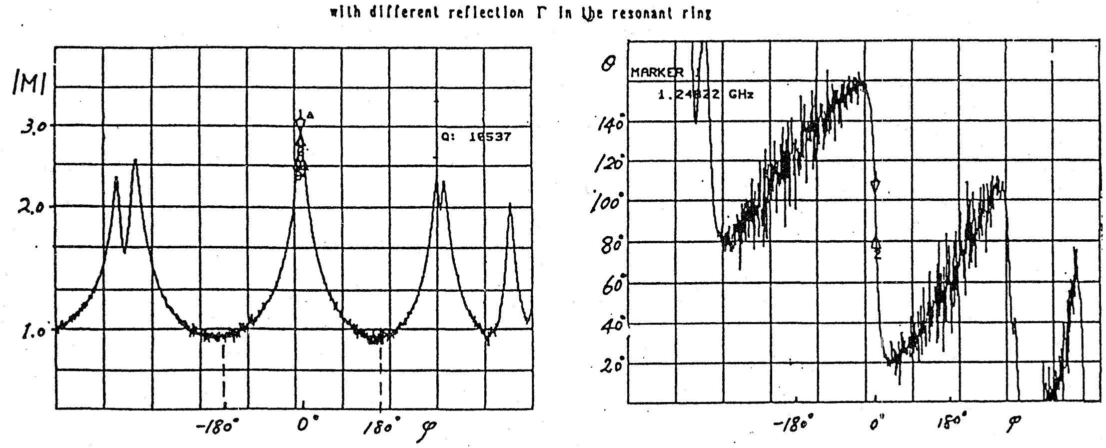


Fig. 4. the M and θ vs. φ and Q value of measurements