The 9th Symposium on Accelerator Science and Technology, Tsukuba, Japan 1993

Study of Characteristics of Linac with TWRR

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Abstract

High power electron linac which is developed by PNC is an electron linac with the TWRR (Traveling Wave Resonant Ring). Some phenomena occurred on our high power test are mentioned. Some important characteristics such as stabitity and phase characteristic are discussed.

1, Introduction

A high power CW (continuous wave) test electron linac was designed to develop a higher power linac to transmute radioactive wastes.[1]

The test linac is energized by two 1.2MW CW L-band klystrons to produce an electron beam with the energy of 10MeV and current of 100mA. The average beam power is 200kW-1MW for the duty factor 20%-100%.

In designing such a high power linac, we selected a traveling- wave accelerator with TWRR (Traveling Wave Resonant Ring).[2] This is to enhance the threshold current of BBU (Beam Break-Up) and to get high accelerator efficiency that results from the low value of attenuation constant τ and high field multiplication factor M which are permitted only with TWRR.

During the low and high power test the multiplication factors M and Q value were measured. Thermal characteristics of accelerator guide and elements of TWRR had been tested. The phase characteristic is important for accelerating the beam.

2 , Some experimental results

We have manufactured a prototype accelerating section with TWRR including a phase shifter (PS) and a stub tuner (ST). The picture of TWRR with the accelerating section is shown in Photo.1. There is an accelerator section in the front of TWRR, a phase shifter on the left side and a stub tuner on the right side of TWRR. After its low power test we found that the attenuation of the phase shifter was very high, i.e., about 0.24dB and this was 20 times higher than the design value. The reason was that the resonant frequency of choke parts of the plungers in the phase shifter was near the operation frequency of the accelerator. By installing conductors in its choke parts, the frequency could be changed about 15MHz from the accelerator operation one and the attenuation be reduced to

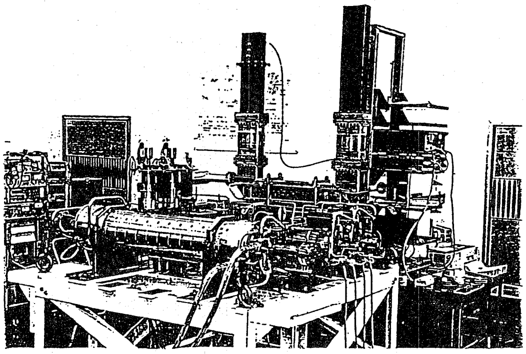

Photo 1, Picture of TWRR with accelerator

0.08dB. But in the later high power test, this phase shifter made a lot of troubles, because discharges occurred in conductor parts frequently. Therefore, the phase shifter was replaced with a straight waveguide. In this case, we adjusted the frequency of the RF source to make the ring at resonance, and adjusted the stub tuner to match the ring.

Figure 2 shows the high power test system. When the RF power from the klystron passes through the magic T, the power will be divided into equal two parts: one half power transmits to TWRR, another half passes a stub tuner (ST1) reaches to the dummy load. The ST1 is to cancel the reflection from TWRR. The signal from directional coupler (DC2) forward is measured for TWRR input power, one from DC3 forward is for TWRR resonant power and one from DC3 backward is for TWRR reflection power. From these data we can measure multiplication factor M and reflection coefficient Γ.

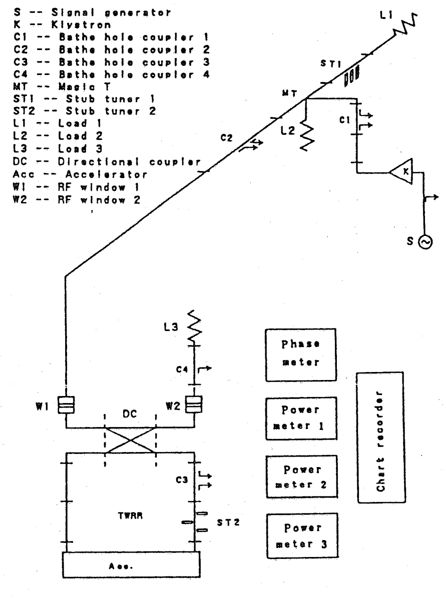

Fig. 2, high power test system for TWRR with the accelerator section

Using this high power test system, after a few days aging we could add input power of 88.8kW and get the resonant ring power at 810kW operation. For TWRR with accelerator section, the data from calculation, low power measurement and high power measurement are listed at the Table 1. The multiplication factor M dependence on the reflection Γ from calculation and high power test measurement are listed at the Table 2. Figure 3 shows that when input power changes the multiplication factor M can keep constant by changing frequency f to make the ring at resonance.

Table 1, comparison of data of TWRR

	Theoretic Calculation Value	Low power Measurement Value*	High power Measurement Value
M	3.02	2.90	3.03
$d\theta / d\varphi$	9.22	8.20	9.00
N	0.123	0.16	0.12
$d\psi / d\varphi$	68.71	50.4	70.2
Q	10797	10601	11478

* At low power measurement case TWRR including the phase shift has high attenuation, so multiplication factor M a little bit low.

Table 2, M dependence on reflection Γ

Γ	Calculation		Measurement (high power)	
	M	Γ_{ring}	M	Γ_{ring}
0	3.00	0.0	3.02	0.09
0.029	2.793	0.295	2.87	0.24
0.053	2.405	0.534	2.47	0.46
0.074	2.030	0.737	1.65	0.73

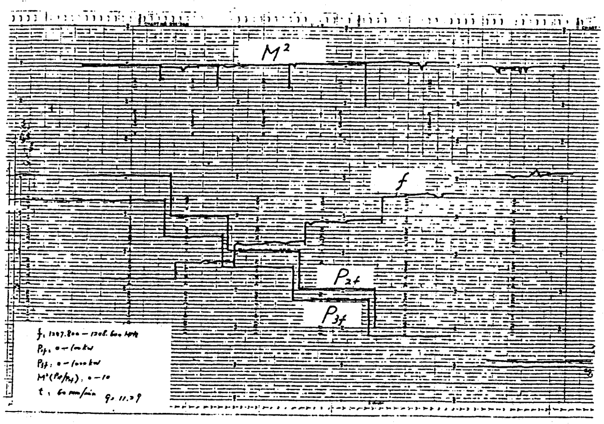

Fig. 3, M vs. P_{in} by high power measured

From the Tables 1, 2 and fig.3, one can see that the parameters of TWRR with accelerator section are very good agreement between the calculation and measurement data.

Figure 4 shows the resonance curve and phase characteristic. It means that at resonant point the phase difference θ_{13} between input point of accelerator and input point of TWRR is 90 °. When the ring deviated from resonance by some reason, for example, in TWRR phase of the phase shifter has some error $\Delta\ \phi_{ps}$, the phase difference θ_{13} will be changed

$$\Delta\theta_{13} = 9.2\,\Delta\,\phi_{ps},$$

If we want to keep the beam bunch phase in ±5 ° the phase control accuracy of the phase shifter is about ±0.5 °.

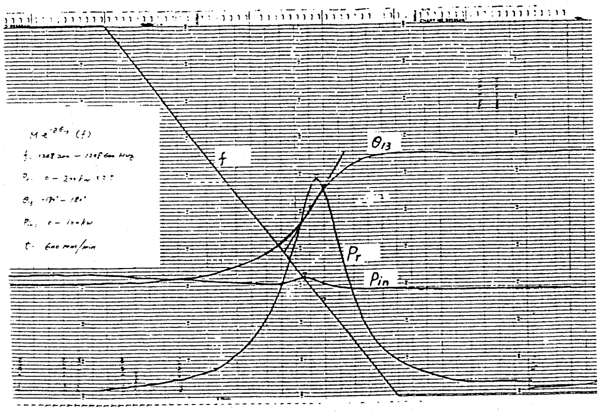

Fig.4 , resonance curve and phase characteristic

The thermal characteristics of the accelerator are as following;

$$dT / dP_{ring} = 2.4\ ° / 100KW$$

$$df / dP_{ring} = -57.5\ KHz / 100KW$$

and $$df / dT = -24KHz / 1°C\ .$$

During the high power test when we adjusted the temperature T of accelerator guide from low to high there is no problem, but from high to low sometimes it were out of control.

This phenomenon can be analyzed as following. On the resonant curve of TWRR the right side is stable, but the left side is unstable. It is shown on Fig.5. Let's suppose that the operation frequency is higher then the resonant frequency of TWRR. It includes two cases: in one case, TWRR resonant frequency is f_0, but the operation frequency is f_0+df_1 (at B point); in another case, the operation frequency is f_0, but the resonant frequency of TWRR is f_0-df_1 (at B' point). The result is the same for both. we only analyze one case. When the temperature becomes lower, TWRR resonant frequency will be higher, this means that the resonant curve will move towards the right, so M becomes higher, the resonant power will be higher too, the temperature will become higher. Therefore, this right side is stable. Supposing that operation frequency is lower then the resonant one (at C or C' points), when the temperature becomes lower, it will be lower and lower, so this left side is unstable. In this side if the temperature or resonant power becomes higher, the operation point will return to the resonant point (A point). TWRR operates at the resonant point (at A point), the resonant curve dPr / df=0, therefore, this is stable point, if the temperature, phase and frequency are controlled within a reasonable accuracy.

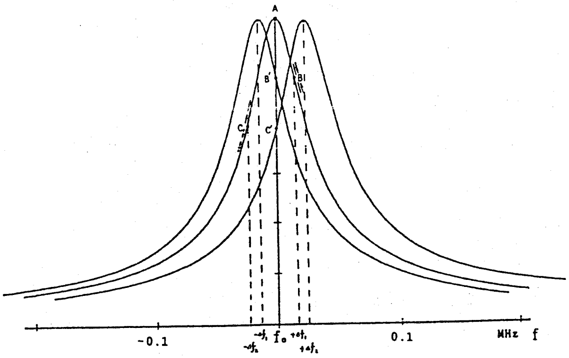

Fig.5, anaiyzsis of unstable phenomenon

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