Development of a Traveling Wave Resonant Ring of JNC High-Power High-Duty Electron Linac

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Abstract

We studied the RF characteristics of the TWRR with use of 100 mA electron beam and we measured the multiplication factor M as a function of a phase shifter position and temperature to find a method to keep it resonance at a high-duty operation.

1. Introduction

The Japan nuclear cycle development institute (JNC) is developing a high-power high-duty electron linac for the transmutation of fission products[1]. Considering the transmutation, an accelerator is required to improve its efficiency. To meet this requirement, we adopted a traveling wave resonant ring (TWRR) [2,3]. A general view of the TWRR is shown in Fig.1. The accelerator structure[4] is designed to have a constant gradient structure under the condition of 100 mA beam loading and contains 13 $2\pi/3$ mode cavities and two coupling cavities. The stub tuner is to cancel a reflection and the phase shifter is to adjust a phase in the TWRR to make it resonance.

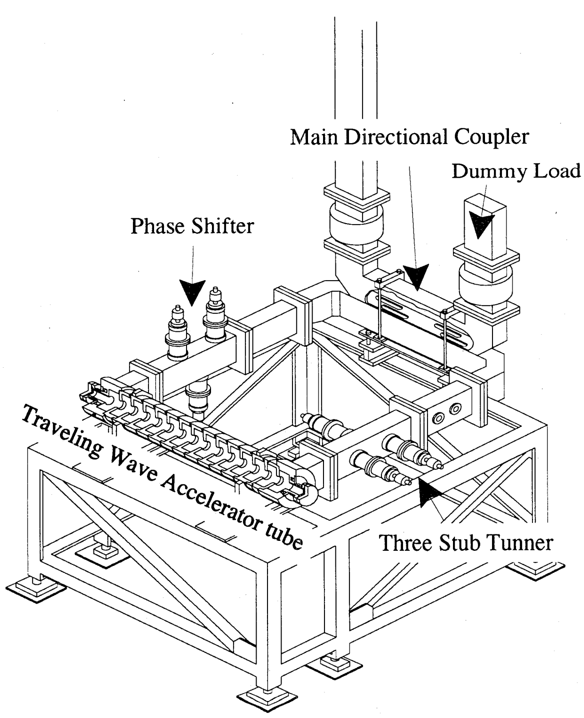

Fig.1. General view of the TWRR

2. Low-Duty Beam Test

The purpose of this test is to study the RF characteristics of the TWRR with use of 100 mA electron beam. In this test, to remove the temperature instability, the repetition R was lowered. We measured forward power P_F and backward one P_B in the TWRR, and power to the dummy load P_D. Experimental conditions and results are shown in Table 1 and Fig. 2, respectively.

Table 1 Experimental conditions.

Repetition R	1 pps
Input power P_0	204 kW
RF pulse width W_{RF}	3 m sec
Beam current I_b	100 mA
Beam width W_b	2 m sec

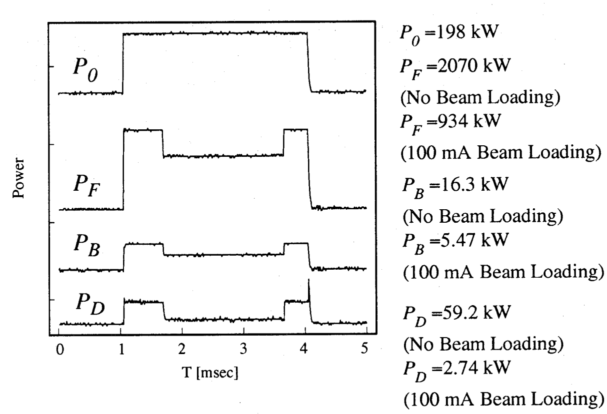

Fig.2 Power in the TWRR.

From Fig.2, compared to the input power P_0, the both power P_B and P_D are small. This means that the reflection in the TWRR is canceled by adjusting the stub tuner and it is at the resonance by adjusting the phase shifter. In the case of no reflection and optimum coupling, no power goes into the dummy load at the resonance. The coupling of the main directional coupler is designed to be optimized under the condition of 100 mA beam loading. Fig.2 shows that little power goes into the dummy load with 100 mA beam loading.

The multiplication factor M can be calculated from P_0 and P_F by means of Eq.1 [5].

$$M = \sqrt{\frac{P_F}{P_0}}, \tag{1}$$

M = 3.2 without Beam Loading,

M = 2.1 with 100 mA beam Loading.

We compare the experimental results with calculations. The calculations are

M = 3.15 without Beam Loading,

M = 2.03 with 100 mA beam Loading.

The experimental results are in good agreement with the calculations. At the low-duty operation, the TWRR shows good RF characteristics.

3. High-Duty RF Test

At a high-duty operation, the phase length of the TWRR changes with rise in temperature of it so that we must keep it resonance by adjusting the phase shifter. To meet this requirement. We measured M as a function of the phase shifter position x at two kinds of temperatures of 28.4 and 29.8°C. These temperatures were changed by the repetition R. The experimental conditions and results in a temperature of 28.4°C are shown in Table 2. and Fig.3.

Table 2 Experimental conditions.

Repetition R	1, 20 pps
Temperature T	28.4, 29.8°C
RF pulse width W_{RF}	3 m sec
Input power P_0	196 kW
Phase shifter position x	0.5 ~11.5 mm

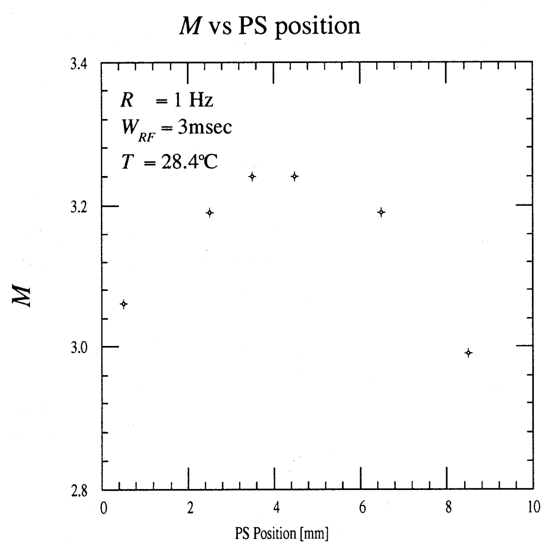

Fig.3 M vs. phase shifter positions (28.4°C).

If we assume that there is no reflection in the TWRR and the main directional coupler is ideal one with infinite directivity, M can be written:

$$M = \frac{c}{\sqrt{1 + T^2\left(1 - c^2\right) - 2T\sqrt{1 - c^2}\cos\phi}}, \tag{2}$$

where T, c and ϕ are the voltage transmission and coupling coefficient and total phase of the TWRR, respectively. Fig.3 shows that the phase shifter changes the phase length of the TWRR so that M changes. M has the maximum value at the resonance.

We can get the ratio of the change in phase $\Delta\phi$ to the phase shifter displacement Δx and temperature change ΔT by making Eq.3 fit the experimental results.

$$M = a + \frac{c}{\sqrt{1 + T^2\left(1 - c^2\right) - 2T\sqrt{1 - c^2}\cos\left\{\frac{\Delta\phi}{\Delta x}(x - x_0) + \frac{\Delta\phi}{\Delta T}(T - T_0)\right\}}}, \tag{3}$$

where a is a fitting parameter which includes experimental error and x_0 is the position of the phase shifter at the resonance at a temperature of T_0. The parameters are listed in Table 3.

Table 3 Parameters.

Temp.[°C]	a	$\Delta\phi/\Delta x$[deg./mm]	x_0.[mm]
28.4.	0.11	0.87	4.2.
29.8.	0.12	1.1	7.1.

In an individual test of the phase shifter, we measured $\Delta\phi/\Delta x$ = 0.93 [deg./mm]. $\Delta\phi/\Delta x$ from the fitting accords substantially with the individual test result.

We also find $\Delta\phi/\Delta T$=-2.1 [deg./°C] from $\Delta\phi/\Delta x$ and $\Delta x/\Delta T$. $\Delta x/\Delta T$ can be calculated from x_0 and temperature difference between the two resonances. From calculation, $\Delta\phi/\Delta T$ is -1.3 [deg./°C]. The experimental result is larger than the calculation. The change of the phase length is mainly caused by the temperature change of the inside diameter of the accelerator. In this experiment, actually we measure the temperature of the outside of it. The discrepancy between experimental result and the calculation can be considered to be caused by the temperature difference between inside and outside of it because we measured $\Delta\phi/\Delta T$ = -1.2 [deg./°C] when the temperature of the whole TWRR was changed from 30° to 36°C by a cooling water system.

A graph of M as a function of the phase shifter position x and temperature T is given in Fig.4. It is understood From Fig.4 that the resonance can be kept by moving the phase shifter along a ridge.

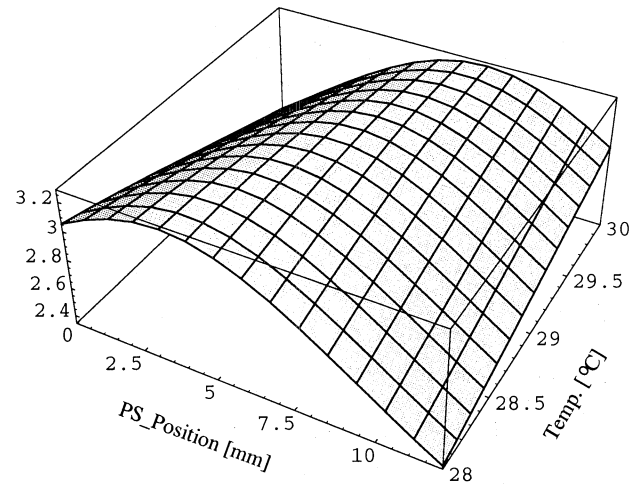

Fig.4 A graph of M as a function of the phase shifter position x and temperature T

Finally, we discuss this adjustment method to keep the resonance which is based on Eq.3. $\Delta\phi/\Delta x$ in Eq.3 was found by changing the phase shifter position on the condition of keeping the temperature. $\Delta\phi/\Delta T$ was calculated from $\Delta\phi/\Delta x$ and $\Delta x/\Delta T$. $\Delta\phi/\Delta T$ was not found directly from the temperature dependence of M. If Eq.3 can reproduce the experimental result of the temperature dependence of M, it can show the both dependent of the phase shifter position and temperature of M. We measured the temperature dependence of M. Experimental conditions are shown in Table 4. The temperature of the TWRR was changed from 28.5 to 29.8°C by the RF pulse width W_{RF}. During this experiment, we fixed the phase shifter position where M is maximum at a temperature of 28.5°C. The comparison with the experimental result is shown in Fig.5.

Table 4 Experimental conditions.

Repetition R	20 pps
RF pulse width W_{RF}	0.5,1,2, 3 m sec
Input power P_0	196 kW
Phase shifter position x	3.5 mm

Fig.5 shows Eq.3 is in good agreement with the experimental result. It shows the temperature dependence of M successfully. This means this adjustment method based on it can keep the resonance at the high-duty operation.

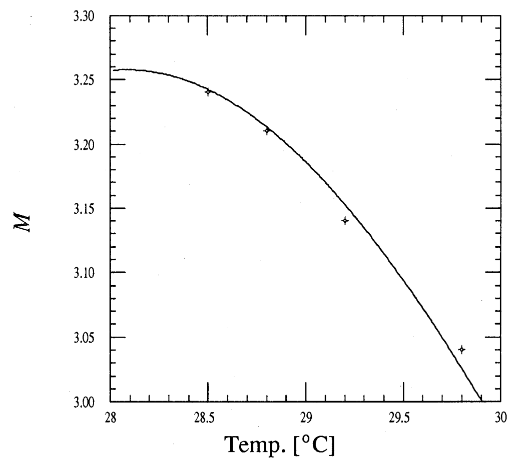

Fig.5 Comparison with the experimental result

At a high-duty operation, the temperature of the TWRR is raised so that the TWRR comes off the resonance. We found the adjusting method at the high-duty RF test which is based on the both parameters $\Delta\phi/\Delta x$ and $\Delta\phi/\Delta T$. This method can keep the resonance at the high-duty operation.

4. Summary

We studied the RF characteristics of the TWRR with use of 100 mA electron beam at the low-duty beam test. The experimental results show that the reflection in the TWRR is canceled by adjusting the stub tuner and it is at the resonance by adjusting the phase shifter. The multiplication factor M from the experimental results is in good agreement with calculations.

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Reference

[1] S.Toyama *et. al.*, "Transmutation of long-lived fission product(^{137}Cs, ^{90}Sr) by reactor-accelerator system", Proc. Int. Symp. on Advanced Nuclear Energy research, 1990.

[2] Y.L.Wang, "A Study of Traveling Wave Resonant Ring Characteristics", PNC Report, 1993.

[3] Y.L.Wang *et. al.*, "Design of High Power Electron Linac at PNC", Journal of Nuclear Science and Technology, 30[12], pp1261-1274, 1993.

[4] Y.L.Wang *et. al.*, "Accelerator Structure of PNC High Power Quasi-Electron Linac", Proceeding of the 11th Symposium on Accelerator and Technology, 1997.

[5] M.Nakamura, Japanese J. Appl. Phys., 7 [3], 257 (1968).