High Power CW Linac in PNC

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Abstract

Power Reactor and Nuclear Fuel Development Corporation(PNC) is developing a high power electron linac for various applications. The electron beam is accelerated in CW operation to get maximum beam current of 100mA and energy of 10MeV. Crucial components such as a high power L-band klystron and a high power traveling wave resonant ring(TWRR) accelerator guides were designed and manufactured and their performance were examined. These design and results from the recent high power RF tests were described in this paper.

1. INTRODUCTION

The development of a high intensity CW electron linac to study feasibility of nuclear waste transmutation was started in 1989[1]. Its purpose is to establish the high current beam acceleration technique with more than 50% efficiency. The specifications of the PNC linac are described in Table 1. An accelerating guide and klystron was newly developed in L-band 1249 MHz RF so as to achieve high efficiency. The accelerator facility building was constructed in August, 1991. The exterior of the building is shown in Figure 1. The facility has three floors, where there are the accelerator in the basement, klystrons and its power supply in the first floor. The base floor has 2.3 m concrete shielding on its roof. The high power RF test for the components started in 1992. The study of high current beam operation will be started in 1996 after the injector test in 1995 using partially built accelerator.

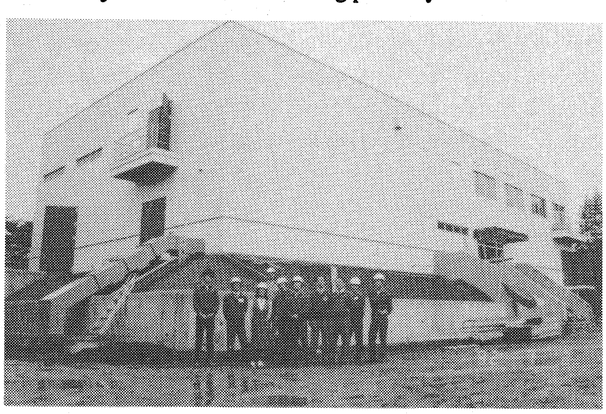

Figure 1. View of accelerator facility.

2. STRUCTURE OF HIGH POWER CW ELECTRON LINAC

A conceptual RF diagram of PNC accelerator is shown in Figure 2. The accelerator consists of eight normal conducting accelerator guides which each have TWRR including one buncher guide.

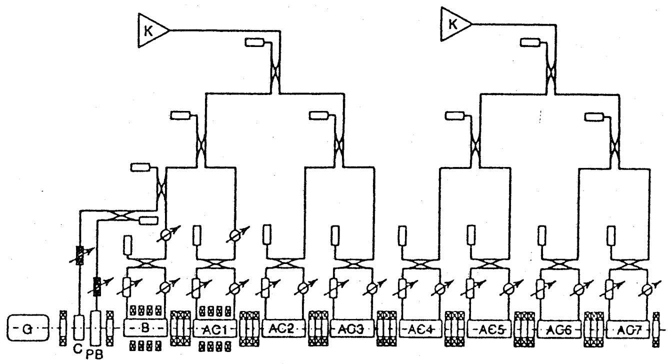

Figure 2. Conceptual diagram of PNC accelerator:
G is the electron gun; C, a chopper; PB, a prebuncher; B, a buncher; AC, a acc.guide; K, a klystron.

The injector section consists of an electron gun, a prebuncher, a chopper and a buncher guide. A water cooled chopper slit is designed because of high heat removal of 11 kW. Prebuncher system with two standing wave cavities is designed to compress phase angle of beam bunch without large energy dispersion which happens to escape from beam transportation. Two high power CW klystrons feed RF into four accelerator guides respectevely. The linac accelerates 10MeV-100mA electrons with the duty factor of 20~100%. A 5 mmϕ impregnated cathode generates electron beam of 200kV and average current 100mA. It is very important to keep low beam emitance in order to avoid beam break up(BBU) in the case of high current beam acceleration The high quality LaB_6 cathode which can emit stable and brilliant electron beam will be future candidate for the smaller emitance electron gun besides of thermionic cathode. The buncher guide was designed in constant gradient structure for uniform power dissipation along the buncher cavity wall. Klystron is driven by 90kV DC power supply to produce 1.2

MW RF with the efficiency of more than 65%. The 1.2MW RF power is fed into four TWRR through two 3 dB directional couplers.

The constant gradient regular accelerator guide and phase shifter and stub tuner form a recirculating wave guide called TWRR, which get high accelerating efficiency using traveling wave. This guide has a efficiency 65% and field multiplication factor two with full beam loading, which is almost same efficiency by standing wave type. The advantage to employ TWRR rather than standing wave accelerator guide is as follow; simplicity of cavity structure, larger aperture size of disk hole, less effort of fabrication, and easy mechanical separation from the recirculating wave guide. These make it easy to handle under heavy radiation field.

3. RESULTS FROM RECENT DEVELOPMENT

Low power RF characteristic of an accelerator guide was measured in preceding experiment[2]. The maximum RF power from the klystron was limited to 330 kW by unexpected heat generation from the klystron ceramic window. High power RF characteristic of a accelerator guide and a klystron output window was examined by using the klystron powered by a 90kV DC power supply in the national laboratory for high energy physics(KEK).

A. Accelerator guide

The experiment of an accelerator guide is performed with a one TWRR unit and one klystron. The RF power was loaded into the TWRR unit with CW and long pulse (~4 ms) aging to squeeze the RF spark and gas emission inside of the TWRR. It took about two weeks to reach the final RF power level, which power dissipation was equivalent to full beam loading.

Unexpected heating of a phase shifter in the TWRR occurred when RF power level reached 35 kW. One of the phase shifter choke cylinder temperature increased more than 100 degree. This phenomenon came from incomplete electromagnetic contact of a finger strip between a stub and a outer cylinder of choke component. It was turned out the RF attenuation of the phase shifter must be reduced less than 0.05 nep. After the phase shifter was replaced by straight wave guide, the accumulated power in the TWRR achieved 800 kW in CW operation. The Q value was 1150 which is in accordance with calculation. The temperature changes and changes of resonant frequency along TWRR RF power are summarized in Figure 3 a and b. The following values can be

1. frequency deviation per RF -50.1 kHz/100kW
2. temperature deviation per RF 2.1 °C/100kW
3. frequency deviation per temperature -23.4 kHz/ °C.

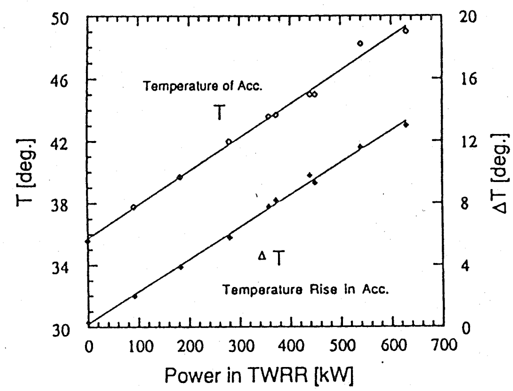

Figure 3 a. RF power dependence of acc. temperature.

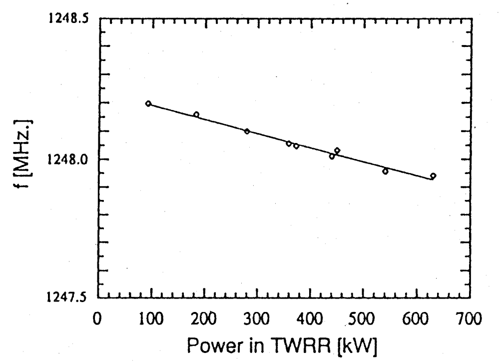

Figure 3 b. RF power dependence of resonant frequency.

The result is in good agreement with the result from low power experiment carried out in preceding experiment, which means there is no local heating inside the accelerator guide in final use. The field multiplication factor M for TWRR was three, which was reasonable from the expectation by calculation with no beam loading. The choke structure of phase shifter should be modified in next development.

B. Klystron window

The maximum power of the klystron is limited to 330 kW, because the temperature of ceramic window increased up to 90 degree, which is one third of the critical points of destruction by thermal stress. So the modified output window was designed and three different pieces of pill-box type windows were tested with TWRR unit replaced the accelerator guide. The materials, dimension and VSWR of each piece are summarized in Table 2. The high power test was done by increasing RF in TWRR with the careful watch by video camera for light emission from ceramic surface and by infrared-thermometer for the surface temperature. The aging of these windows is done by CW and long pulse (duty factor 5~20% at 50 Hz). The results from three test windows are shown in Figure 4. The beryllia window which has long dimension was able to endure the 1.7 MW CW RF power. The temperature increase is 48 degree and there was no glow discharge by multipactoring effect on the ceramic surface. Only some light spots was observed from the small dust attached to the ceramic surface. The alumina window which has shorter dimension was broken down at power of 0.5 MW in CW. The crack was caused by thermal stress. The test of higher power with long pulse was carried out to look for the possibility to produce more than 1.2MW from klystron with long pulse operation. The experiment was done by using 2 ms and 4 ms pulse and duty factor of 10 % and 20 %. There was no multipactoring bellow 4 MW and weak light emission was observed above 4.25 MW.

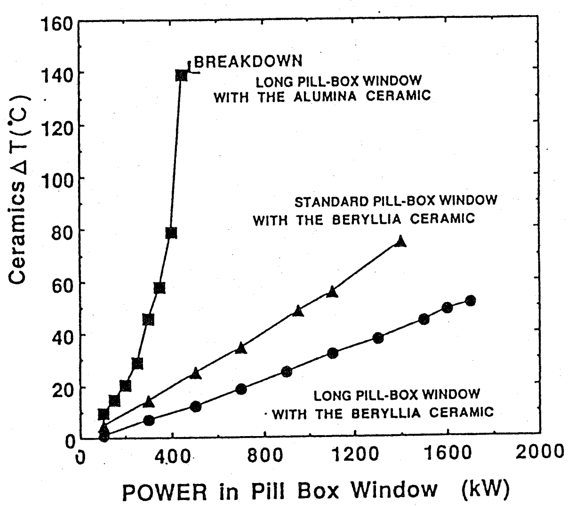

Figure 4. Temperature increase of test windows.

The result agrees with the characteristic of field decrease and reduction of VSWR by the design and suggests that the klystron will be able to produce more than 1.2MW RF after changing the design of the window.

4. SUMMARY

The high power CW electron linac is designed using normal conducting TWRR and high power CW klystron to accelerate electron beam with 10MeV-100mA at peak current. The efficiency of acceleration is designed to get more than 65% at full beam loading and 65% efficiency for klystron. The high power component test was carried out to check the design parameters. It was turned out that an accelerator guide and klystron output window are able to show sufficiently enough performance for high power CW operation, however the phase shifter in TWRR should be modified to get less attenuation.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] S. Toyama *et al*, "Transmutation of Long-lived Fission Product (137Cs,90Sr) by a Reactor-Accelerator system," *Proceedings of The 2nd International Symposium on Advanced Nuclear Energy Research*, (1990)

[2] A. Enomoto *et al*,"Development of the CW Electron Linac Using Traveling Wave Resonant Ring," *Proceeding of European Particle Accelerator Conference*, (1992)

Table 1. Parameter of The PNC Linac

operation mode	CW	pulse
General		
pulse width	-	0.8 ms
repetition rate	-	250 pps
energy	10MeV	18MeV
current	100mA	55mA
total length	20 m	
Accelerator section		
type	traveling wave constant-gradient	
mode	2π/3	
frequency	1249MHz	
gain(max)	1.4 MV/m	2.0MV/m

	CW	pulse
Resonant ring		
transmission(no load)	0.946	
transmission(load)	0.850	
multiplication(no load)	3.0	
multiplication(load)	2.0	
Klystron(target)		
power	1.2MW	4.1MW
beam voltage	90kV	147kV
micro-perveance	0.8	
gain	50 dB	55 dB
efficiency	65%	50%
modulation	modulating anode	

Table 2. Parameters of window test

No.	material	length of pill-box	dia. of pill-box	VSWR	phase length
A	BeO	402mm	190.5mm	1.04(measured)	751.6deg.
B	Al_2O_3	412mm	193.7mm	1.30(measured)	777.8deg.