

# Status of High Power CW Linac at PNC

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## Abstract

Power Reactor and Nuclear Fuel Development Corporation(PNC) is developing a high power CW electron linac. This paper shows the development of the main components which are an injector, an accelerator section, a klystron and a beam dump. We also report the result of the high power test of an accelerator guide and klystron windows.

## 1. INTRODUCTION

High power CW electron linac is under development in PNC for various applications [1]. The linac was designed so as to be able to accelerate an electron beam current of 100 mA at energy of 10 MeV. Main specification of this electron linac is shown in Table 1.

Table 1 Main specification of the electron linac

Energy	10 MeV
Max. Beam Current	100 mA
Av. Beam Current	20 mA
Norm. Emittance	50 $\pi$ mm mrad
Energy Spread	1.0 %
Pulse Length	4 ms
Pulse Repetition	50 Hz
Duty Factor	20 %
Accelerating Frequency	1249.135 MHz
Accelerating Mode	2 $\pi$ / 3 mode
Number of Klystron	2
Klystron Power	1.2 MW
Number of Accelerator Guide	7
Overall Length	18 m

The accelerator guide and the klystron were newly developed in order to achieve a high power CW operation. The accelerator guide equipped with a TWRR (Traveling Wave Resonant Ring) is adopted in order to achieve the high accelerator efficiency. The high power RF tests for the accelerator guide and klystron windows were finished in 1993 at KEK. Now, the basic design has been completed. The linac will be installed by the end of March, 1997 after the test of the injector in 1995.

## 2. MAIN COMPONENTS

### 2.1 Injector

The injector was designed so as to reduce the emittance growth and energy spread as possible. The injector consists of a 200 kV DC electron gun, two magnetic lenses, a RF chopper and a chopper slit, a prebuncher and a buncher. Solenoid coils cover from the exit of the electron gun to the first accelerator guide except between the RF chopper and the chopper slit. We chose the L-band as accelerating frequency in order to enhance the threshold current of the regenerative beam break up. In our linac there is thick concrete wall between the electron gun room and the accelerator room for the radiation protection. Therefore the design of the injector is important because the space charge effect is large in this injector. The arrangement of injector is shown in Figure 1.

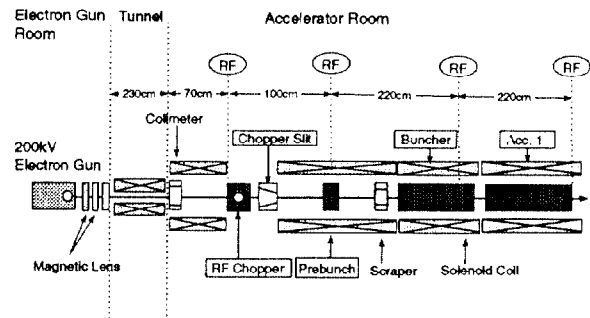


Figure 1. The arrangement of injector

A peak current of 400 mA with beam energy 200 keV is required for the electron gun from the chopper and the buncher system design. However its average current is very high (duty factor 20%), a mesh grid can not applied for current control because of heating up or melting of grid. Furthermore, the beam current have to be variable up to 400 mA to match with downstream elements. We employed the electron gun with two aperture grids to control the beam current and the diameter. When the anode potential is constant and a voltage on an aperture grid is changed, equipotential surface near the grid are distorted to convergent or divergent a beam. This

effect affects a beam diameter. The dimension of the electrode, the electron trajectory, the size of the beam radius and the gun emittance were simulated by EGUN[2]. Figure 2. shows that one of the simulation results of the geometrical condition and the beam trajectory with a peak beam current of 400 mA. The beam current vs. the first grid potential is shown in Figure 3.

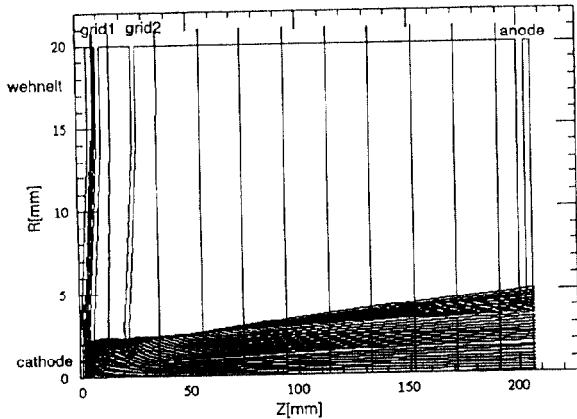


Figure 2. An example of EGUN simulation results. A peak beam current is 400 mA. The potential of 1st grid and 2nd grid are 5 and 20 kV, respectively.

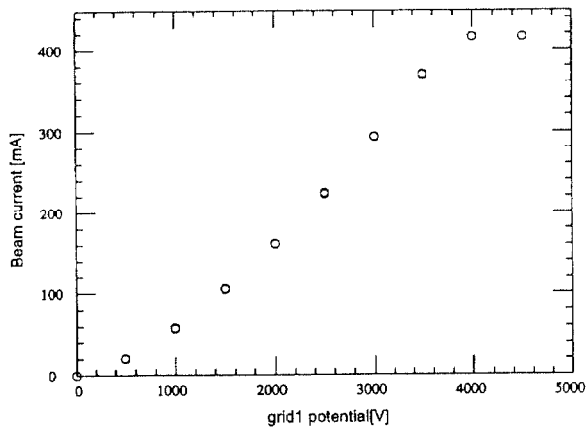


Figure 3. Beam current vs. 1st grid potential by EGUN simulation.

A beam of 200 keV electrons from the electron gun initially enters the RF chopper through two magnetic lenses and solenoid coils. The beam during a quarter RF period (90 degree) passes through the chopper slit. In our chopper system[3], the transverse momentum is only added to the part of beam which will stop at the slit. There is no transverse momentum added to the part of beam which will pass through the slit. The beam trajectory from the exit of the electron gun to the chopper slit and the normalized emittance which were simulated by PARMELA are shown in Figure 4, and Table 2, respectively. It can be seen from Table 2 that our chopper system reduce the emittance growth.

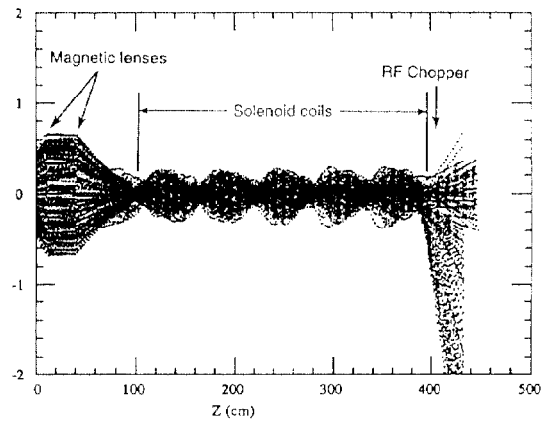


Figure 4. The beam trajectory in the chopper system

Table 2. The normalized emittance in the chopper

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$(\epsilon_x, \epsilon_y) = (17.2, 19.0) \pi$ [mm mrad]:	at the enter of the RF chopper
$(\epsilon_x, \epsilon_y) = (105.4, 18.8) \pi$ [mm mrad]:	at the exit of the RF chopper
$(\epsilon_x, \epsilon_y) = (12.9, 9.7) \pi$ [mm mrad]:	at the exit of the chopper slit

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The prebuncher and buncher are designed so as to avoid the over bunch. The beam is initially bunched by the prebuncher into 20 degrees. It is further bunched into 5 degrees and accelerated to 1.2 MeV in the traveling-wave buncher equipped with a TWRR. The beam then enters the accelerator section in which it is still further bunched into less than 3 degrees and accelerated to 10 MeV.

## 2.2 Accelerator section

The accelerator section consists of seven accelerator guides. Each unit of accelerator section forms a TWRR. Each of the accelerator guides of which the length is 1.2 m contains 13  $2\pi/3$  mode cavities and two coupling cavities. All accelerator guides are constant gradient structure type under the condition of 100 mA beam loading. The high power test of an accelerator guide was performed as one TWRR unit[4]. A CW klystron is used as RF source. At first the TWRR included the stub tuner and phase shifter. Unexpected heating of the phase shifter occurred when RF power level reached about 35 kW. The reason is that choke part in a plunger made a lot of discharge. Therefore, a straight waveguide was used instead of the phase shifter. Using some spacers and adjusting frequency the TWRR could be tuned at resonance. The accumulated power in the accelerator guide achieved 800 kW in CW operation. The thermal characteristics of the accelerator guide are shown below,

$$\begin{aligned} dT/dP &= 2.4 \text{ degree} / 100 \text{ kW} \\ df/dP &= -57.5 \text{ kHz} / 100 \text{ kW} \end{aligned}$$

$$df/dT = -24 \text{ kHz / degree}$$

The calculation and the measurement values of the Q value, multiplication factor M and nullification factor N are shown in Table 3. It can be seen from Table 3 that the agreement between the calculation and measurement is very good.

Table 3. The calculation and measurement values of the Q value, multiplication factor M and nullification factor N

	Calculation value	Low power test	High power test
Q	10797	10601	11478
M	3.02	2.90	3.03
N	0.12	0.16	0.12

According to the high power test, this accelerator guide equipped with TWRR can operate stable at resonance. The choke structure of phase shifter should be modified for the next fabrication.

### 2.3 klystron

The first klystron energizes a buncher and three accelerator guides and second one energizes the remaining four accelerator guides. The RF power fed to the buncher and each accelerator guides are 220 to 250 kW, respectively. Between the prebuncher, the buncher, the first accelerator guide and the first klystron, there are phase shifters to keep electrons bunch in phase in each elements.

The maximum power of the prototype klystron is limited to 330 kW with CW operation, because the temperature increase of the window was 53 degree, which is two thirds of the critical points of destruction by thermal stress. So the modified window was designed and tested with TWRR unit[4]. The beryllia window which has long dimension was able to endure the 1.7 MW CW RF power. The temperature increase is 51 degree and there was no glow discharge by multipactoring effect. The window of the prototype klystron will be replaced with this long type beryllia window.

### 2.4 Beam Dump

The concept of the design for the high power low energy beam dump is that the electron beam is stopped at the edge of the cylinder block which is cooled by water. The potential advantages are the elimination of a window for the incident electron beam and possibly reduction in the radiolysis of the cooling water. In this design the target consists of 22 hollow cylinder blocks(40 cm outside diameter), which inside diameter becomes increasingly small. Each block is cooled by water. The electron beam is stopped in the cylinder block and thus does not interact directly with the cooling water. Schematic view is given in Figure 5.

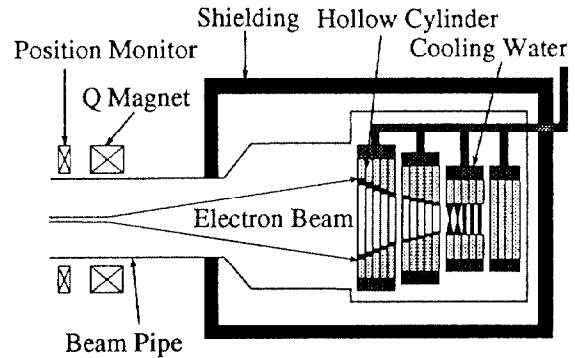


Fig 5. Schematic view of the beam dump

For copper block the maximum power density is about 3 kw/cm<sup>3</sup> assuming gaussian distribution of the electron intensity. As this heat deposited in the block can easily be removed by water, the maximum temperature increase is estimated about 400 degree.

## 3. SUMMARY

The development is in progress for the high power CW electron linac with peak current of 100 mA at energy of 10 MeV. The basic design of the main components which are an injector, an accelerator section, a klystron and a beam dump is completed. According to the high power test, it is turned out that the accelerator guide and the klystron window have enough performance for high power CW operation.

## 4. ACKNOWLEDGMENT

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## 5. REFERENCES

- [1] S.Toyama *et. al.*, "Transmutation of ong-lived Fission Product (137Cs, 90Sr) by a Reactor-Accelerator system," Proceedings of the 2nd International symposium on Advanced Nuclear Energy research, (1990)
- [2] W.B.Herrmannsfeldt, "EGUN an electron optics and gun design program", SLAC-Report-331,Oct,1988.
- [3] Y.L.WANG *et. al.*, "A Novel chopper system with Very Little emittance Growth", in this proceedings.
- [4] S.Toyama *et. al.*, "High Power CW Linac in PNC", Proceedings of the 1993 Particle Accelerator Conference.