THE DESIGN OF INJECTOR FOR THE PNC HIGH POWER CW LINAC

S. Tōyama, M. Nomura and Y. L. Wang
Power Reactor and Nuclear Fuel Development Corporation (PNC) 4002 Narita-cho, Oarai-machi,
Higashi-ibaraki gun, Ibaraki-ken 311-13, Japan
I. Sato and A. Enomoto
National Laboratory for High Energy Physics (KEK) 1-1 Oho-cho, Tsukuba-shi, Ibaraki-ken 305, Japan

Abstract

The injector system for PNC high power CW electron linac has been developed so as to accelerate 100mA high current electron beam with high beam quality. The injector system consists of an electron gun, a beam chopper, a single cavity prebuncher, a buncher accelerator guide and transport magnets. The electron beam from the electron gun is chopped by RF cavity and a slit. Electron beam is velocity modulated in single standing wave cavity with heavy beam loading and is transmitted to the buncher. The type of the buncher accelerator is Traveling Wave Resonant Ring(TWRR) which accelerates electron beam efficiently. The beam transport and accelerator characteristics for the injector has been investigated to suppress the emittance growth and to get enough matching for acceptance of followed accelerator section.

Introduction

The PNC high power CW electron linac has been designed in order to establish high current particle beam acceleration for basic study of transmutation and other application. The main parameters for PNC linac are summarized in other paper[1]. PNC linac consists of injector part and regular accelerator part and the beam dump. The injector generates electron beam and bunches electron beam for regular acceleration up to 10 MeV. The component of injector system is designed to suppress beam blow up(BBU) in followed accelerator section. It is of great importance to get excellent beam quality with good transmission when accelerating high beam current. The detailed characteristics of the injector section is calculated by PARMELA and other numerical analysis.

Apparatus of injector section

The design parameters of the injector section are summarized in Table 1.

TABLE 1
Beam Parameters of the Injector and Linac

	Injector	Linac
Emittance (gun)	5π mm mrad	50π mm mrad
Energy dispersion	0.1 %	0.5 %
Beam radius	2 mm	2 mm
RF Power (peak)	250 kW	2.0 MW
Gain	1.4 MV	10 MV

The linac is driven by 20 % duty 4 ms long pulse repetition, so each component substantially needs CW performance. Low emittance growth is achieved by means of the chopper system and low energy gain accelerator guide. The structure of the injector is shown in Fig. 1. This figure presents the apparatus of the injector test in 1995, which includes additional one accelerator guide(Acc. 1) at the end of the injector.

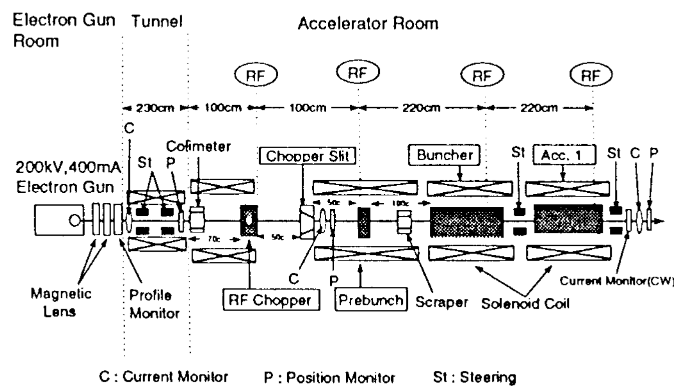

Fig. 1 Schematic diagram of the injector.. Acc. 1 is placed for the check of regular acceleration.

A 2.3 m concrete shield is located between the gun room and accelerator room. The 200kV-400 mA electron beam from the electron gun[2] drifts 2.5 m long beam pipe with Brillouin flow by a series of solenoid coils, and reaches the chopper system [3]. The electron gun has not modulation mesh grid because it causes large emittance growth [4] and the grid will be suffered by high current electron beam. The chopper cavity by 1249 MHz fundamental and second harmonics suppresses the emittance growth. The beam is chopped into 90 degree in phase angle and thereafter bunched in 20 degree by the single cavity prebuncher. The high duty chopper slit is under the development. The type of the prebuncher is a standing wave reentrant cavity. Induced field is exited when chopped beam passes through the prebuncher cavity. The prebuncher is designed to cancel out this effect by the counter phase shift from detuning tuner for our heavy beam loading.

The 100 mA beam is bunched and accelerated over 1 MeV by TWRR buncher which has low accelerator gain and solenoid focusing for the keep of beam quality and prominent energy conversion from RF to the beam. The beam is finally bunched into 5 degree at the exit of the injector section. The performance of TWRR for this linac was checked by high power RF test at

KEK using newly developed 1.2 MW CW L-band klystron[5]. RF power is fed into all cavities in the injector by one klystron. Beam monitors and steering system are equipped in each section for high current beam optics study.

Beam Transport

When linac accelerates high current electron beam in CW condition, it is important to study the beam transport considering space charge effect. Especially, the investigation of low energy section between after the electron gun and before the prebuncher is essential for total design of PNC linac.

Electrons which velocity is 0.695c passes long drift space and cavities, and are strongly bunched by the buncher. Initial beam parameters calculated by EGUN are used for input parameter of beam transport calculation by PARMELA which includes space charge effect.. Dimension of each device and drift space are shown in Fig. 1. The EGUN input parameters of electron beam are mentioned in Table 2.

TABLE 2
Gun Parameter for the Injector

Voltage of cathode	200 kV
Voltage of aperture grid 1	5 kV
Voltage of aperture grid 2	20 kV
Emission current	400 mA
Radius of cathode	2 mm
Magnetic lens 1	600 G
Magnetic lens 2	500 G

Double magnetic lenses are employed to adjust beam waist point and optimize the beam transport in the long drift space between electron gun room and accelerator room. The parameter for magnetic lenses is changed for different beam current. The example of the beam tracking through injector section by PARMELA is shown in Fig. 2.

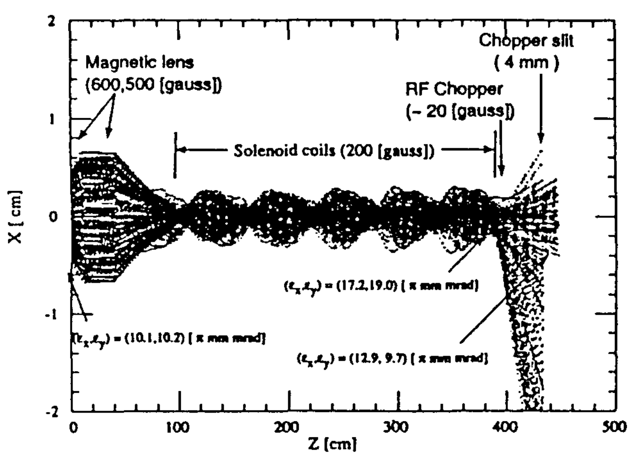

Fig. 2 Beam tracking of injector section. The tracks for 177 electrons are displayed.

PARMELA was modified in order to get more fine mesh generation and add the chopper slit subroutine. Original mesh generation is rough for L-band structure like PNC. RF parameters are chosen in order to achieve 5 degree phase bunching and less than 2 % momentum resolution after first regular TWRR accelerator guide. Power fed into brebuncher is adjusted to get weak bunching avoiding over-bunch which causes the deterioration of beam quality. Solenoid coils in 2.5 m drift space generates 200 G magnetic field which is about twice higher than critical value by simple Brillouin flow.

The normalized emittance in the chopper system is summarized in Table 3. It can be seen from this table that our chopper system reduces emittance growth. In the chopper system for PNC linac, the transverse momentum is only added to the part of beam which stops at the chopper slit. There is no traverse momentum added to the part of beam which will pass through the slit. The behavior of the beam in phase calculated by PARMELA space is shown in Fig. 3.

TABLE 3
Normalized emittance in the chopper system

(e_x, e_y)	= (17.2, 19.0)	π mm.mrad at the enter of the RF chopper
(e_x, e_y)	= (105.2, 18.8)	π mm mrad at the exit of the RF chopper
(e_x, e_y)	= (12.9, 9.7)	π mm mrad at the exit of the chopper slit

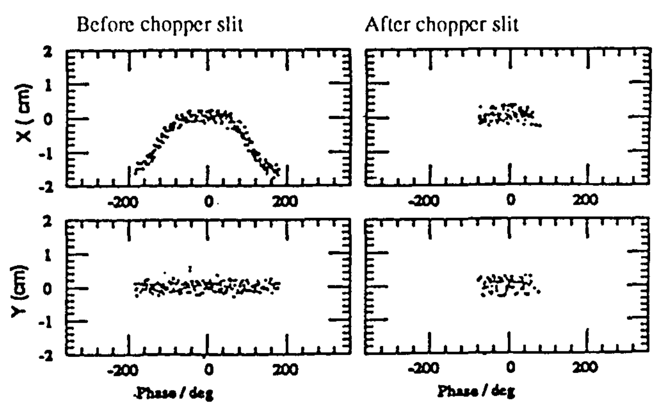

Fig. 3 Beam Phase Space before and after Chopper Slit

The Fig 3 shows three quarter of electron beam which does not contribute acceleration is reasonably removed in X direction by this deflecting system. The total beam tracking above shows enough beam quality to accelerate electrons in followed regular accelerator section. It also shows a little beam dispersion after the chopper slit This means there is no focusing action between chopper cavity and the slit.

Accelerator Characteristics

The injector section includes one TWRR buncher which bunches finally and then accelerates electron beam up to enough energy for regular acceleration. The TWRR consists of RF recirculator and constant gradient (C-G) accelerator guide and two tuners which optimize resonant phase and VSWR each other[5,6]. C-G structure is designed in order to suppress regenerative BBU by TM_{11}-like mode[1]. Any other TW includes constant impedance(C-I) accelerator guide for its simplicity for manufacturing, so TWRR with C-G structure in PNC linac is a new application in high power RF. The energy gain and loading efficiency are shown in Fig. 4 and 5.

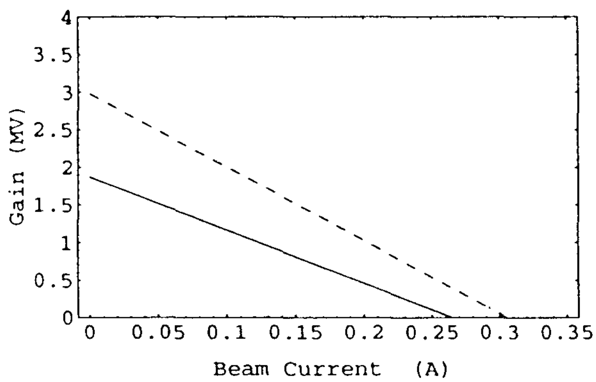

Figure 4 Energy gain of TWRR for Injector. Solid line is for Buncher, and dashed line is for Acc. 1.

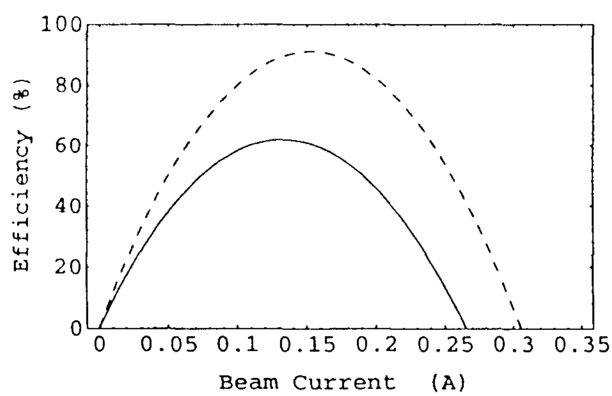

Figure 5 Loading efficiency of TWRR for Injector. Solid line is for Buncher, and dashed line is for Acc. 1.

An analytic formulae[7] was used for PNC injector, which presents enough agreement with previous high power test. Above characteristics were derived by not C-G but C-I structure, because the result of the formula does not cause significant difference by low attenuation 0.056 Nep. such as this accelerator guide. The energy gain is calculated at the feeding power of 250 kW with 0.36 and 0.45 coupling constant for TWRR and RF input for each case. More than 1.4 MV gain is achieved at 100 mA and linearly decreased because of optimum coupling for this current. The efficiency of loading(energy transfer ratio from RF to beam power) for buncher is about 60 %, whereas one for Acc 1 is 80 % which means small phase slip from wave crest. The efficiency when coupling is unity, which means simple traveling wave accelerator is about 40%. The theoretical limit in this case is 90 % when power loss is only originated from thermal loss by RF circuits. So TWRR efficiency is twice better than ordinary TW accelerators. The drive of TWRR is easer than standing wave accelerators when drive parameters is defined.

Summary

The beam quality and characteristics by design parameters was studied by numerical calculation. Results from injector design calculation above turned out that it is possible to accelerate beam current up to 1.2 MeV-100 mA with three quarter transmission and about 60 % loading efficiency. The performance of the injector section will be examined in the high power injector test in 1995 to prove these characteristics.

Acknowledgement

This study is carried out under the collaboration between PNC and KEK. Authors would like to thank Dr. S. Ohsawa and other KEK accelerator group members, and to thank Dr. K. Hayakawa, Dr. T. Tanaka and Dr. Y. Torizuka, who all gave us fruitful suggestion.

References

[1] T. Emoto et al , "PNC High Power CW Electron Linac Status ", this conference.
[2] Y. Yamazaki et al , "The Electron Gun for the PNC High Power CW Linac ", this conference.
[3] LY. Wang et al , "A Novel Chopper System for High Power CW Linac", this conference.
[4] C.A.J. van der Geer et al , "Bunching of an intense electron beam extracted from a triode gun modulated at 1 GHz", Nuc. Instr. and Meth., **A307** 553 (1991)
[5] S. Tōyama et al , " High Power CW Linac in PNC", Proc. of 1993 Particle Accelerator Conference, (1) 546 (1993).
M. Nomura et al , " Status of High Power Linac at PNC", Proc. of 1994 European Accelerator Conference, to be published.
[6] A.Enomoto et al , " Development of CW Electron Linac Using Traveling Wave Resonant Ring", Proc. of The third European Accelerator Conference, 533 (1992)
[7] L.Y. Wang, "RESEARCH ON ELECTRON LINEAR ACCELERATORS WITH TRAVELING WAVE RESONATORS (2)", IEEE Trans. Nucl. Sci., Vol. **NS-30**, No. 4, 3024 (1983)