PNC HIGH POWER CW ELECTRON LINAC STATUS

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Abstract

The Power Reactor and Nuclear Fuel Development Corporation (PNC) high power CW (Continuous Wave) electron linac is a Traveling Wave Resonant Ring (TWRR) accelerator. The 10 MeV CW linac delivers a beam current of 100 mA with 4 msec pulse and pulse repetition 50 Hz. The accelerator itself is not due to be completed until March 1997 but PNC has planned injector tests at 3.5 MeV beam energy by summer 1995. In this paper we present an overview of recent progress of the PNC linac.

Introduction

Design and construction of a high power CW electron linac to study feasibility of nuclear waste transmutation [1] was started in 1989 at PNC . Main specification of the accelerator is shown in Table 1.

TABLE 1
Main Specification of the Electron Linac

Energy	10 MeV
Max. Beam Current	100 mA
Average Beam Current	20 mA
Norm. Emittance	50 π mm mrad
Energy spread	0.5 %
Pulse Length	4 ms
Pulse Repetition	50 Hz
Duty Factor	20 %
Accelerating Frequency	1249.135 MHz
Accelerating Mode	2π / 3 mode
Number of Klystron	2
Klystron Power	1.2 MW
Number of Accelerating Tube	8
Overall Length	18 m

A high power L-band klystron and a prototype high power TWRR accelerating tube were built and successfully validated many of design concepts until end of 1992. The whole facility will be completed in March 1997 but the injector will be operated at 3.5 MeV beam energy by summer 1995 using partially built accelerator.

Injector System

The injector consists of a 200kV DC gun, magnetic lens, a RF chopper,a chopper slit, a prebuncher, and a buncher. Solenoid coils cover these elements from the exit of the gun to the first accelerating tube except between the RF chopper and chopper slits.

Electron Gun

The pulse characteristics of the accelerator beam are initially determined by the electron gun system. The accelerator requires a range of pulse widths of from 100 μsec to 20 msec, rise and fall times of ~20 μsec, and a range of beam current amplitude from 100 μA to 400 mA. Any combination of these pulse widths and height has to be available on a pulse-to-pulse at repetition rates from single pulse to 50 pulses/sec.

Several common technique are available to vary the amplitude of the emitted current. However average beam current is very high (20 mA), a grid (intercepting wire mesh) cannot be used for current control because of exceeding electron beam energy deposit to the grid wire. Furthermore, the beam currents have to be variable up to 400 mA to satisfy with downstream elements requirement such as the beam loading of accelerating tubes. Varying the cathode-to-anode voltage cannot be used for current control, since a changing injection energy is not compatible with tight bunching. A non-intercepting aperture grid is only capable of high beam current control. The two aperture grids configuration is necessary to control a greater range of beam current according to numerical simulation. The gun electrode configuration was designed using a computer code EGUN [2] to solve the Poisson equation. With this code, the electron trajectories through the gun in the presence of space charge is calculated [3].

Chopper System

The RF chopper [4] consists of a RF chopping cavity and a slit. The RF chopping cavity is a rectangular cavity driven at f_0 (fundamental frequency: 1.249135GHz) with TM_{210} mode and $2f_0$ with TM_{410} mode. There are three field mixed together in the chopper cavity. First one is a fundamental (f_0) magnetic field, second one is second harmonic ($2f_0$) magnetic field, and third one is a DC magnetic field bias. Adjusting RF field amplitude and phase, a superposed magnetic field can be equal to zero on the beam center line in 90 degree phase length.

Buncher System

The buncher is a TM_{010} room-temperature cavity at same frequency (1.249135GHz) as the fundamental of the accelerating tubes. Bunching in the PNC injector occurs in two lumped components: the prebuncher and the 1.2 m long, traveling-wave resonant ring buncher. The electrons are accelerated or decelerated depending on their phase with respect to the buncher RF field. After a drift distance, the high energy electrons reach the lower energy electrons, producing a compression of the longitudinal phase of the beam. The beam current from the DC gun is 400 mA and a quarter RF periodic (90 degree) beam passes through the chopper slits. The prebuncher and buncher are designed to avoid over bunch as much as possible. In the buncher the wave phase velocity varies linearly from 0.695 to 1.0 of light velocity. The bunch width becomes about 10 degree at prebuncher exit and 5 degree at buncher exit. The injector has been modeled with the code PARMELA [5], which simulates the beam trajectory from the exit of the electron gun to the accelerating tube.

Accelerator Section

The accelerator property is a traveling-wave accelerator with TWRR excited with microwave power at a frequency of 1.249135GHz. The accelerating tube has a cylindrical, disk-loaded shape made by OFHC (Oxygen Free High-purity Copper). The structure is designed to produce a constant axial electric field over the length of each independently fed. The number of the accelerating sections is seven and one injector section. Each of the accelerating section whose length is 1.2 meters contains 13 of $2/3\pi$ mode cavities and two coupling cavities.

All accelerating sections are designed to have constant gradient structure under the condition of 100mA beam loading. The regenerative type and the cumulative type of BBU (Beam Break Up) will be suppressed partially in the constant accelerator structure because the one accelerator sections of each cavity are designed with the same frequencies of TM_{01} mode and with very different frequencies of TM_{11} -like mode. According to the progressive stop-band technique, the iris diameters in the initial region of the accelerator section are smaller than those in any preceding ones but larger than those in subsequently located ones.

The Brillouin diagrams (ω-β diagram, i.e. characteristics of frequency dispersion) of the accelerator structure are shown in Figure 1. The frequency characteristic curves of TM_{01} mode (accelerating mode) in every cavity cross at one point A. The frequency is 1.249135GHz. Each cavity has $2\pi/3$ phase shift and the phase velocity V_p equals the light velocity c. However the curve of TM_{11} -like mode (defecting mode) located at different ranges of TM_{01} mode. The figure shows only No.1 and No.16 cavity 's curves of each accelerating section.

In the high power linac operation, considerable amount of heat is generated in accelerator structure due to RF loss. The dimension of the accelerating section is determined by the analyses of a three-dimensional finite-element heat transfer and thermal stress analysis code NASTRAN. The choice of short accelerating section and low attenuation constant structures made possible increase the threshold BBU current and liberate the tolerance of the TWRR resonate frequency, temperature stability, and fabrication. A detail TWRR with accelerating section is described else where [6].

Beam Dump and Vacuum System

The high power low energy beam (200 kW of 10 MeV electron beam) dump poses some challenging problems. For electrons with energy 10 MeV, the range of electron in water is only few centimeters in comparison with few meters for few GeV electrons. The resulting this short range with high power energy deposit causes high power densities in a beam dump target.

Major components are a emergency shutter valve, a dispersion magnet, hollow disks, and a cylindrical support carriage and radiation shielding. The beam enters into the cylindrical vessel through a dispersion magnet which is located about 2 m front of hollow disks. The dispersed beam is stopped at the inner edge of the hollow disks which are cooled by water. In order to reduce radiolysis of cooling water and to eliminate the vacuum window between the beam dump (target) and the accelerating tube, cooling water is not exposed to the direct incident electron beam. The target consists of 22 hollow disk blocks (40 cm outside diameter), which inside diameter is smaller step by step. Each disk is made from OFHC and sit on the electrically insulated support in order to measure the beam current. The maximum power density in the copper disk is about 3 kW/cm^3 with full beam power assuming Gaussian distribution of the transverse beam intensity. The maximum temperature rise in the disk (around inner edge of hollow disk) is estimated about 400 degree from this power density. The energy deposit was simulated with EGS4 [7] code and temperature distribution were done by ALGOR ®[8] (Heat Transfer Analysis Processor).

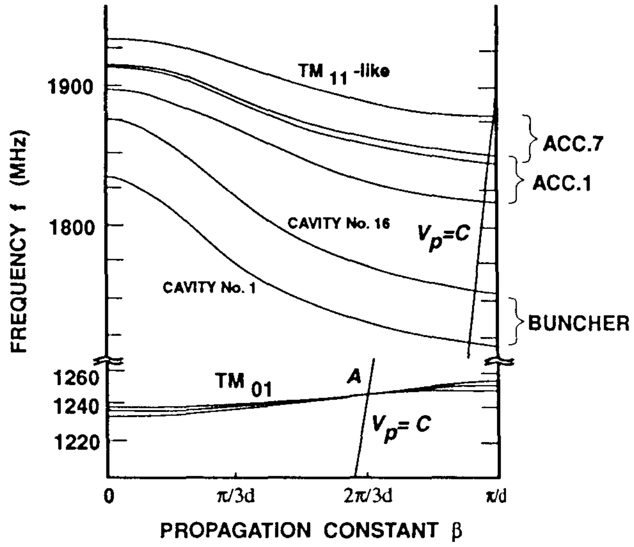

Figure 1. Brillouin diagram of accelerator structure
(d: distance between cavity centers).

The problem of connecting the beam dump system to the accelerator system and bridging the pressure difference between 1×10^{-5} torr and 1×10^{-7} torr in the accelerating tube was solved by using a differential pumping stations and a low conductance beam transport tube.

RF modulator and Klystron

The RF system of PNC accelerator requires 90 kV power converters of about 1 MW continuous rating which could be fully controlled and short-circuited regularly on their output. The specification required a voltage source is shown in Table 2.

TABLE 2
Main Specification of Klystron Power Supply

	Mode 1	Mode 2	Mode 3
Cathode Voltage	90kV	65kV	147kV
Beam Current	50A	13.8A	113A
Pulse Width	1~4ms	CW	>0.1ms
Repetition Rates	<50pps	CW	<50pps
Pulse Output	4.5MW	0.9MW	16.6MW
Voltage Sag	<5%	-	<±1%

There are three different mode for the klystron operation which are: [mode 1] a principal operation for cathode voltage of 90 kV and 4 msec pulse for two klystrons, [mode2] CW(DC) operation for one klystron, [mode3] pulse operation for cathode voltage 147 kV and 0.1msec pulse for two klystrons. The klystron is able to operate complete CW (90 kV CW) but the facility power station could not supply such large power(~5MW). Modulation of the klystron pulse voltage is accomplished by controlling the anode voltage for mode 1 and mode 2 operation. For mode 3, the beam voltage modulation is employed, using pulse transformers and solid-state switch.

The klystrons used on the PNC accelerator were developed specifically to operate in CW and pulse with good efficiency(>65%). Extensive window development work was necessary to achieve continuous power of 1.2MW at L-band. The output window was designed and tested for pill-box type windows with using TWRR unit replaced the accelerating tube. The test results agrees the characteristic of field decrease and reduction of VSWR in the pill-box by the design and suggests that the klystron will be able to produce more than 1.2MW RF with this new window [9].

Control and Data Acquisition Systems

A control system consists of two major parts: (1) computer control and monitor system, (2) an interlock system for use of the machine protection that shuts off the accelerator equipment and to protect personnel.

The computer control and monitor system is consisted of three network layers, which are Ethernet layer, VME-bus layer (reflective memory bus), and high speed communication layer. A diagram of the these layers ia shown in Figure 2. The beam control contains controls and status displays for each individual linac equipment (an electron gun, an injector, a beam transport, and a beam dump, etc). The beam control is classified as part of central control system which can be divided into five parts; the beam control, a operator's console, utility equipment for water-cooling, radiation monitor system, and gas processing equipment. These systems are connected Ethernet layer (Ethernet with TCP/IP protocol). The communication network is supervised by the system control work stations which also manage the whole linac operation. These processors are not responsible for crucial operations such as interlock system.

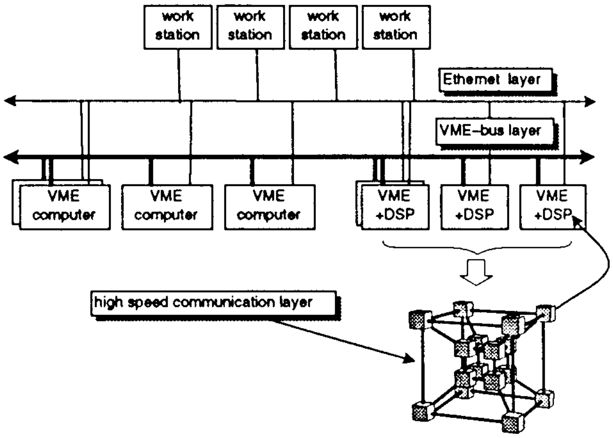

Figure 2. Schematic diagram of control and data acquisition system.

The VME-bus layer (served as the beam control and some of them contained PIOP (Parallel Input/Output Processor) system) is interfaced with the linac equipment and each VME-bus systems connected with Ethernet and reflective memory bus (20MB/sec). Each PIOP node is connected with high speed communication lines as horizontally(or hypercube shape connection), which makes each node communicate with another node a short time as compared with shared bus system. A combination with high speed communication layer and DSP (Digital Signal Processor as node processor) makes fast data processing for large number input events simultaneously. This kind of data processing could not be achieved in conventional system.

The interlock system employs hard wire programmable sequencer system connected crucial equipments, which is completely independent from computer assist system because of more redundancy for safety aspect.

Conclusion

The construction is under the progress for the high power CW electron linac with average current of 20 mA at energy of 10 MeV. The basic design of the main components were completed.

References

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