

HIGH AVERAGE BEAM CURRENT ACCELERATION AT JNC HIGH POWER ELECTRON LINAC

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Abstract

JNC is developing a high power electron linac with energy of 10MeV and an average beam current of 20mA for various applications including the transmutation of fission products. The JNC linac [1] with a TWRR (Traveling Wave Resonant Ring) is designed to accelerate the 4ms pulse width electron beam with repetition rate of 50Hz. An average beam current of 5mA has been accelerated up to 7MeV with the pulse width of 1.5ms and repetition rate of 35Hz in December 1999. This paper describes the RF control system for operations of the high average beam current and shows the test results.

1 INTRODUCTION

A schematic of the JNC linac is shown in Fig.1. The beam current from the DC gun is 300mA. The RF chopper cavity [2] is driven at the fundamental frequency of 1249.135MHz, the second harmonics of 2498.27MHz, and the DC magnetic field bias to reduce the Emittance growth by obtaining a flat top magnetic deflection field. The beam current of 300mA with phase length of 120 degrees passes through the chopper slit. After passing the prebuncher the electron bunch length is about 30 degrees at the buncher entrance and 10 degrees at the buncher exit. The accelerator has a buncher section and seven accelerating sections. The beam energy can be changed

up to 10MeV by adjusting output power of the klystron No.2. The beam with the beam current of 100mA enters into the beam dump [3] through a dispersion magnet. Hollow disks in the beam dump are placed on the electrically insulated support to stop the beam and to measure the beam current.

The accelerating section with the TWRR is adopted in order to achieve the high accelerator efficiency of 70%. There are individual three stub tuners for matching the impedance and a phase changer for adjusting the resonance frequency in the TWRR. When an average beam current of 20mA is accelerated, the temperature rise of the accelerating section is estimated to be 3°C so that the phase length changes by 5.7degrees and the RF power in the TWRR decreases by 30% [4]. If the RF and beam duty factor increase with holding the peak beam current during the adjustment, it is difficult to control phase and amplitude stability by adjusting tuners and phase changer in a TWRR. We developed a new operation method, in which the duty factors of RF power and the beam could be adjusted individually. We controlled the RF pulse width and repetition to keep the power loss constant in the accelerating section with a TWRR along in increasing an average beam current. It could be easy to increase the beam power without doing those complicated tuning.

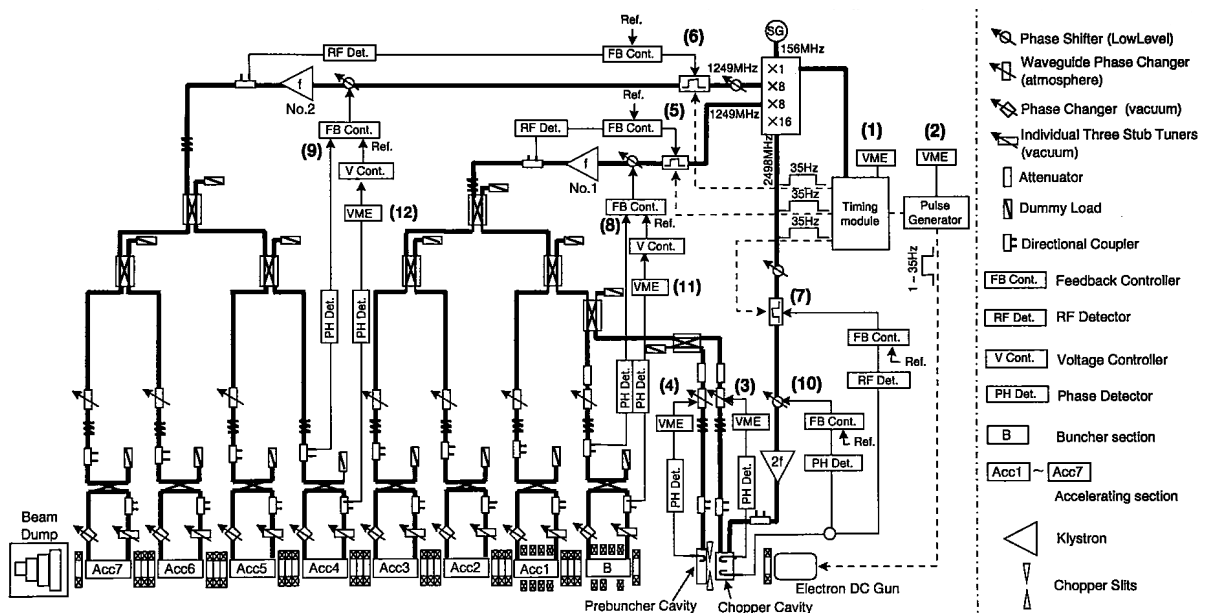


Figure 1: Schematic of the JNC linac and a block diagram of the RF control system.

2 OPERATION OF THE LINAC

The beam with the long pulse width of 1.5ms has been accelerated on the condition of Table 1.

Table 1: Linac operating conditions.

Frequency (f0)	1249.135 MHz
Gun voltage	180 kV
Gun beam current	300 mA
Beam current after chopper	100 mA
Maximum beam pulse width	1.5 ms
Beam repetition rate	1 Hz - 35 Hz
Klystron No.1 peak power	940 kW
Klystron No.2 peak power	220 kW
RF repetition rate	35 Hz
Klystron cathode voltage pulse width	4.6 ms
Beam energy	7 MeV

2.1 RF Follow-up Control

First, the beam current of 100mA with a 50 μ s pulse width at a 1Hz rate has been accelerated with the high power RF fed, which is 940kW with a 2.71ms pulse width at a 35Hz rate for the KLY1 (klystron No.1 in Fig. 1) and 220kW with 1.39ms for the KLY2 (klystron No.2 in Fig. 1). Then, the beam repetition rate was increased until 35Hz equal to the RF repetition rate by using a timing module and a pulse generator (Fig.1 (1), (2)).

The power loss of a buncher section with a TWRR is 340W when the beam current of 100mA with 3ms and 35Hz is accelerated by the TWRR power of 1670kW with 4.11ms and 35Hz. This is equal to the power loss in supplying RF pulses of 2.71ms width at 35Hz without beam current. Increasing the beam pulse width without changing the power loss of 340W, the RF pulse width is increased along with the relation of equation (1) for KLY1. Fig. 2 shows the RF pulse shape in such RF follow-up control. The power loss for each section of ACC1-ACC3 (the accelerating section No.1-No.3 in Fig.1) is approximately the same as that.

The power loss of second group (KLY2) of ACC4-ACC7 is 33W. The relation is maintained constant by changing as the equation (2).

$$Y = 2.71 + 0.466 X. \quad (1)$$

$$Y = 1.39 + 0.907 X. \quad (2)$$

where X(ms) is the beam pulse width and Y(ms) is the RF pulse width.

2.2 Cavity Phasing

The peak power of the chopper cavity and the prebuncher cavity is constant, regardless of changes in the RF pulse width. The phase of the chopper cavity changes over a long period because of slow fluctuations in temperature of cooling water which is controlled over 30 \pm 0.1 $^{\circ}$ C range. The phase difference between the measurements and the initial phase of the chopper cavity has been kept over \pm 0.2 degrees range by a mechanical

high power waveguide phase changer as shown in Fig.1 (3).

The surrounding body of the prebuncher cavity was made of the stainless steel. The re-entrant parts of it were made of the copper and were cooled by water because of reducing a phase dependence on temperature. The phase of the prebuncher cavity changed 1.5 degrees in this operating condition. In increasing the beam pulse width, the phase of the prebuncher cavity without the beam loading has been controlled similarly to the chopper cavity phase as shown in Fig.1 (4).

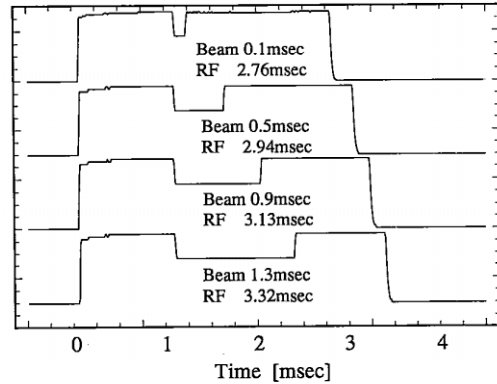


Figure 2: The RF pulse shape of the buncher section with a TWRR using RF follow-up control.

2.3 RF Control and Data Acquisition System

The RF signal picks up at the directional coupler of the KLY1 output. The signal is detected and compared with the reference voltage. The difference of these two signals is fed to control the RF driver power of the KLY1 through the feedback controller. This amplitude feedback loop shows Fig.1 (5). The amplitude feedback loops for KLY2 and the second harmonics klystron (2fKLY) are shown in Fig.1 (6), and (7).

The phase signal picks up at the directional coupler of the feeding point of the buncher section. The phase signal is locked to the reference line phase by converting to 20 MHz at the phase detector (configured as the phase lock loop controller). We set the RF level for the best phase resolution, which was 20mV per degree of phase differential. This phase lock loop for the KLY1 shows Fig.1 (8). The phase lock loops for the KLY2 and the 2fKLY are shown in Fig.1 (9), and (10).

In each TWRR this is same fluctuation of the phase in the long term because of varying temperature of cooling water. We controlled the reference voltage of the phase as shown in Fig.1 (11) and (12), and it has been kept over \pm 0.2 degrees range that the phase difference between the measurements and the initial phase which beam was not loaded in the TWRR. The phase stabilization can be maintained constant by this control if average RF powers in each TWRR dose not change in the long term.

The computer control and monitor system is consisted of Ethernet layer (Ethernet with TCP/IP protocol) and VME-bus base layer (SCRAM-net). UNIX engineering

workstations (EWS) and UNIX-based VME systems are connected Ethernet layer. The VME-bus layer served as the beam control is interfaced with each individual linac equipment (RF control system, a waveguide phase changer, the timing module, a beam current monitor, and a magnet, etc). We have introduced the NeXTSTEP (UNIX base window system) written by object-oriented programming software for EWS.

3 BEAM TEST

The beam pulse width was increased at intervals of 0.1ms per 1.5 min until 1.5ms by RF follow-up control in the beam test. Typical pulse forms measured by the CT current monitor are shown in Fig.3.

The RF power and the phase were measured with the RF pulse width followed the beam pulse width. With and without controlling the chopper cavity phase, the prebuncher cavity phase, and the reference phase, we measured phase and amplitude stability as shown in Fig.4. The phase fluctuation in TWRR was not more than 0.4 degrees without beam loading and 1 degree with it, and the amplitude fluctuation was below 0.6 % without it and 2.5 % with it. Those with beam loading were worse than without it, because the pulse width was changed before stabilizing temperature of the accelerating section and the phase of the prebuncher cavity has changed together with an increase in the pulse width. It was necessary to wait load increase until the phase in the TWRR with beam loading has had adequate time to stabilize at its initial reference phase. A part of the scattering electrons from the chopper slits have reached in the prebuncher cavity about 50 cm apart. Those electrons have caused electrical discharges in the prebuncher cavity. We must convert the drift tube near the prebuncher cavity to stop the electrons scattered toward it for improvements of those stability.

4 SUMMARIES

An average beam current of 5mA with the long pulse width of 1.5ms has been accelerated by RF follow-up control for the beam pulse width.

We will optimise the phase control and stabilization of the acceleration beam after taking steps to stop electrons scattered toward the prebuncher cavity.

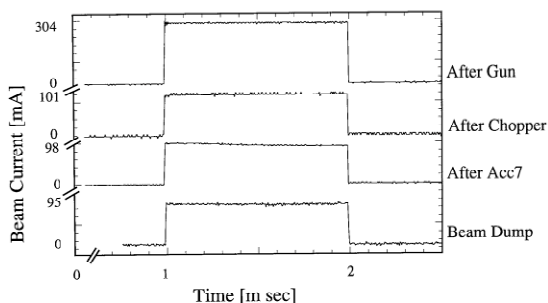


Figure 3: Typical beam pulse forms with a 1ms pulse width at a 35Hz rate.

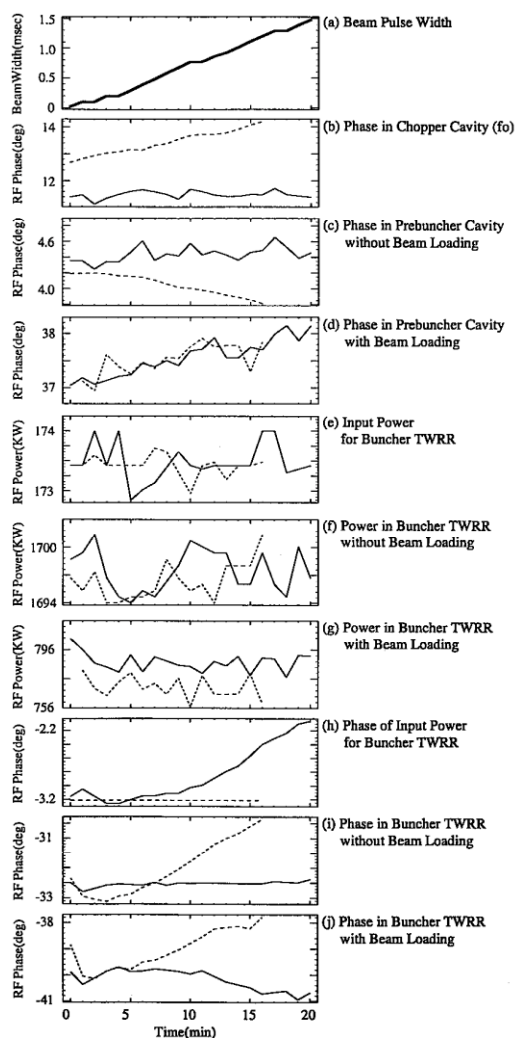


Figure 4: Phase and amplitude stability using RF follow-up control with controlling the phase of cavities and the reference phase (a broken line) and without controlling those (a dashed line).

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