CONSTRUCTION OF NEW 90 MeV INJECTOR LINAC FOR THE 1.2 GeV BOOSTER SYNCHROTRON AT TOHOKU UNIVERSITY

Shigeru Kashiwagi[#], Fujio Hinode, Masayuki Kawai, Toshiya Muto, Ikuro Nagasawa,
Ken-ichi Nanbu, Yoshinobu Shibasaki, Ken Takahashi, Hiroyuki Hama
Research Center for Electron Photon Science, Tohoku University, Sendai, Miyagi 982-0826, Japan
Nuan Ya Huang, Institute of Photonics Technologies, National Tsing Hua University, Taiwan

Abstract

The Great East Japan Earthquake (March 11, 2011) has inflicted enormous damage on the accelerator facility of Research Center for Electron Photon Science, Tohoku University. A 300 MeV linac operated for 46 years as an accelerator for radioisotope (RI) production and also as an injector of a 1.2 GeV booster synchrotron for nuclear physics experiments. The low energy part of the linac will be rebuilt with all the recyclable components and will be run for RI production. New small linac is constructed as the injector for the booster synchrotron. The injector consists of a thermionic rf-gun, an alpha magnet, two 3m-long accelerating structures, and transport line to the synchrotron. The maximum energy of injector is 90 MeV with beam loading. The detail of the injector linac is introduced in this conference.

INTRODUCTION

The 300 MeV electron linac had been operated for 46 years at Tohoku University, which was constructed as the machine for high energy experiment of nuclear physics. It was design to achieve a high average beam current and the linac was used for radioisotope (RI) production by irradiating targets with 300 Hz repetition rate. However the performance such as emittance and peak current was markedly inferior to most recent machines. The 1.2 GeV electron synchrotron have been operated to provide an energy-tagged photon beam [1]. To recover from the disaster, the Great East Japan Earthquake, we decided to remove the high energy part of the damaged linac and construct new linac as a dedicated injector for the booster synchrotron, while the low energy part of the old linac is going to be repaired for the RI production.

90MeV INJECTION FOR SYNCHROTRON

As a result of examining the some configurations of the injector, we decided to build a new injector linac which is that a thermionic rf gun is employed as electron source and only one klystron modulator unit is used to accelerate a beam up to 90 MeV. Since injection energy is lower than the previous linac, the beam instability due to the low energy injection is concerned. However we believe that the beam instability does not occur, because it has been renewed to a sophisticated synchrotron power supply for the magnets in this recovery. A beam line of the injector consists of a thermionic rf gun, an alpha magnet, two 3m-long S-band accelerating structures and two transport lines, one is injection beam line to the synchrotron and another is test beam line for beam tuning (Fig. 1). In the following sub-section, the details of each system are presented.

Electron Source

In new injector linac, a thermionic rf gun in combination with an alpha magnet system is used as electron souse. We have developed a thermionic rf gun consists of two independent cavities so as to manipulate the longitudinal phase space distribution of electron beam, named the Independently-Tuneable Cells (ITC) rf gun [2]. There are two waveguides connected to the two cells separately for controlling the rf field strength and the relative phase between cells. This makes it possible to manipulate the energy-time correlation of electrons by varying the rf field strengths and phase difference between the two cells. The generated beam by the ITC rf

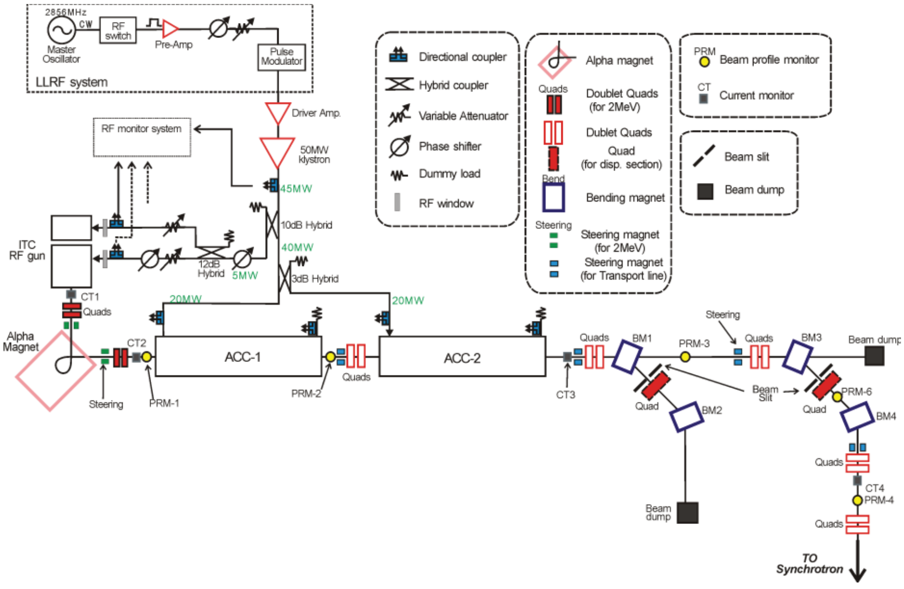

Figure 1: 90 MeV injector linac for the booster synchrotron.

[#] kashiwagi@lns.tohoku.ac.jp

gun has strong energy-time correlation because the electrons are continuously extracted from the cathode in the duration of half rf cycle and the electrons are densely populated at the bunch head. Using the beam slit installed in vacuum chamber of the alpha magnet, it is possible to cut a desired part of the bunch head.

The quality factors Q_0 for the cathode cell and the accelerating cell are estimated to be 9500 and 12500, respectively. The coupling constant β from the waveguide to each cell is designed to be relatively large so as to get a shorter cavity filling time around 200 ns for both cells. The macro-pulse duration has to be shorter to avoid excrescent heating of the cathode due to the back-bombardment. A LaB_6 single crystal cathode with a diameter of 1.78 mm has been chosen to obtain low emittance and high current density.

RF System

High power rf unit consists of a 50 MW klystron, a klystron modulator, rf vacuum waveguide system, ITC rf gun, two accelerating structures as shown in Fig.1.

The high power S-band klystron, model E3730A, produce rf pulses with peak power of 50 MW and pulse durations of 3.0 μs. The klystron needs a 317 kV pulsed voltage with a 3.0 μs flat-top to operate the 50 MW. A conventional line type modulator consists of 9 sections of pulse–forming network (PFN), and is resonantly charged and discharged by a thyratron switch. This klystron pulse modulator has good stability and flatness of the output pulsed voltage. The amplitude jitter of output voltage was about 0.22 % (p-p) and the pulse flatness was 0.30 % (within > 3.0 μs pulse flat-top).

The klystron output power is distributed using the vacuum waveguide system, including the hybrid couplers, high power attenuator, phase shifter and rf windows to the ITC rf gun and S-band accelerating structures as shown in Fig. 1. The amplitude and the phase of rf fed to the two rf gun cells can be independently controlled using the high power attenuators and phase shifters, respectively.

Accelerator Section

The 3 m-long accelerating structure is a constant gradient and high shunt impedance type. It consists of input and output couplers and 84 normal cells. The input and output of accelerating structure are quasi-symmetric coupler to minimize the beam deflection and emittance growth. The main parameter of accelerating structure; the shunt impedance (*r*), attenuation parameter (*τ*) and filling time (t_f), are 59 MΩ/m, 0.57 and 0.83 μs, respectively. With 20 MW input rf power for each structure, it can accelerate electron beam to about 98 MeV without beam loading and the energy loss due to beam loading is estimated about 4 MeV with 50 mA electron beam. The energy gain with different klystron output power listed in Table 1.

Table 1: Klystron output power and energy gain.

Kly. Output [MW]	50	48	46
Acc. Input [MW]	19.6	18.8	18.1
Eg [MeV/m]	16.19	15.86	15.56
Eg/str. [MeV]	48.58	47.58	46.68
Eg/linac [MeV]	97.15	95.15	93.36
Eg/linac with BL [MeV] (Vb [MeV, Ib = 50mA])	93.05 (-4.1)	91.05 (-4.1)	89.26 (-4.1)

Figure 2: Photograph of new injector linac and the beam profile of first accelerated beam at dispersion section.

Transport Line

The beam transport consists of quadrupole doublets and beam monitors as shown in Fig. 1. A dispersion section is located at downstream of the accelerator section, and maximum dispersion function (η) is 0.6 m at the center of quadrupole magnet. A beam current along the injector beam line was measured using the fast current transformer (CT) at four points. The button type beam position monitors (BPMs) and the beam profile monitors (PRMs) with 200μm thickness YAG crystal screen installed for beam instrumentation.

BEAM COMMISSIONING

The beam commissioning of the injector linac was started in January 2013, and the first beam acceleration up to 95 MeV with 3mA was succeeded in January 29th, 2013. Figure 2 shows the photograph of new injector linac taken from upstream of the linac and the profile of accelerated beam first observed at dispersion section.

The characteristics of the electron beam strongly depend on the operating parameters of ITC rf gun such as input rf power and phase. Figure 3 shows the result of phase scan which was measured by changing the ITC gun phase. Keeping the field strength of two cells, field gradient of 1st and 2nd cells were 27MV/m and 70 MV/m respectively, the relative phase between two cells was changed by every 10º steps. Comparing the measured beam current at gun exit with the simulation, we can know the approximate operating phase of the rf gun. The measured beam current at downstream of alpha magnet is lower than at gun exit, since a low-energy part of the

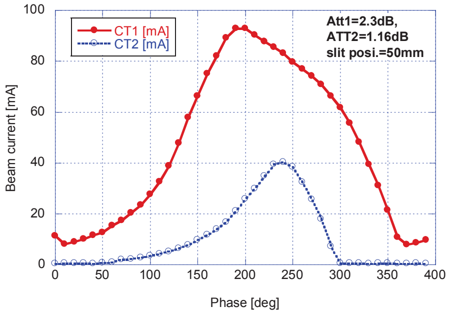

Figure 3: Measured beam current at the gun exit (red dot circle) and downstream of alpha magnet (blue open circle), respectively.

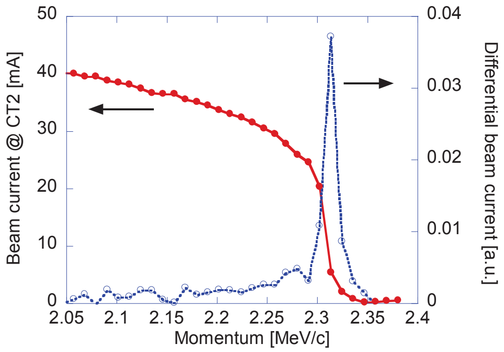

Figure 4: Measured beam current (solid circles) and its variation (open circles) at downstream of alpha magnet with different slit position.

beam is cut by the slit in the alpha magnet. Since there is a correlation between the momentum and trajectories of electron in the alpha magnet, we can measure an energy spectrum of the beam using a movable slit in alpha magnet. Figure 4 shows the measured beam current and its variation at downstream of the alpha magnet with different slit position. The current variation corresponds to the energy spectrum of beam. Beam with small energy spread can be achieved by measuring the energy spectrum and adjusting the field strength and phase of the ITC gun.

The transverse emittance measurement was performed by means of a quadrupole scan downstream from the second accelerating structure. The transverse beam size was measured using PRM with digital CCD camera for different quadrupole focusing. Figure 5 shows the measurement result of the quadrupole scan. Columns left and right represent the measurement results of the horizontal and vertical directions, respectively. Upper of Fig.5 shows the measured beam size (solid dots) as function of the quadrupole strength and the solid line retrieved from the χ^2 minimization. For the beam of 25 mA and 92 MeV (γ=180), the projected transverse emittance were ε_{nx}=6.7πmm mrad and ε_{ny}=8.9πmm mrad. This large measured emittance could be due to an inhomogeneities emission from the cathode surface and edge. It is expected that the cathode surface has been damaged in the past operation, therefore we will replace with new cathode. The lower of Fig. 5 shows beam parameters (α, β, ε) as ellipse in the phase space derived from the quadrupole scan. These parameters and

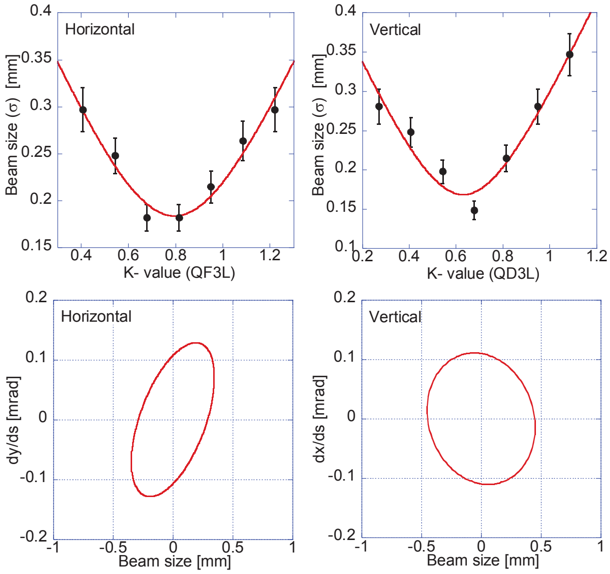

Figure 5: Quadrupole scan using single magnet in horizontal (left) and vertical (right) directions. The graphs of bottom row are beam ellipses in transverse phase space.

emittance were used to the optics matching from the injector to the synchrotron. The current setting of quadrupoles in transport line calculated from the optics matching.

SUMMARY

New injector linac for the 1.2GeV booster synchrotron has been constructed in Research Center for Electron Photon Science, Tohoku University. The operation has been started in January 2013 and we succeeded in beam acceleration up to 90 MeV. The parameters of beam generated by the ITC rf gun were measured with the movable slit in the alpha magnets. The quadrupole scan and the optics matching have been performed downstream of accelerator section with 92 MeV beams to measure the emittance and optics parameters. By improving the optics matching, we will achieve an efficient beam injection to the synchrotron.

ACKNOWLEDGMENT

The authors would like to thank Dr. S. Miura, Messrs. D. Suzuki and M. Nakagaki of Mitsubishi Heavy Industries Ltd., for their considerable cooperation in the construction of the new injector linac.

REFERENCES

[1] Hinode et al., Proc. 21st Particle Accelerator Conf., (2005) 2458-2460.
[2] H. Hama et al., New J. Phys. 8 (2006) 292.
[3] T. Tanaka et al., Proc. 27th Int. FEL Conf. (2005) 371.