PERFORMANCE OF THE L-BAND ELECTRON LINAC FOR ADVANCED BEAM SCIENCES AT OSAKA UNIVERSITY

G. Isoyama[#], R. Kato, S. Kashiwagi[†], Y. Morio, Y. Terasawa, K. Furuhashi, N. Sugimoto, J. Shen, S. Hirata, M. Fujimoto, S. Suemine, Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka 567-0047, Japan

Abstract

The 40 MeV, L-band electron linac at the Institute of Scientific and Industrial Research, Osaka University is used for various studies on beam sciences. Stability of the electron beam or the linac is crucial for these advanced studies with the linac. In order to evaluate the performance of the linac in view of stability, the intensities of the electron beam are measured at the electron gun, the end of the linac, and the experimental port, and the intensity fluctuations are analysed based on the amplitude fluctuations of the 1.3 GHz RF power provided to the linac. The intensity fluctuations at the end of the linac seem to be produced in the bunching section and those at the experimental port to be produced owing to the energy fluctuations in the acceleration tube.

INTRODUCTION

The 40 MeV, L-band electron linac is one of the main installations at the Research Laboratory for Quantum Beam Science of the Institute of Scientific and Industrial Research (ISIR), Osaka University. The linac was constructed in 1975-1978 for experiments on radiation chemistry and had been upgraded sometimes for higher performance, so that it can produce a high-intensity single-bunch electron beam with charge up to 91 nC/bunch. Recently, experiments with the linac have been extended to various studies on advanced beam sciences, including laser-synchronized pulse radiolysis in the time range down to sub-picoseconds, development of a far-infrared free electron laser (FEL), and basic study of self-amplified spontaneous emission (SASE) in the far-infrared region. In these advance studies with the linac, stability of the electron beam and reproducibility of the linac operation are crucially important. The linac was, however, constructed 30 years ago and the stability and the reproducibility were not satisfactory due to its superannuated power supplies and analogue control system based on helical potentiometers. The long-term drift of the beam intensity is more problematic than the short-term fluctuation, because the former is generally larger than the latter.

The linac was largely remodelled in 2002-2004 for higher operational stability and reproducibility. The upgrades of the linac have been continued since the remodelling, including upgrades of the timing system and of the RF cavities of the sub-harmonic buncher (SHB) system.

In this paper, we will introduce the outline of the L-band linac and will report results of evaluation of stability in the beam intensity.

LINAC

The L-band linac consists of the thermionic electron gun, the three-stage SHB system comprising two 108 MeV and one 216 MHz cavities, the pre-buncher and the buncher of the 1.3 GHz travelling-wave type, and the 3-m-long 1.3 GHz travelling-wave accelerating structure, as shown schematically in Fig. 1. The main parameters of the L-band linac are listed in Table 1. The beam-line from the linac branches off to the left beam-line for the sub-picosecond pulse-radiolysis, to the right beam-line for FEL, and to the straight beam-line leading to the second experiment room for pulse-radiolysis in the nanosecond range.

The linac is operated in four operation modes for various experiments; the transient mode, the steady mode, the single bunch mode, and the multi-bunch mode. The transient mode is used for pulse radiolysis experiments in the nanosecond range in the second experiment room. The linac is operated without the SHB system and the pulse duration is approximately 10 ns. The steady mode is used for irradiation experiments in the first experiment room. The linac is operated also without the SHB system but the pulse duration is extended to 4 μs. The single bunch mode is used for pulse radiolysis experiments down to sub-picosecond range in the left beam line and for SASE experiments in the FEL line. The linac is operated with the SHB system and a single electron bunch of the 20 ps duration is accelerated with charge typically around 30 nC/bunch. The pulse duration is further reduced to shorter than 1 ps for the sub-picosecond pulse-radioysis study with the magnetic pulse compression method. The multi-bunch mode is used for FEL. The linac is operated with the SHB system to make intervals between bunches longer to 9.2 ns. The pulse duration is extended to 8 μs for multiple amplifications of light pulses with successive electron bunches.

The thermionic cathode of the electron gun is of the dispenser type with the cathode area of 3.0 cm^2 (Eimac, YU-156) and it is operated at DC 100 kV. The RF cavities of the SHB system, which are of the quarter-wavelength type, were recently replaced with new ones, whose temperature stability is significantly improved for stable operation of the linac with the SHB system. Three independent power amplifiers with vacuum tubes provide RF pulses with the peak power 20 kW to the three cavities of the SHB system.

[#] isoyama@sanken.osaka-u.ac.jp

[†] Present address: Research Center for Electron Photon Science, Tohoku University, Sendai, Japan.

The 30 MW klystron (Thales, TV3022E) provides the 1.3 GHz RF power to the pre-buncher, the buncher, and the main acceleration tube. The klystron has two operation modes; the normal mode with the peak power of 30 MW and the pulse duration of 4 μs for usual operation, and the long pulse mode with 25 MW and 8 μs for FEL. The pulse modulator can provide square pulses with the maximum voltage of 295 kV and the maximum current of 275 A with the pulse duration of 4 μs and the repetition rate of 60 pulses per second (pps) in the normal mode, while the pulse duration is extended to 8 μs in the long pulse mode but the repetition rate is reduced to 30 pps. Stability of the klystron modulator is crucial for stable operation of the linac. The klystron modulator is designed and fabricated to realize the pulse amplitude fluctuation of 0.05 % and the flat top undulation of 0.1 %. The measured value of the amplitude fluctuation is 0.06 % (standard deviation) and the undulation on the flat top is measured in the long-pulse mode to be 0.12 % over 8 μs.

The master RF and timing system provides four synchronous RF signals, which are the 1.3 GHz CW signal for the klystron, the 108 MHz and the 216 MHz ones for the SHB system, and the 81 MHz one for the laser system used in laser-synchronized pulse radiolysis, and a 27 MHz clock signal as well as many and various timing signals for operation of the linac and for experiments. The master RF source begins with a rubidium atomic clock producing a 10 MHz RF signal with the fractional stability of 10^{-15} in the long term. It is used as the time base for a frequency synthesizer, which is used as the master oscillator for generating the acceleration frequency of 1.3 GHz. The 1.3 GHz RF signal is directly counted and frequency-divided to produce RF signals of the 6th and the 12th sub-harmonics at 108 MHz and 216 MHz, respectively, and the 16th sub-harmonic at 81 MHz together with the clock signal of the 48th sub-harmonic signal at 27 MHz. The timing part is configured with commercially available components and devices, such as standard NIM logic modules and digital delay generators, so that it is flexible for future expansion and improvement. Any timing signals can be made at an integer multiple of 37 ns and the timing jitter of the delayed signal is determined by stability of the clock, which is measured to be slightly larger than 1 ps.

A computer control system is used in order not only to realize precise reproducibility of operation but also to make routine operation of the linac possible even by an experimenter. The control system is based on personal computers (PCs) and programmable logic controllers (PLCs). The PCs and the PLCs are connected with networks using two different communication protocols. As the network connecting the PLCs, we have chosen FL-net, which is an open PLC network for factory automation.

Table 1: Main Parameters of the L-band Linac

Acc. frequency	1.3 GHz
Sub-harmonic bunchers	108MHz × 2 216MHz × 1
Accelerating structures	Prebuncher × 1 Buncher × 1 Accelerating tube × 1
Injector	Thermionic gun (DC 100kV)
Operation modes and intensities	Steady mode : 1.9 A Transient mode : 30.6 A Single-bunch mode : 91 nC Multibunch mode : 1.9 A
Max. energy	40 MeV
Pulse width	20 ps - 8 μs
Max. repetition	60 pps
Total length	10.5 m

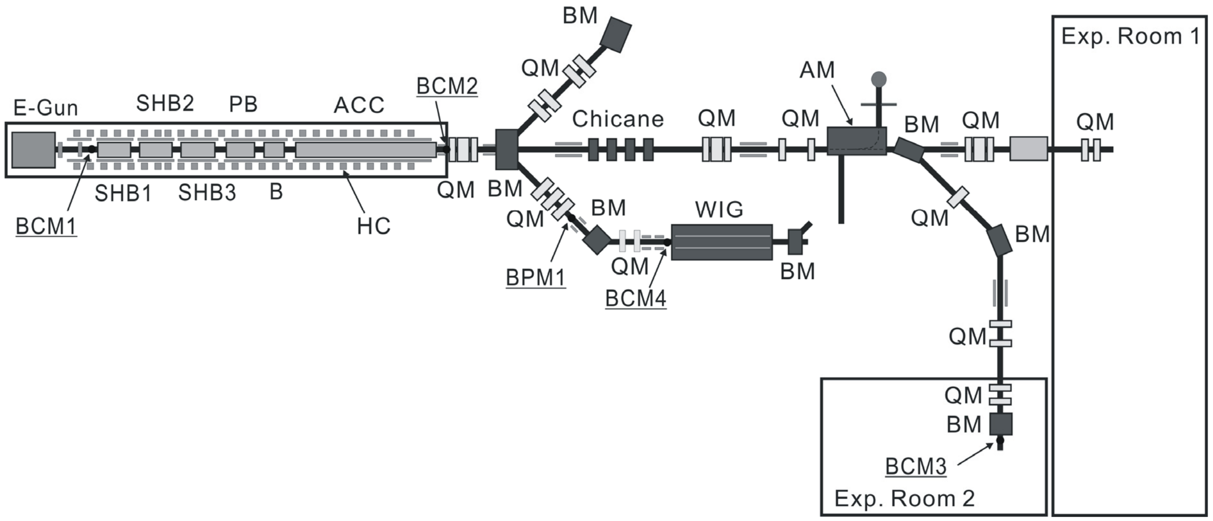

Figure 1. Schematic layout of the L-band linac. E-GUN: Electron gun, SHB1: 108MHz SHB cavity #1, SHB2: 108MHz SHB cavity #2, SHB3: 216MHz SHB cavity, PB: Prebuncher, B: Buncher, ACC: 1.3 GHz accelerating tube, HC: Helmholtz Coil, BM: Bending magnet, QM: Q-magnet, AM: Analyser magnet, WIG: Wiggler, BCM1-4: Beam current monitors, BPM1: Beam position monitor.

The PCs are connected with Ethernet and one of them works as a gateway between the two networks. The linac can be started up or shut down by a few mouse clicks of a virtual console panel on a computer screen.

Since stability of the electron beam accelerated with an RF linac is extremely sensitive to temperatures of its RF cavities and RF structures, we use a water-cooling system with high temperature stability of ±0.03 ºC for them. Another source of instability is the voltage fluctuation and drift of the 3-phase AC 200 V input power lines, which affect the amplitude of the RF power generated with the klystron. An automatic voltage regular is inserted in the AC line for the klystron modulator power supply, so that the fluctuations of the input AC voltage are reduced from ±5 V around 210 V to less than 0.05 V.

EVALUATION OF STABILITY

The 1.3 GHz RF power and the beam intensity in the transient mode were simultaneously measured with time over a period of longer than two hours, because the variation of the RF phase does not significantly affect the beam intensity in the transient mode. The long-term drift of the RF power per ten minutes is 0.016 % for the buncher and it is negligibly small for the accelerating tube. The drift was subtracted from the data for the buncher and then the intensity distributions were derived. The standard deviations of fast fluctuations in the RF power are 0.109 % for the buncher and 0.102 % for the accelerating tube. These values are approximately 1.5 times larger than the theoretical value calculated with the measured fluctuations of the high voltage applied to the klystron.

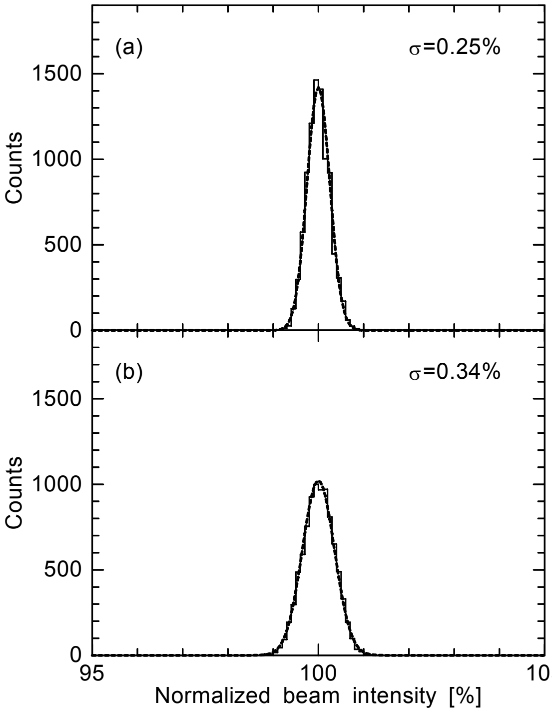

Fig.2: Histograms of the normalized beam intensities in the transient mode measured with (a) BCM2 at the exit of the linac and (b) BCM3 at the beam port in the 2nd experiment room.

The beam intensity was measured as a function of time for more than one hour with the beam current monitor of the transformer type at the exit of the electron gun BM1, with BM2 at the exit of the acceleration tube or at the end of the linac, and with BM3 at the beam port in the second experiment room, whose positions are shown in Fig. 1.

The standard deviation of the beam current extracted from the gun is 0.16 % and no long-term drift was observed. The measured beam intensities show the long-term drift of 0.04 % in ten minutes at the end of the linac and 0.08 % at the experimental port, so that the intensity fluctuations are derived after subtracting these long-term effects. The short-term fluctuations increase from 0.16 % at the exit of the electron gun to 0.25 % at the end of the linac and then to 0.34 % at the experimental port.

The increase of the intensity fluctuations may be attributed to the short-term variations of the amplitude of the RF power provided to the 1.3 GHz RF structures. Assuming the fluctuations are added randomly, we can estimate the intensity fluctuations added in the linac and in the beam transport line from the linac to the second experiment room by the error propagation theory. The intensity fluctuation is thus estimated to be 0.19 % produced in the linac after the electron gun and 0.23 % in the transport line. The electric field in the acceleration structures is proportional to the square root of the input RF power, so that the standard deviation of fluctuation in the electric field is calculated to be 0.05 %. It is approximately a quarter of the intensity fluctuation in the linac except for the gun, 0.19 %, indicating that the beam loss is produced in non-linear effects of the electric field. The fluctuations of the electric field produce energy fluctuations in the acceleration tube. Because there is no energy dispersion at the end of the linac, the energy variation does not produce the intensity variation, so that the intensity variations is considered to be produced in the bunching section consisting of the pre-buncher and the buncher. The intensity fluctuation further increases by 0.23 % in the transport line from the linac to the experimental port though there is no RF field in the part. The beam transport line bends by 90 degrees from the linac to the experimental port. If the energy of the electron beam changes, the trajectory of the beam moves due to the energy dispersion in the transport line, resulting in the loss of electrons because the tail of the transverse distribution of the electrons is scraped by the wall of the beam pipe. The process is thought to be also non-linear in the energy change, which is consistent with the fact that intensity fluctuation is 0.23 % in the transport line for the given fluctuation in energy, 0.05 %.

As a conclusion, the intensity fluctuations of the renewed linac is as low as 0.25 % at the end of the linac and 0.34 % at the beam port in the transient mode, in which the SHB system is not used. These intensity fluctuations are due to the fluctuations in the amplitude of the RF power from the klystron but the effect is amplified four times, indicating that the stabilization of the RF power can reduce the intensity fluctuations significantly.