UPGRADE OF THE L-BAND LINAC AT ISIR, OSAKA UNIVERSITY FOR A FAR-INFRARED FEL

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Abstract

The L-band linac at the Institute of Scientific and Industrial Research, Osaka University, has been renewed in order to realize high stability of the electron beam and easy changes of operation modes for various kinds of experiments. In the modification, it was included the replacements of the klystron and the pulse modulator for it to provide the rf power with the pulse duration up to 8 µs to realize power saturation of the FEL. The modification of the linac has been completed and commissioning is now in progress. The intensity fluctuations of the beam intensity in the transient and the single-bunch modes were decreased to one-tenth compared with previously measured values before the remodelling. The fluctuation of the beam energy in the single-bunch mode was less than 0.1% in standard deviation.

INTRODUCTION

We are developing the far-infrared free-electron laser (FEL) using the L-band electron linac at the Institute of Scientific and Industrial Research (ISIR), Osaka University. The first lasing of the FEL was obtained at wavelengths from 32 to 40 µm in 1994 [1], and the wavelength region has been extended up to 150 µm [2]. The linac was designed and constructed for producing the high-intensity single-bunch beam for pulse radiolysis, but not optimized for development of FEL. Though the duration of the rf pulse could be extended to 4 µs, the maximum macro-pulse length of the electron beam is limited to 2 µs, since the filling time of the accelerating structure is 1.8 µs. As a result, the FEL could not reach power saturation because the number of amplification times was limited.

Recently, the linac has been extensively remodelled to realize high operational stability and reproducibility for advanced studies in beam science and technology. Almost all the power supplies, including the main rf power source, are replaced with new ones. At this opportunity, the linac is also made suitable for FEL. The electron beam with a macro-pulse up to 6 µs can be accelerated, so that the FEL will reach power saturation. The modification of the linac has been completed and commissioning is now in progress. In this paper, we will report performance and characteristics of the linac after the modification.

NEW LINAC SYSTEM

The schematic layout of the L-band linac is shown in Figure 1.The linac consists of a thermionic gun, three-stage sub-harmonic buncher (SHB) system, a pre-buncher, a buncher, and a 3 m long accelerating tube. The thermionic gun (Eimac, YU-156) is a dispenser type with

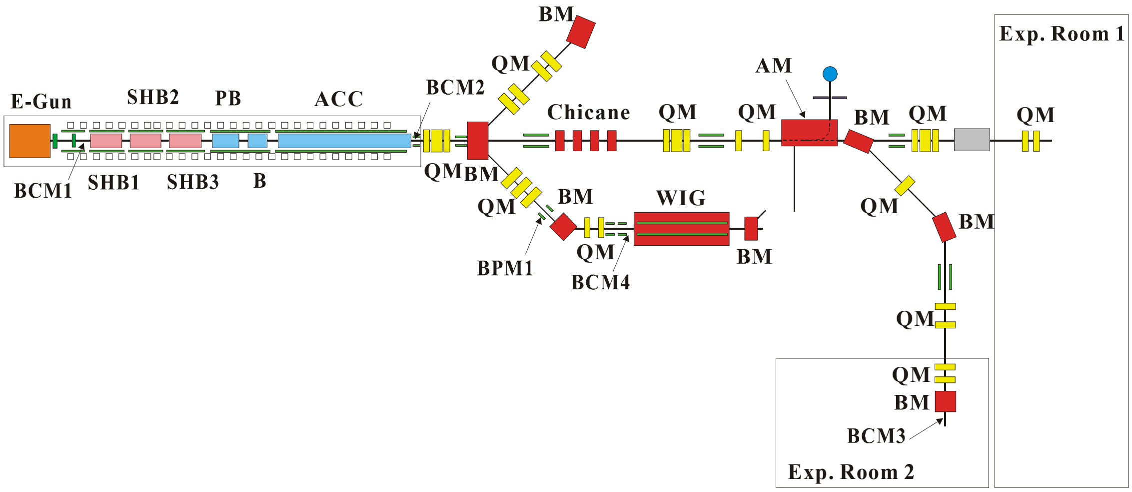

Figure 1: The schematic layout of the L-band linac. E-GUN: Electron gun, SHB1: 108MHz SHB cavity #1, SHB2: 108MHz SHB cavity #2, SHB3: 216MHz SHB cavity, PB: Prebuncher, B: Buncher, ACC: 1.3 GHz accelerating tube, BM: Bending magnet, QM: Q-magnet, AM: Analyser magnet, WIG: Wiggler, BCM1-4: beam current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

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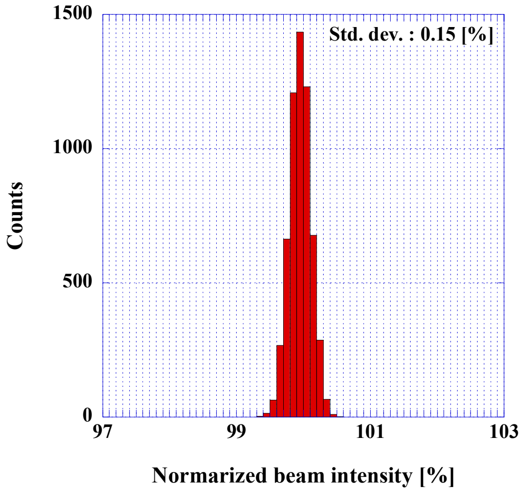

Figure 2: Histogram of the electron beam intensity extracted from the cathode. The intensity was measured with BCM1 at the entrance of the first SHB cavity.

the cathode diameter of 3.0 cm^2 and the operating voltage is 100 kV. The cathode voltage and the cathode heater are stabilized with regulated AC power sources (Behlman, BL1350; Takasago, ARH500). The SHB system is composed of two 108 MHz and one 216 MHz standing wave cavities, and each cavity is independently driven with a 20 kW rf amplifier. The pre-buncher, the buncher, and the accelerating tube have travelling wave type structures with the accelerating frequency of 1.3 GHz driven with one 30 MW klystron (Thales, TV-2022E) and a new pulse modulator, while they were driven with two klystrons before the remodelling. The new klystron system has two operation modes with different pulse durations. One is called the normal mode, in which the flat top is 4 µs long and the peak power is 30 MW. The other is the long pulse mode for FEL experiments, in which the pulse duration is 8 µs but has the peak power is 25 MW. The maximum reputation rate is 60 Hz in the normal mode, while it is reduced to 30 Hz in the long pulse mode. The pulse height fluctuation of the output voltage of the modulator is measured to be less than 0.1 % (peak-to-peak) and the undulation of the flat top to be below 0.2 % (peak-to-peak). In a test experiments, the flatness of 0.1 % was realized over a 5.5 µs time region on the flat top.

BEAM STABILITY

Stability of the beam current from injector

A histogram of the electron beam intensity extracted from the cathode is shown in Figure 2. The beam intensity was measured with a current transformer, BCM1 at the entrance of the first SHB cavity. A sampling period is 0.5 seconds and the measurement time is 1,500 seconds. The intensity is normalized with the average. The standard deviation is 0.15 %.

Stability of the beam current in the transient mode

The transient mode is most frequently used in the L band linac. In this operation mode, the SHB system is switched off. Since the single rf power source is used for the three rf structures, the beam stability deteriorated mainly by the fluctuation of the rf amplitude in the short period. In the long period, it becomes worse due to the temperature drift of the electron gun cathode, as well as the periodical temperature change of the cooling water system and the air-conditioner.

The beam intensities measured with time in this mode are shown in Figure 3. They were measured with BCM2 at the exit of the accelerating tube and with BCM3 at the beam port in the 2nd experimental room. The sampling period is 0.5 seconds and the measurement time is 4,500 seconds. The intensities are normalized with their respective average values. Figures 4 and 5 show respective histograms of the beam intensities derived from the data shown in Figure 3. In addition to fluctuations of the beam intensities in short periods, it can be seen that the intensities slightly decrease with time. The long-term drift per ten minutes is 0.04 % for the beam intensity at the exit of the accelerating tube and it is 0.08 % for that at the beam port of the 2nd experimental room. These long-term drifts were subtracted from the data and then the intensity distributions were calculated. The standard deviation is 0.25 % for the beam intensity at the exit of the accelerating tube as shown in Figure 4 and it is 0.34 % for the beam intensity at the beam port of the 2nd experimental room. These values are as small as one-tenth of previously measured values before the

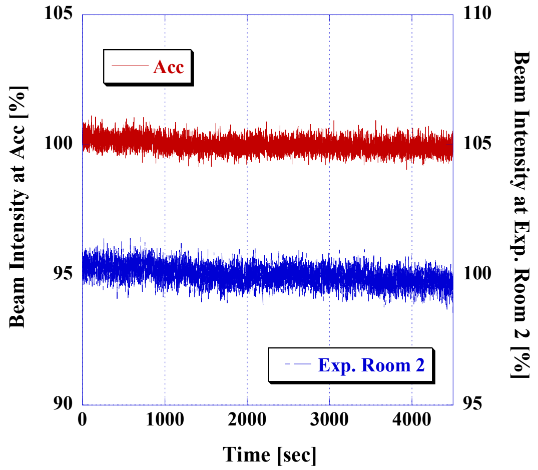

Figure 3: The beam intensities measured with BCM2 at the exit of the accelerating tube (red lines) and with BCM3 at the beam port in the 2nd experimental room (blue lines).

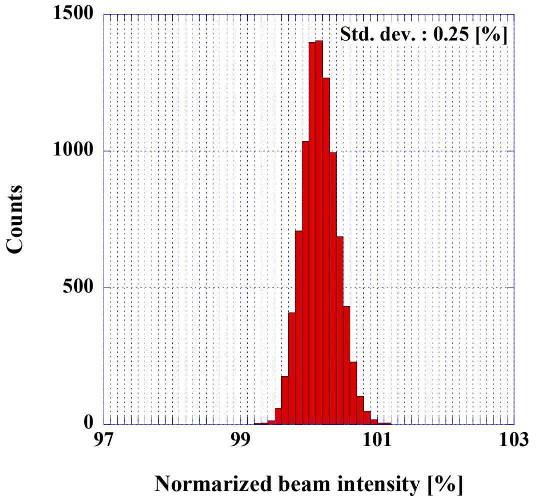

Figure 4: Histogram of the beam intensity measured with BCM2 at the exit of the accelerating tube in the transient mode.

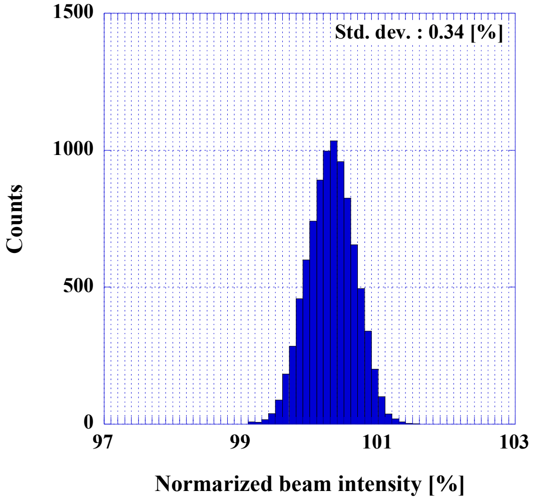

Figure 5: Histogram of the beam intensity measured with BCM3 at the beam port in the 2nd experimental room in the transient mode.

remodelling. The fluctuation of the beam intensity is larger at the beam port in the 2nd experimental room, 0.34%, than at the exit of the accelerating tube, 0.25 %.

The transverse position of the electron beam is determined by the energy of the electron beam, which is a characteristic of the electron beam, and by the dispersion function, which is a characteristic of the beam transport line. At the exit of the accelerating tube, the dispersion function is zero, so that the beam does not move even when the energy changes. For the beam port in the 2nd experimental room, on the other hand, the beam line is long and there are some regions where the dispersion function is not zero. If the electron energy fluctuates, the horizontal position changes there and portion of the electron beam scraped out, so that the beam intensity changes. This is the reason why the standard deviation of the beam intensity measured with BCM3 is larger than that measured with BCM2. Similarly, the standard deviation of the beam intensity measured with BCM2, 0.25 %, is larger than that measured with BCM1, 0.15 %, because a part of the beam is lost in the bunching process due to the fluctuation of the rf power.

Stability of the rf power

As mentioned previously, the variation of the rf phase does not significantly affect the beam intensity in the transient mode. We, therefore, simultaneously measured the beam intensity and the rf power with time. Figure 6 shows the rf power measured at dummy loads for the buncher and the accelerating tube. They are normalized with respective average values. The fluctuation of the rf power is 0.14 % (standard deviation) for the buncher and 0.11 % (standard deviation) for the accelerating tube. Since the single rf power source is used for buncher and the accelerating tube, both of the rf power shows similar fluctuation pattern.

Stability of the single-bunch beam

The single-bunch mode is used in the SASE-FEL experiments. In this mode, the SHB cavities are driven with the independent rf sources. Since the number of the rf sources is four in the single-bunch mode, which should be compared with one in the transient mode, influences of phase jitters of the sources are added to the beam. Figure 7 shows the beam intensities measured with BCM2 at the exit of the accelerating tube and with BCM4 at the entrance of the wiggler with time. The measurement time is 730 seconds and the sampling period is 0.73 seconds. The intensities are normalized with respective average values. The long-term drift per ten minutes is 0.76 % for

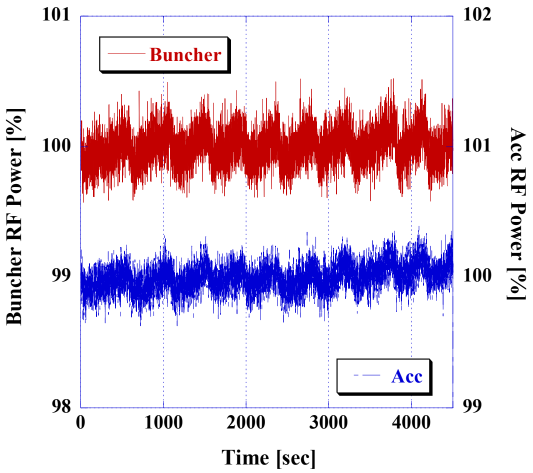

Figure 6: The rf power measured with time at dummy loads for the buncher and the accelerating tube.

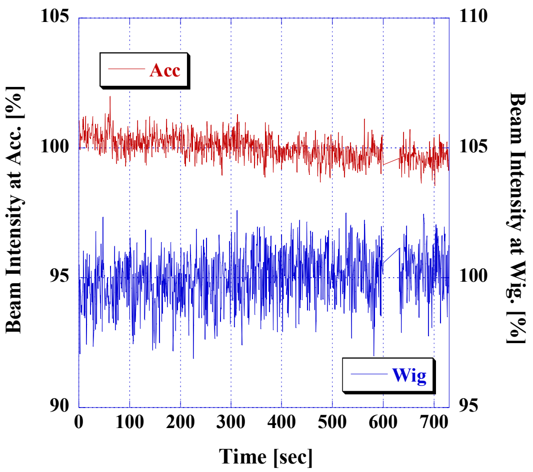

Figure 7: The beam intensities measured with BCM2 at the exit of the accelerating tube (red lines) and with BCM4 at the entrance of the wiggler (blue lines) in the single-bunch mode.

the beam intensity at the exit of the accelerating tube and it is 0.77 % for that at the entrance of the wiggler. The standard deviation of the beam intensity without the long-term drift is 0.40 % at the exit of the accelerating tube, while it is 1.00 % at the entrance of the wiggler. These values decreased one-tenth in comparison with previously measured values before the remodelling, too. However, since the stability of the SHB system is not enough, it is thought that there is still room for improvement in the system.

Figure 8 shows the beam energy measured with BPM1 on the beam transport line to the FEL system in the single-bunch mode. The sampling period is 0.73 seconds and the measurement time is 730 seconds. The standard deviation of the beam energy was 0.08 % as shown in Figure 9. Since almost energy fluctuation is included within the limit of ±0.15 % from the centre energy, wavelength shift caused by the energy fluctuation is estimated to be less than ±0.3 %.

SUMMARY

We evaluated the beam stability of the transient and the single-bunch modes after the remodelling. In the both modes, the current stability was improved drastically, the fluctuation of the beam intensity decreased to one-tenth compared with measured values before the remodelling. Since the fluctuation of the beam energy for the single-bunch mode was less than 0.1% in the standard deviation, the FEL oscillation can be expected to be more stable. Next we will evaluate the beam stability of the long pulse mode for the FEL oscillation experiment.

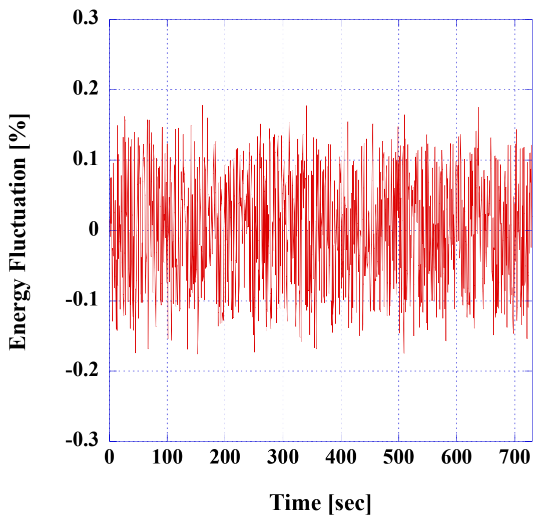

Figure 8: Temporal fluctuation of the beam energy measured with BPM1 on the beam transport line to the FEL system.

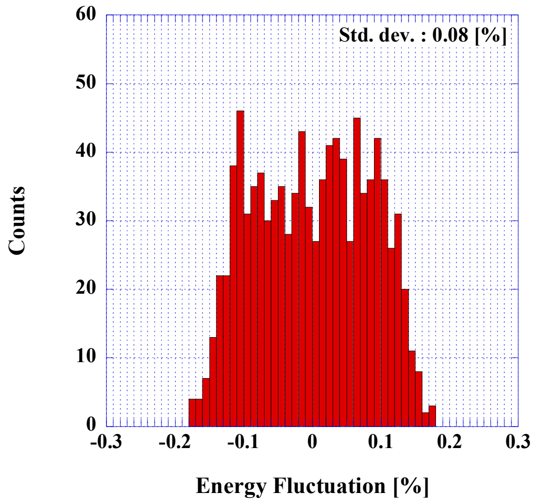

Figure 9: Histogram of the beam energy fluctuation measured with BPM1 on the beam transport line to the FEL system.

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[2] R. Kato, et al., Nucl. Instr. and Meth. A445 (2000) 169.