Multi-bunch generation by thermionic gun

M. Kuriki, H. Hayano, T. Naito, KEK, Tsukuba, Ibaraki, Japan
K. Hasegawa, Scientific university of Tokyo, Noda, Chiba, Japan

Abstract
KEK-ATF is studying the low-emittance multi-bunch electron beam for the future linear collider. In ATF, thermionic gun is used to generate 20 bunches electron beam with the bunch spacing of 2.8 ns. Due to a distortion of the gun emission and the beam loading effect in the bunching system, the intensity for each bunch is not uniform by up to 40% at the end of the injector. We have developed a system to correct the gun emission by precisely controlling the cathode voltage with a function generator. For the beam loading effect, we have introduced RF amplitude modulation on Sub Harmonic Buncher, SHB. By these technique, bunch intensity uniformity was improved and beam transmission for later bunches was recovered from 67% to 91%, but intensity for first five bunches is still lower than others.

1 INTRODUCTION
KEK-ATF is a test facility to develop the low emittance multi-bunch beam and beam instrumentation technique for the future linear collider. That consists from 1.5 GeV S-band linac, a beam transport line, a damping ring, and a diagnostic extraction line.

In the linac, the electron beam is generated by a thermionic electron gun. Typical intensity is $1 \times 10^{10}$ electron/bunch. The bunch length is compressed from 1 ns to 10 ps by passing a couple of sub-harmonic bunchers, a TW buncher, and the first S-band accelerating structure. This area is called as injector part. After the injector part, electron energy becomes 80 MeV.

The electron beam is then accelerated up to 1.3 GeV by 8 of the S-band regular accelerating section. One section has two accelerating structures driven by a klystron-modulator. Klystron is Toshiba E3712 generating 80 MW with a pulse duration of 4.5 ns RF. A peak power of 400 MW with a pulse duration of 1.5 ns is obtained by SLED cavity and makes a high gradient accelerating field, 30 MeV/m.

20 of bunches separated by 2.8 ns are accelerated by one RF pulse. This multi-bunch method is one of the key technique in the linear collider.

In April 2000, we achieved horizontal emittance $1.3 \times 10^{9}$ rad m, vertical emittance $1.7 \times 10^{11}$ rad m (both for $2 \times 10^9$ electron/bunch, single bunch mode ) (2) which are almost our target.

In November 2000, we have started the multi-bunch operation. The commissioning was successfully done. Due to lack of the instrumentation device for the multi-bunch diagnostic, emittance for each bunch is not measured yet.

2 MULTI-BUNCH BEAM GENERATION
The gun assembly consists from a thermionic gun, Grid pulser, and a high voltage gun pulser.

The thermionic gun, is a triode type, EIMAC Y796. The electron current is controlled by Grid bias.

To make a multi-bunch electron beam with a bunch spacing of 2.8 ns, 357 MHz RF signal is applied to the GUN cathode. 357MHz ECL level RF signal is amplified by a power amplifier. This output has a pulse height of 400 V peak-to-peak, but the amplitude is gradually changing at the rise and fall edge as shown in FIG. 1.

FIG. 2 shows the multi-bunch beam generated by thermionic gun. The vertical and horizontal axes show time in ns and the beam current in A respectively. The grid bias was set to 240 V. The left side is early bunch. The beam current is measured by a current transformer which is set right after the gun exit. The current transformer measures the beam current as the induction voltage, so the output decays with a time constant.

Intensity for the first three bunches is still increasing. This behavior is due to the rounded rising edge of the clipping rectangular pulse.

In addition, several bunches around 13th and 14th have lower intensity than others. A study for the gun emission (2) demonstrated that the gun response to the rectangular
pulse reproduced this dip, but the reason was not fully understood. This is not any problem on the electrical circuit such as reflection signal because any dip was not observed in direct measurement of the rectangular pulse applied to the cathode.

To correct this dip, an additional signal source was introduced. The correction signal is produced by a function generator, Tektronix AWG 510 which can make an arbitrary waveform with 1 GHz clock speed. The signal is transferred to the gun high voltage station through an optical cable, amplified 20 W RF amplifier, and combined with the main signal through a resistive power combiner. Typical amplitude of the correction signal is 30 V which is roughly 10% of the main signal applied to the gun cathode.

Figure 3: Multi-bunch beam applying the correction signal. Grid bias was 240 V.

4 SHB AMPLITUDE MODULATION

Electron beam generated by the thermionic gun has approximately 1 ns bunch length which is larger than acceptance of S-band acceleration. A couple of 357 MHz standing wave Sub-harmonic bunchers, and a traveling wave S-band buncher are placed to gather electrons into the S-band acceptance, 10−20 ps.

In multi-bunch operation, the bunching field is decreased by beam induced field, i.e. wake field. This is the beam loading effect. Beam loading effect is larger for later bunch, so the condition becomes worse for the later bunches.

To compensate the beam loading effect, we have introduced amplitude modulation on pulsed RF for SHBs. In amplitude modulation, the amplitude of pulsed RF is changed synchronously with the beam timing. Cavity RF amplitude is then gradually increased with the filling time as shown by the dashed line. On the other hand, RF amplitude is decreased by the beam loading effect as shown by the dotted line. Totally, cavity RF amplitude is kept flat.

Figure 4: In amplitude modulation method, amplitude of input RF is changed synchronously with the beam timing. Cavity RF amplitude is then gradually increased with the filling time as shown by the dashed line. On the other hand, RF amplitude is decreased by the beam loading effect as shown by the dotted line. Totally, cavity RF amplitude is kept flat. The bunching quality becomes equal for all bunches.

The beam loading effect always decelerates the followed bunches. In ATF, the first SHB, SHB1 is operated in deceleration mode and the second, SHB2 is in acceleration mode. The beam loading effectively increases RF amplitude in SHB1 and decreases in SHB2. Modulation sign is then negative for SHB1 and positive for SHB2.

Optimization for the amplitude modulation has been done by looking beam transmission at the end of injector part. A wall current monitor is placed at the exit of the injector part to observe the beam current. FIG. 5 shows the response of the wall current monitor to the multi-bunch beam. The dotted and solid curves indicate those obtained with the conventional pulsed RF and the amplitude modulated pulsed RF on SHBs respectively. Transmission for
the later bunches was recovered by the amplitude modulation.

The beam loading effect affects the transmission for the later bunches, then we should investigate the bunch transmission to examine the beam loading effect. Since the absolute transmission for each bunch is hard to measure exactly, the intensity ratio of the early bunch and later bunch can be used instead of the absolute transmission.

Intensity of the last bunch is much lower than others due to the less sharpness of the clipping rectangular pulse. Because of that, effect of the amplitude modulation should be examined by the last second bunch rather than the last bunch.

The transmission ratio of the second last bunch was 0.67 for the conventional SHB RF and 0.91 for the amplitude modulation SHB RF respectively. The most intense bunch was used as the reference. Improvement of the transmission by the amplitude modulation was 24%.

FIG. 6 shows distributions of bunch intensity for 6th and later bunches. The peak voltage of wall current monitor is here used instead of the real beam current. The solid and hatched histograms are those with the amplitude modulation and the conventional pulsed RF on SHB respectively. With the amplitude modulation, most bunches are distributed more than 18 V, but with the conventional RF, bunches are spread widely from 12 V to 20 V. The amplitude modulation improved the flatness of intensity for these later bunches.

FIG. 6 does not include the first five bunches. The lower intensity of these bunches is due to the rounded rising edge of the clipping pulse. That will be one of the main issue on the multi-bunch operation.

5 SUMMARY

In KEK-ATF, multi-bunch beam was successfully generated by a thermionic electron gun with bunch spacing of 2.8 ns. The beam already reached to the extraction line, but the emittance was not measured yet due to lack of the instrumentation for multi-bunch beam.

Intensity for each bunch is not uniform because of: 1) gun emission un-uniformity; 2) beam loading effect.

For gun emission problem, we have applied a correction signal generated by an arbitrary function generator to Gun cathode. Bunch intensity flatness was significantly improved by this emission correction. However, Gun emission for first five bunches is still lower than others. That will be one of the main issue in future.

For beam loading effect, we have introduced amplitude modulation on SHB RF. The amplitude modulation compensated the beam loading effect and recovered the beam transmission from 67% to 91%.

6 REFERENCES

[1] http://lcdev.kek.jp/ATF/
[2] M. Kuriki et al., 'Multi-bunch beam generation by Thermionic Electron Gun', 24th Linac meeting at Sapporo, 1999