BEAM CHARGE FEEDBACK SYSTEM FOR THERMIONIC CATHODE RF-GUN

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Abstract

A feedback system to stabilize a long-time operation of thermionic cathode RF-Gun has been developed in Kyoto University free electron laser (KU-FEL) facility where a 4.5-cell thermionic cathode RF-gun provides electron beam to drive a mid-infrared FEL. Since the back-bombardment effect seriously increases the temperature of the cathode surface and, consequently, increases the beam charge, a stable operation is difficult without continuous control of the thermal emission from the cathode. We have tried to stabilize the beam charge of the thermionic cathode RF-gun by using a feedback system. The beam charge was monitored with a current transformer (CT), which was located at the exit of the gun, was read by an oscilloscope. The total charge was calculated in a PC and the LabView PID-module controlled the cathode heater current. As the result, the long term stability of the beam charge was dramatically improved from 18%/h to 0.1%/h in variation. The variation at the undulator section was also improved, 1.2%/h.

INTRODUCTION

The KU-FEL is a mid-infrared FEL system aiming at development of advanced energy sciences [1]. The construction of the facility building ended in spring of 2004 and the installation of the driver linac and the commissioning has started on the fall of 2005. We succeeded in acceleration of 40 MeV, -60 mA electron beam [2]. Since the system uses an S-band thermionic RF-gun of 4.5 cell, the output charge is severely affected by the cathode temperature, the vacuum condition in the gun, the RF power, and so on. So it is difficult to operate the RF-gun with constant output charge and, thus, difficult to obtain a constant energy electron beam. Even within the macro-pulse duration, typically 3 μs, the output charge drastically increases due to the back-streaming electron hitting on to the cathode surface. Thus we need a feedback system to obtain a stable operation of the thermionic RF-gun. The aim of the feedback system is to stabilize the beam charge from the thermionic RF-gun for a long term (-hours). The control variable of the feedback system is an essential parameter. We tried two control variables, 1) a cathode surface temperature and 2) a total beam charge from the RF-gun. In this paper, we describe the system configuration of the present feedback system, the experimental results with each control variable and conclusions.

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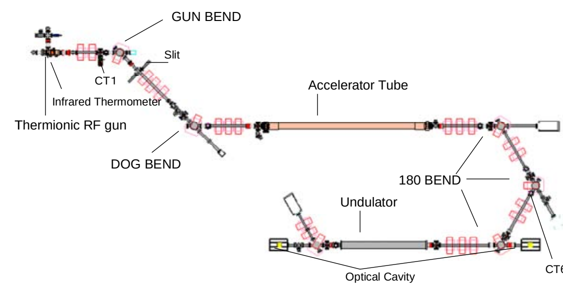

Fig.1 Schematic view of the KU-FEL system

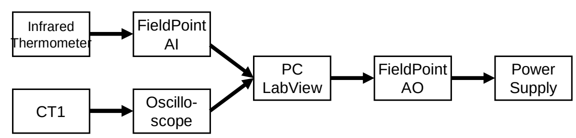

Figure 2: Block diagram of the feedback system.

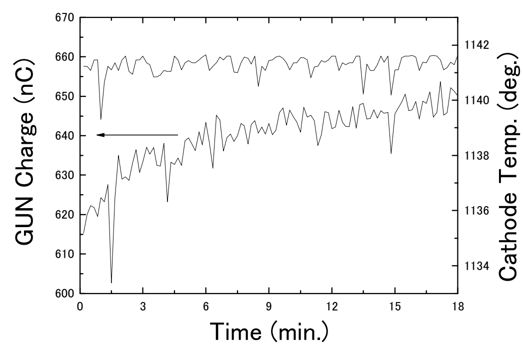

Figure 3: Time trend of the beam charge and the cathode surface temperature without a feedback system.

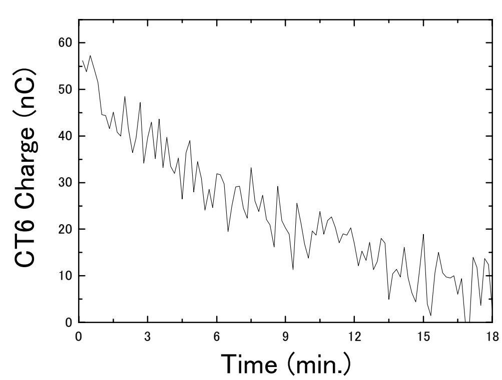

Figure 4: Time trend of the beam charge at 180-bend section without a feedback system.

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OUTLINE OF THE FEEDBACK SYSTEM

The feedback system for the thermionic RF-gun system consists of an infrared thermometer or a beam current monitor, a cathode heater power supply which is controlled by FieldPoint (National Instruments) and a LabView running on the control PC. Since the time constant of the feedback system is about 10 second, a software PID control given by LabView is employed in this system. Figure 2 shows the block diagram of the feedback system.

The time trend of the beam charge without the feedback system is shown in fig.3 as a comparison. Figure 3 also shows the temperature fluctuation. The variation of the beam charge was 5.5% in 18 minutes (18%/h). The large dip in fig.3 was originated by a discharge event in the RF-gun. We should mention about the other important parameter, beam energy, as well. Since the KU-FEL driver linac has an energy filtering section ("slit" in fig.1) from the gun to the accelerator tube, the beam energy fluctuation also affects both to the beam charge and to the beam position at the undulator section and leads to an unstable FEL oscillation. So the beam charge observed at CT6 which is located in the 180-bend section is shown in fig.4. As is shown in fig.4 the beam charge at the 180-bend section is almost zero after 18-minutes operation. We could say that without a feedback system our RF-gun can not operate even in a short time.

Control with Cathode Surface Temperature

At first we tried to use the cathode surface temperature, which is monitored by a two-color infrared thermometer (Chino, IR-FA), for the process variable of the PID control. The output signal was fed into the AI module of the FieldPoint and was processed as the process variable (PV) in the ActiveX-CA in our control system [3]. Figure 5 shows the time trend of the beam charge of the thermionic RF-gun and the corresponding cathode surface temperature which was controlled to be constant. Under the controlled condition, however, the beam charge of the RF gun could not be stabilized so well. The variation of the beam charge of the RF-gun was 4.2% in 65 minutes (3.9%/h). This result suggests that the thermal emission from the thermionic RF gun does not only depend on the cathode temperature, but also depend on other parameters, such as the vacuum condition at the cathode surface. The beam charge observed at CT6 which was located at the 180-bend section is shown in fig.6. It is clear that the temperature feedback system could work only 20 minutes or so and can not suitable for our purpose.

Control with Beam Charge

Secondly we tried to use the output charge, which was monitored by a current transformer ("CT1" in fig.1) located on the downstream of the RF-gun, for a process variable of the PID control. The signal from the CT1 was measured by an oscilloscope (LeCroy, WaveRunner) which was also connected to the control LAN. The waveform from the oscilloscope collected by a PC was integrated over the macro-pulse length to calculate the total charge of the electron beam, then, the total charge

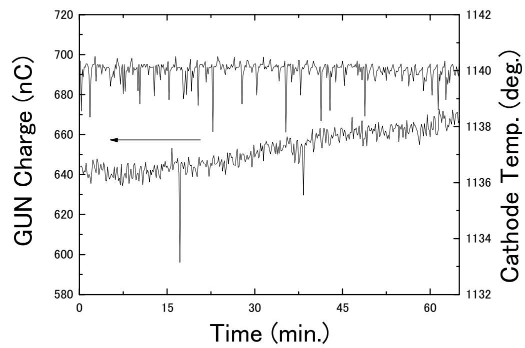

Figure 5: Time trend of the beam charge and the cathode surface temperature with the temperature feedback system.

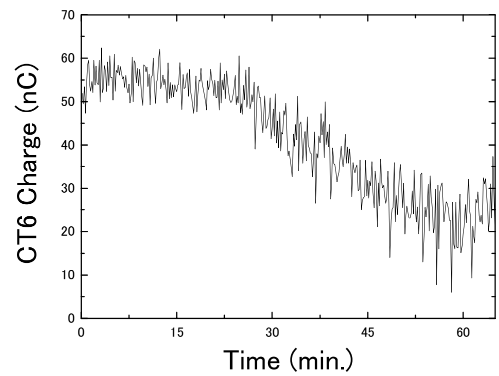

Figure 6: Time trend of the beam charge at 180-bend section with the temperature feedback system.

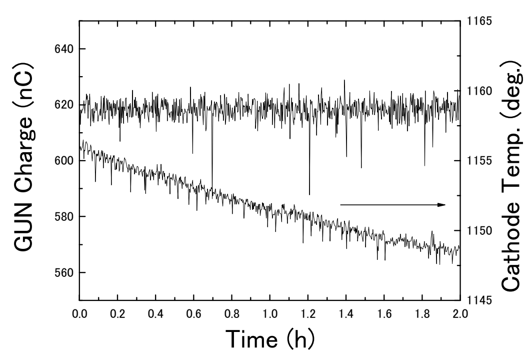

Figure 7: Time trend of the beam charge and the cathode surface temperature with the beam charge feedback system.

was turned into a PV of the ActiveX-CA. Figure 7 shows the output charge of the RF-gun with the feedback system on. As shown in fig.7 the output charge was successfully stabilized in 0.2% variation during 2 hours (0.1%/h). The beam charge at the 180-bend section monitored by CT6 (fig.8) was also well stabilized in 2.3% in 2 hours (1.2%/h). We have to say that the short term fluctuation, a shot-by-shot fluctuation, still remains in large, 18% in peak-to-peak. The short term fluctuation was also observed in the output charge of the RF-gun shown in fig.7. Since the CT measurement includes the noise from the klystron, the intrinsic fluctuation could be smaller than 18%. However, further improvement for reducing the measurement noise should be tried to reduce the short term fluctuation of the feedback system.

CONCLUSIONS

A beam charge feedback system for the 4.5 cell thermionic RF-gun installed in the KU-FEL driver linac has been developed. The feedback system consists of the LabView PID module running on the PC based control system with a two-color infrared thermometer for the cathode surface temperature control and with a CT for the beam charge control. Since the thermal emission from the cathode was not only influenced by the cathode temperature, but also influenced by the vacuum condition around the cathode, the cathode surface temperature control did not work well. On the other hand, the beam charge control successfully stabilized the output charge of the RF-gun. The variation of the beam charge was 0.1%/h at the RF-gun and 1.2%/h at the 180-bend section. We still observed short term fluctuation of 18% at 180-bend section. The feedback system should be needed a further improvement to reduce the short term fluctuations.

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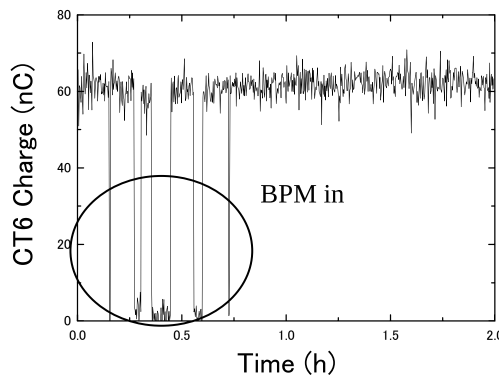

Figure 8: Time trend of the beam charge at 180-bend section with the beam charge feedback system. The zero charge events, "BPM in", correspond to the beam position monitor interrupts the beam at the upstream of the beamline.