A DC/PULSE ELECTRON GUN WITH AN APERTURE GRID

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Abstract

A prototype thermionic-electron gun for a highly bright X-ray generator has been developed. Its extraction voltage and design current are 60 kV and 100 mA (DC), respectively. Based on the EGUN simulation, the first prototype electron gun is fabricated. The main specifications of the prototype electron gun were firstly measured by pulsed beams, and confirmed that the maximum beam current of 85.7mA focused on the rotating anticathode with a spot size of 0.79mm x 0.13mm. In the DC beam test in progress, beam current is limited by the increase of temperature on the periphery of beam duct. With the treatment for the heating, extracted beam current has been growing to 24 mA without serious increase of temperature

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INTRODUCTION

A large-sized synchrotron radiation (SR) source is used for studies which need high brightness pulse X-rays now. Due to ring structure, a synchrotron light source cannot change its time structure freely. On the other hand there is not a commercially-supplied ultra bright X-ray generator which can install in a laboratory; therefore S/N is not so good. In addition, commercially-supplied X-ray generator cannot generate pulse X-rays. Consequently developing the ultra bright X-ray generator which can generate DC or pulsed X-ray in a normal-size laboratory is required by X-ray users.

On the basis of such a demand, we have been developing a laboratory use X-ray generator [1] whose brightness is ten times stronger than that of conventional X-ray generator. In order to realize such a generator, a high-average current and low-emittance electron gun is essential. In this paper, we will focus on a performance of such an electron gun.

DESIGN PRINCIPAL

The first prototype X-ray generator will provide information about feasibility of the system including a rotating anticathode, electron beam optics, and so on. The prototype generator has been developed efficiently using existing hardware. From specifications of high-voltage power supply, beam extraction voltage and extraction current are decided to be 60 kV and 100 mA (DC), respectively, with the proviso that the extraction voltage of 120 keV will be taken into consideration in a production version. An aperture grid is introduced instead of conventional mesh grid. This is because damage of a mesh grid caused by beam is a worrying factor, especially when beam increases up to 300 mA in the production version. Furthermore emittance growth will be smaller in case of an aperture grid. This is a welcome situation because low emittance beam is required in order to focus a beam on a rotating anticathode within 1.0 mm x 0.1 mm. A cathode is commercially-supplied thermionic single crystal of LaB_6 or CeB_6 whose diameter is 2.0 mm. The maximum voltages between cathode and grid are 5 kV in DC operation and 3.5 kV in pulse operation. These maximum voltages are limited by existing a stabilized power supply and a pulse generator. The main specifications for the first prototype electron gun are summarized in Table 1.

Table 1: Main Specifications

Extraction Voltage	60 kV
Maximum current	more than 100 mA
Grid type	aperture grid
Cathode emission	thermionic
Cathode material	LaB_6 or CeB_6
Cathode diameter	2.0 mm
cathode-grid voltage	5.0kV (DC)/ 3.5kV(pulse)
Beam size@ anticathode	1.0 mm x 0.1 mm
Emittance	a few π·mm·mrad

SIMULATION

Conditions for simulation

Geometry of electrodes of the electron gun is optimized by the EGUN code simulation. Conditions for simulations are followings. The aperture grid thickness must be at least 1 mm in consideration of mechanical strength, thermal melting and the fact that the edge of aperture grid should be round in order to suppress discharge. A diameter of the aperture grid must be sufficiently large in comparison with the size of the beam. Nominal grid voltage is set to 3 kV in order to keep a performance margin for high-voltage power supply whose maximum voltage is 5 kV. As for the diameter of cathode, two cases of 1 mm and 2 mm are simulated. Extraction voltages are 60 kV in nominal operation and 120 kV in the future upgrade.

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Simulation result

Figure 1(a) shows the simulated beam current as a function of grid voltage. The cathode of 2mm in diameter exceeds 100 mA in any combinations of grid voltage and extraction voltage, while in the case of the cathode of 1 mm in diameter, maximum extraction current is considerably smaller than the target value. An additional remark which should be made here is on the maximum current from the cathode of 2 mm in diameter with the extraction voltage of 120 keV and the grid voltage of 5kV. It exceeds 300 mA, which is the target value in the production version.

Figure 1(b) shows the simulated beam emittance plotted against the grid voltage. Although the smaller diameter of cathode gives smaller emittance, the beam emittance from the cathode of 2 mm in diameter is still tolerably small. The cathode, when operated at the conditions of the extraction voltage of 60 keV and the grid voltage of 3 kV, gives extraction current of 145 mA and beam emittance of 2.8 π·mm·mrad, which meet the requirements for the prototype electron gun. Figure 2 shows an output of the EGUN simulation. It shows that the extracted beam is almost parallel.

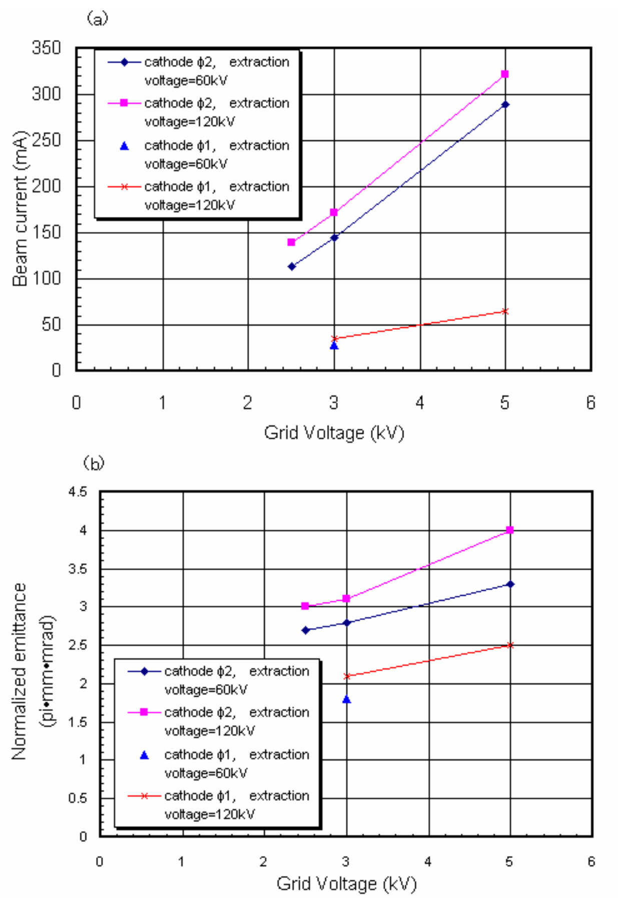

Figure 1: EGUN simulation result.

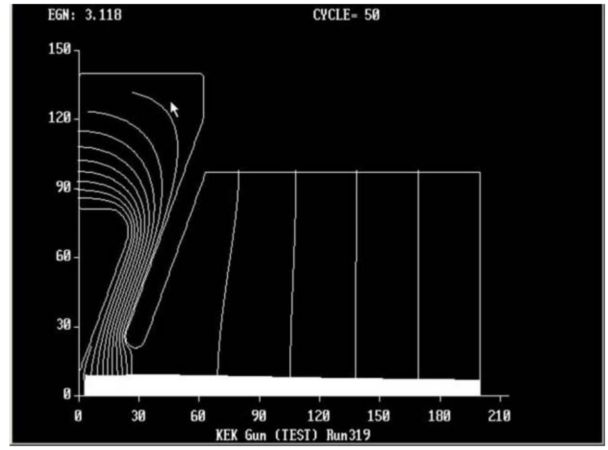

Figure 2: Output of EGUN simulation for the case of the extraction voltage of 60 kV, grid voltage of 3 kV and the cathode diameter of 2 mm.

BEAM TEST

The fabricated prototype electron gun is based on the optimized geometry. Especially as for the cathode-grid assembly, Hitachi Haramachi Electronics Co.,Ltd. drafted engineering drawings and fabricated it.

Pulse beam test

The electron gun was installed in a test stand. Figure 3 shows a schematic layout of a system configuration of the test stand. The high voltage power supply applies 60 kV DC to the cathode-grid assembly and the high voltage (HV) station. The grid pulsar superimposes a pulsed voltage between the cathode and aperture grid electrodes. A typical pulse width is 1 μsec and repetition rate is 1 Hz. An extracted beam is transported to a fixed target by beam optics, which consists of steering magnets, a magnetic lens, a quadrupole magnet and a bending magnet [1]. The fixed target is wired to the oscilloscope with 50 Ω termination. A beam current is transformed to voltage and read out.

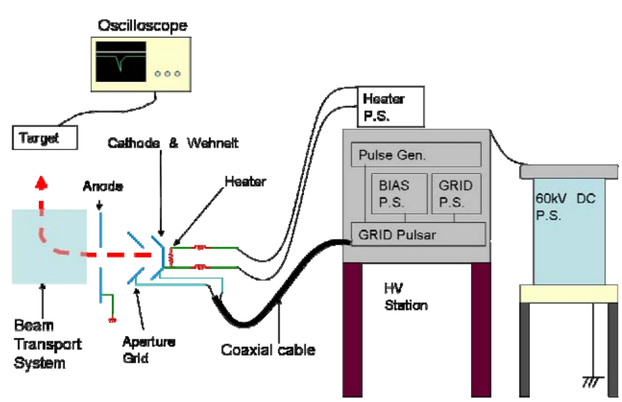

Figure 3: System configuration of test stand.

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Figure 4 shows a beam current as a function of grid pulse voltage. A beam current of 85.7 mA is extracted at the grid voltage of 2.8 kV. We refrained from applying higher voltage to the grid on account of high frequency of electric discharge which comes from a lack of sufficient aging process.

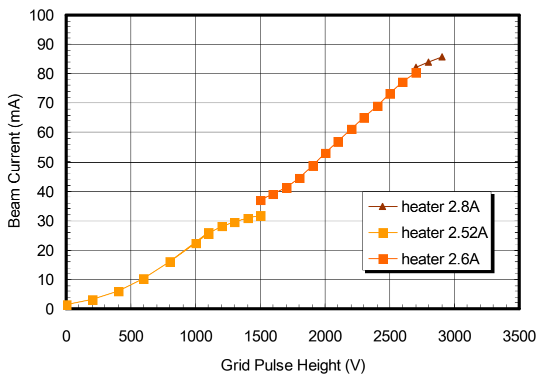

Figure 4: Plot of beam current.

The electron gun has been installed in the X-ray generator in order to measure beam sizes on the rotating anticathode. X-rays from the anticathode are projected through a pinhole of 10 μm in diameter to a fluorescent screen, which is on the position at the angle of 6 degrees against the anticathode surface and gives a 5-times magnified image. Visible light from the fluorescent screen is recorded by a chilled CCD camera (C5985, Hamamatsu Photonics). Figure 5 shows a schematic layout of the X-ray measurement system.

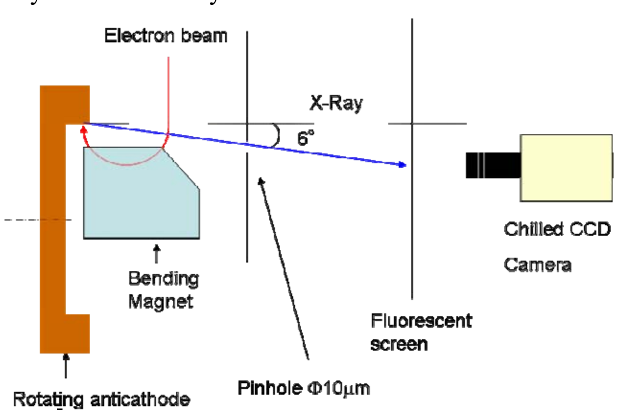

Figure 5: A schematic view of X-ray measurement system.

Figure 6 shows a beam profile taken by the CCD camera. Measurement conditions, such as beam pulse width, beam current, repetition rate and exposure time, are 10 μsec, 20 mA, 200 Hz and 80 sec, respectively. From the profile, the beam sizes on the anticathode were obtained by fitting to gauss shapes: FWHM sizes are 0.79 mm in horizontal, and 0.13 mm in vertical. These values almost meet the specification values.

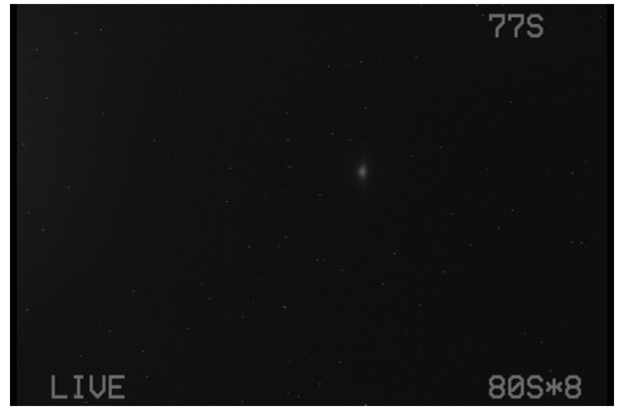

Figure 6: A pulse beam profile with beam current of 20 mA.

DC beam test

A DC beam test has been performed with thermal problems which didn't occur in pulse beam test. Though we had been adjusting the transport optics in order to lower the temperature of beam duct, it was 85 degree Celsius with the beam current of 11.8 mA. The beam duct of 6 mm in inside diameter must be considerably narrow for the simulated beam size of 3.5 mm [1]. A broadened beam duct 10 mm in inside diameter has been able to transport a beam current of 24 mA without serious increase of temperature. We are gradually increasing beam current with the care about the heating toward the goal of 100 mA.

SUMMARY

The prototype thermionic-electron gun for a highly bright X-ray generator has been developed. Its extraction beam current is 85.7 mA in the pulse beam test with extraction voltage of 60kV and grid voltage of 2.8kV. The beam sizes of 0.79mm x 0.13mm (FWHM) have been achieved on the anticathode. These values almost satisfy the specification values. In the DC beam test, extracted beam current recently reached to 24 mA. The point that needs to be worked out in the DC beam test is a thermal problem. The beam current will be increase with the treatment for the heating.

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