IDENTIFICATION OF EMITTING SOURCES OF DARK CURRENTS FROM GRIDDED THERMIONIC ELECTRON GUN AND MEASURES TO SUPPRESS DARK CURRENTS FROM ELECTRON GUN IN SPRING-8 LINEAR ACCELERATOR

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Abstract

Dark current emitted from the gridded thermionic electron gun of the SPring-8 linear accelerator has been investigated by means of our offline electron-gun test equipment applying DC acceleration voltage to its electron gun. The investigations revealed that the dark current was generated from the wehnelt electrode, the grid electrode, and the cathode surface. Based on this identification of the emitting sources, the electron gun of the test equipment was improved. The anode and wehnelt electrodes were replaced with new electropolished ones. A cathode assembly was replaced with a newly-developed cathode assembly with a grid electrode smoothed by electro-polishing. The improved electron gun of the test equipment emitted dark current below 4×10^{-12}A during an initial heating time of ten days under the same operating condition as the real accelerator. This dark current was smaller by three orders of magnitude than that of the existing electron gun.

INTRODUCTION

The SPring-8 linear accelerator injected electrons into the SPring-8 electron storage ring via a booster synchrotron. Electrons were emitted from a gridded thermionic electron gun of the linear accelerator. Although bias voltage for the cathode with respect to the grid electrode was large enough to suppress the cathode emission current, dark current was emitted and injected to the downstream electron storage ring. This dark current caused satellite bunches unignorable for precise experiments in the downstream electron storage ring.

To remove this dark current on beam transport, RF kickers and a deflector were installed in the booster synchrotron and in the linear accelerator, respectively. For higher reliability to suppress this dark current, dark current from the electron gun was reduced. Emitting sources of dark current from the electron gun were investigated using our offline electron-gun test equipment applying DC acceleration voltage to the electron gun. Based on results of this investigation, the electron gun of the test equipment was improved.

ELECTRON-GUN TEST EQUIPMENT

The offline electron-gun test equipment was the ultra-high-vacuum chamber with an electron gun and a faraday cup. The electron gun was the same as that of the real accelerator using a cathode assembly (CPI, Y-845) except for the anode electrode. Although acceleration voltage was pulsed (180kV in pulse height, 1ns in pulse width (HMFW)) in the real accelerator, acceleration voltage was DC 85kV in the test equipment. The anode electrode of the test equipment, therefore, was different in shape from that of the real accelerator in order to apply the same electric field on the cathode surface as that in the real accelerator.

The faraday cup was installed on the beam axis at 2.27 cm downstream to the ejection port of the electron gun. An opening of the faraday cup was 4 cm in diameter. This installation position and the opening diameter was designed to capture all of the diverging electrons emitted from the cathode surface even at an emission current of 20A. The faraday cup was 6 cm in depth. The faraday cup was made from fine carbon. The depth and the material of the faraday cup was determined to reduce electron loss from the faraday cup due to electron back scattering lower than one percent. The faraday cup had a suppressor electrode in shape of a ring around the opening of the faraday cup to prevent secondary electrons to escape from the faraday cup. The potential of the faraday cup body and of the suppressor electrode was set to be 0V and -700V, respectively.

Current flowing into the suppressor electrode and the faraday cup body were measured with two ultra-high resistance meters (ADC, 5450), respectively. A bias voltage of -700V was applied to the suppressor electrode with the resistance meter. Measured current values by the resistance meters were stored in a personal computer every three seconds.

The test equipment operated at an acceleration voltage of 85kV, at a cathode heater voltage of 6.0V, at a bias voltage for the cathode of 61.0V, and under pressures lower than 1×10^{-6}Pa, made it possible to measure dark current (expressed in magnitude) as faraday cup current under the same operating condition as the real accelerator.

EMITTING SOURCES OF DARK CURRENT

Wehnelt Electrode

Faraday cup current and suppressor electrode current from the existing electron gun using a new Y-845 cathode assembly was measured to be -4.3×10^{-9}A and -2.5×10^{-10}A, respectively under the same operating condition as the real accelerator. Since the faraday cup was designed to capture all of the electrons emitted from the cathode, this suppressor electrode current was presumed to result from flow of electrons generated at the wehnelt.

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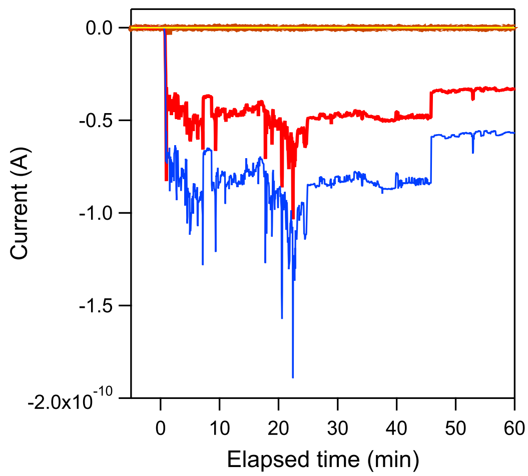

Figure 1: Faraday cup current and suppressor electrode current as a function of elapsed time about the existing electron gun. Blue curve and thick red curve represent faraday cup current and suppressor electrode current with the existing anode and wehnelt electrodes, respectively. Yellow curve and thick brown curve represent faraday cup current and suppressor electrode current with the new electro-polished anode and wehnelt . An accelerator voltage of 85kV was applied at an elapsed time of zero min. Cathode heater voltage was 6.00V. Bias voltage for the cathode was 61V.

It is possible that electrons emitted from the wehnelt flew into the faraday cup as dark current. In order to make this flow clear, faraday cup current and suppressor electrode current was measured under the same operating condition using a 'dummy cathode assembly' with the existing anode and wehnelt and with the new electro-polished ones. The dummy cathode assembly was an electro-polished lump of stainless steel in the same shape as the existing cathode assembly. Figure 1 shows the measured current as a function of elapsed time. Using the new electro-polished anode and wehnelt, faraday cup current and suppressor electrode currents decreased down to 2×10^{-15}A and 2×10^{-13}A, respectively.

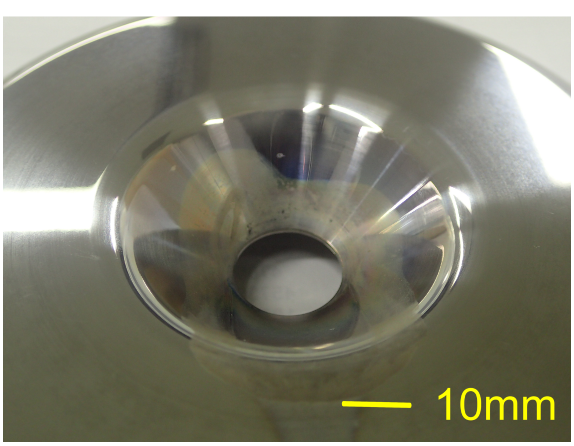

Figure 2: The photograph of the existing wehnelt electrode.

Figure 2 shows the photograph of the existing wehnelt electrode. The cathode assembly showed its grid electrode and cathode surface through the center hole found in the photograph of the wehnelt electrode. Deposit was found on the corn surface around the center hole. Barium was detected as principal elementary component of the deposit in elementary analysis. Rhenium was main component only in the black elliptic spot of the deposit. This barium came from impregnant of the cathode. This rhenium is assumed to evaporate from cathode retainer ring of rhenium-molybdenum alloy. It is supposed that the deposit was rough enough to emit electrons due to the acceleration voltage.

Grid Electrode and Cathode Surface

Figure 3 shows dark current as a function of elapsed time at various bias voltages for the cathode with the new electro-polished anode and wehnelt electrodes. Cathode heater voltage was 6.0V. Acceleration voltage was 85kV. As bias voltage for the cathode increased up to 160V, dark current decreased asymptotically by 87 percent. This indicates that dark current was composed of emission current passing through the grid electrode and current emitted from the grid electrode.

Over 170V of bias voltages for the cathode, dark current was unstable and increased. The grid electrode probably deformed toward the cathode surface due to the high bias voltages for the cathode. This deformation caused discharge between the grid electrode and the cathode surface. And this deformation allowed the acceleration field to penetrate on to the cathode surface so as to make more emission current pass though the grid electrode.

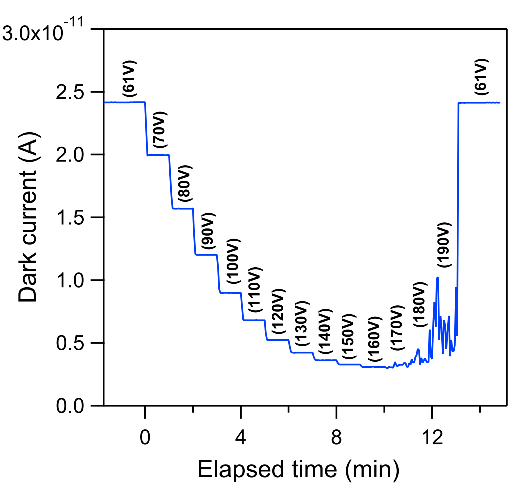

Figure 3: Dark current as a function of elapsed time at various bias voltages for the cathode with the new electro-polished anode and wehnelt electrodes. Elapsed time was set to be zero min when bias voltage of the cathode started to increase from 61V. Cathode heater voltage was 6.00V. Bias voltages for the cathode were expressed in parentheses.

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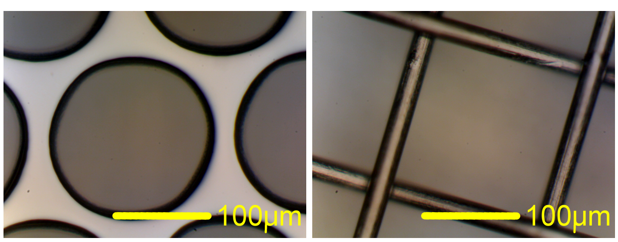
IMPROVEMENT OF ELECTRON GUN

Based on the identification of the emitting sources of dark current, the electron gun of the test equipment was improved. The existing anode and wehnelt electrodes were replaced with new electro-polished ones. And the existing Y-845 cathode assembly was replaced with a newly-developed cathode assembly with an improved grid electrode. The newly-developed cathode assembly had the same structure as the existing Y-845 cathode assembly except for the improved grid electrode. The improved grid electrode was a perforated plate made from molybdenum. The grid electrode was smoothed by electro-polishing enough to eliminate processing traces on surface of the grid electrode. And the grid electrode was located more apart from the cathode surface than that of the existing Y-845 cathode assembly. This position caused less acceleration field to penetrate onto the cathode surface even at the same bias voltage for the cathode.

Optical microscope images of the grid electrodes of the newly-developed and the existing Y-845 cathode assemblies were shown in Fig.4. And specifications for the grid electrodes of the newly-developed and the existing Y-845 cathode assembly were shown in Table 1.



(a) (b)

Figure 4: Optical microscope images of the grid electrodes of (a) the newly-developed and (b) the existing Y-845 cathode assemblies.

Table 1: Specifications for the grid electrodes of the newly-developed and the existing Y-845 cathode assemblies

	Newly-developed	Existing (Y-845)
Material	Molybdenum	Tungsten
Form	Perforated plate	Wire mesh
Surface treatment	Electro-polished	Titanium-coated
Wire diameter	-	20μm
Plate thickness	48μm	-
Pitch	200μm	180μm
Hole diameter	170μm	-
Grid-cathode distance	168μm	120μm

Figure 5 shows heating time dependence of dark current from the improved electron gun and from the improved electron gun using the existing Y-845 cathode assembly under the same operating condition as the real machine. Dark current from the improved electron gun increased up to 4×10^{-12}A during an initial heating time of ten days. This measurement result indicates that the newly-developed cathode assembly decreased dark current by one order of magnitude compared with the existing Y-845 cathode assembly. And this measurement result also indicates that the improved electron gun suppressed dark current by three orders of magnitude compared with the existing electron gun.

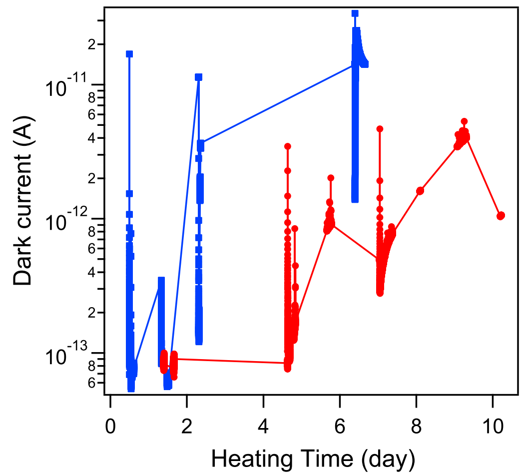


Figure 5: Heating time dependence of dark current from the improved electron gun and from the improved electron gun using the existing Y-845 cathode assembly under the same operating condition as the real accelerator. Red lines with circle makers and blue lines with rectangle markers represent dark current from the improved electron gun and the improved electron gun using the existing Y-845 cathode assembly, respectively.

CONCLUSION

Dark current from the electron gun of the SPring-8 linear accelerator was found to be emitted from the wehnelt electrode, the grid electrode, and the cathode surface using our offline electron-gun test equipment. Based on this identification of these emitting sources, the electron gun of the test equipment was improved to suppress the dark current. The anode and wehnelt electrodes were replaced with new electro-polished ones. The cathode assembly was replaced with a newly-developed cathode assembly with an electro-polished grid electrode. The improved electron gun of the test equipment emitted dark current up to 4$\times 10^{-12}$A during an initial heating time of ten days at the same operating condition as the real accelerator. This dark current was smaller by three orders of magnitude than that of the existing electron gun.

It is necessary to measure dark current from the improved electron gun during a few months or more in the near future.

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