SPECTROSCOPIC MEASUREMENT OF HIGH CURRENT VACUUM ARC PLASMA IN TRIGGERED VACUUM SWITCH

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Abstract

The purpose of this experiment is to improve understanding of the high current vacuum arc phenomena in a triggered vacuum switch (TVS). The TVS used in the experiment has a rod array electrode. The cross section of each rod has trapezoidal shape. A spectroscopic measurement was performed up to 150 kA peak current at the center of electrodes. The tested electrode material was Fe. Measured Fe spectrum range was from 200 nm to 900 nm. Measurement result showed that over 90 percent of the charge states were Fe II, and the others were Fe I and FeIII. By assuming a local thermal equilibrium (LTE), electron temperatures of the TVS arc were determined from the relative line intensity ratio of Fe II. The electron temperatures at the center of electrodes were measured as 1.5 eV and 2.5 eV with 26 kA and 64 kA peak currents, respectively. The electron temperature increased with its peak current.

I. INTRODUCTION

Switching devices are one of the most important part in pulsed power technology. The switching device has to transfer high energy as well as to withstand high voltage. Recently a triggered vacuum switch (TVS) has been developed and widely used as a high coulomb transfer switch [1, 2]. However, its physical characteristics are rarely studied. Especially, spectral characteristics of the TVS arc plasma are seldom studied. To further improve its characteristic, understanding of the high current vacuum arc phenomena in the TVS is important. In this experiment, the fundamental properties of vacuum arc discharge were observed by optical diagnostic method.

II. EXPERIMENTS

The structure of rod array electrodes of TVS is shown in Fig. 1. Each electrode has three trapezoidal rods. Each rod has a diameter of 74mm and a height of 71mm. The electrode material shown in Fig. 1 is oxygen free high conductivity copper (OFHC). For the experiment, Fe electrodes were also used. A trigger electrode made out of Fe was inserted in the middle of the cathode, and a ceramic tube was used to insulate between the cathode and the trigger pin.

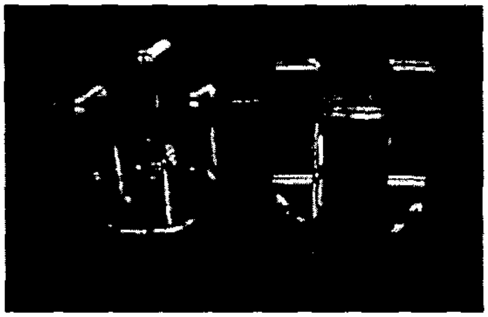

Figure 1. Structure of main electrodes.
Left: Cathode with a trigger pin hole, Right: Anode

Fig. 2 shows the schematic arrangement of experimental apparatus for the electrical and spectroscopic measurement. Before operating the TVS, the pressure in the chamber was held lower 10^{-6} Torr by a turbo-molecular pump. Arc current was generated by discharging capacitor bank of 16.22 μF. Gap between the electrodes was 8mm. As shown in Fig. 2, the TVS was installed in a stainless steel vacuum chamber that had two viewing ports. In front of a viewing port, an optical lens

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with a focal length of 50mm and an optical fiber that was connected to a spectrometer were installed to measure the TVS arc discharge spectrum. An image of the arc discharge was focused on the entrance surface of optical fiber by the lens. Then, the optical image of the arc discharge was guided to the slit of spectrometer. Model of the spectrometer was Yobin Yvon HR460. It has a holographic grating of 1,200 grooves/mm, and its spectral resolution is 0.04nm at 500nm. The spectrometer allows for investigation of the spectral lines in the region from 190nm to 900nm. As shown in Fig. 2, multiple spectra from the TVS arc were simultaneously measured with a two-dimensional array charge coupled device detector (CCD3000), which was installed at the outlet of the spectrometer. The taken spectra were sent via a interface-unit to a personal computer. During operation of the TVS, the arc current and voltage were also measured by a current transformer and a high voltage probe, respectively. Both signals were recorded with a digital signal analyzer (Tektronix DSA 602A).

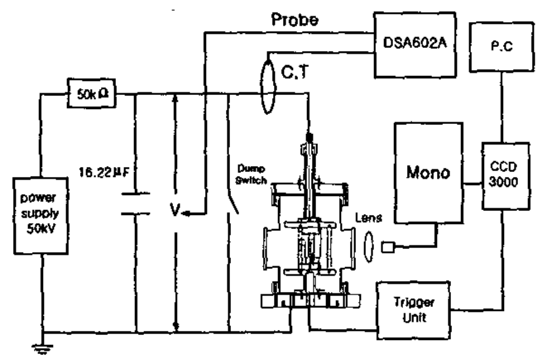

Figure 2. Schematic diagram of the experimental setup

III. RESULTS

A. Current and Voltage Measurement

The tested electrode materials were OFHC and Fe. A typical arc current waveform of the TVS with Fe electrode is shown in Fig. 3. The charging voltage was 15 kV. The peak current in Fig. 3 is 150 kA. The current shows an exponentially decaying sinusoidal waveform with a 7.6 μs period. With the charging voltage of 5kV, 10kV, and 15kV, peaks of the arc current were measured as 50kA, 100kA, and 150kA, respectively. With OFHC electrodes, current and voltage were also measured, and the results were very similar to those with Fe electrodes.

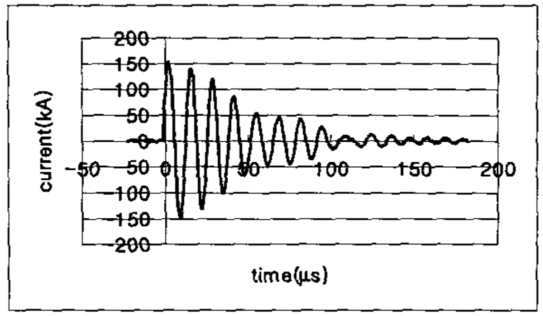

Figure 3. A typical current waveform of the Fe electrode TVS. (150 kA peak with 15 kV charging voltage)

B. Measurement of Charge State Distribution

The emission spectra from the vacuum arc plasma of the Fe electrode TVS were recorded for various peak currents ranging from 20 kA to 64 kA. A center between anode and cathode electrodes was the position of the emission spectrum measurement. The gap between two electrodes was 8 mm. Scanned spectral region was from 200 nm to 900 nm. Slit width of the spectrometer was adjusted to 100 μm. The grating in the spectrometer was adjusted with a step of 20 nm at a time to get the emission spectra. Whenever the grating increased by one step of 20 nm in the scanning region, the spectrometer was again calibrated with reference emission lines that emitted from standard lamps by Oriel. Six standard lamps (Mercury, Argon, Helium, Krypton, Neon, Xenon, lamps) were used for different spectral regions of calibration.

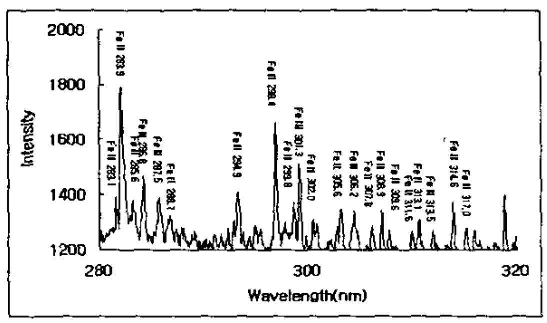

Figure 4. Typical emission spectra of vacuum arc plasma in the Fe electrode TVS in the 280 nm – 320 nm range. The peak current was 64 kA.

Fig. 4 shows typical emission spectra measured in the region of 280 nm to 320 nm. The data in Fig. 4 were measured with 64 kA peak current. In Fig. 4, the spectral lines are labeled in which wavelength and the degree of ionization for each line are listed [3]. Measurement result showed that more than 90 percent of the charge states were Fe II (singly ionized) and other 10% were Fe I (neutral) and Fe III (doubly ionized).

C. *Electron Temperature Measurement*

The electron temperature was calculated from the measured spectral lines. The calculation was done only for the Fe electrode TVS at two different arc currents of 26 kA and 64 kA peaks. In the case of OFHC electrodes, the electron temperature could not be determined from relative intensities of two lines of the same element because of inadequate reference data. As mentioned, the distribution of Fe II state with the Fe electrode TVS was more than 90 percent. Therefore, the collision probability for singly ionized ion with electron is thought to be higher than that of neutral and other charge state atoms. By assuming that the collision process is dominant in the vacuum arc plasma, we could safely approximate that singly ionized iron ions (Fe II) and electrons play the dominant role in approaching the thermodynamic kinetic equilibrium state of the vacuum arc plasma. From these assumptions, the local thermodynamic equilibrium (LTE) model is applied to calculate the electron temperature of the vacuum arc plasma in the TVS [4]. In the equilibrium state, the temperature distribution of Fe II ions and electrons are same. The electron temperature could be calculated from the relative intensities of two lines within the same stage of ionization by using the LTE model. The relation between two transitions of the same stage of ionization can be expressed as

$$\ln\left(\frac{I_1 g_2 A_2 v_2}{I_2 g_1 A_1 v_1}\right) = \frac{E_2 - E_1}{\kappa} T_e^{-1} \qquad (1)$$

where 1 and 2 denote two different transitions within the same species and stage of ionization. I, g, A, v, E and T_e are respectively line intensity, statistical weight, transition probability, line frequency, excitation energy, and electron temperature. Fig. 5 shows a spectral lines scanned from 400 nm to 440 nm of the Fe electrode TVS. The peak current was 64 kA. The two spectral lines (Fe II 402.4 and Fe II 429.6) appeared in Fig. 5 were selected to calculate the electron temperature. The two lines were selected because of three different reasons. Firstly, these two lines could be taken for one arc event during the experiment. Secondly, the two lines were not blended with other spectral lines as shown in Fig. 5. Finally, the two lines were separated more than 1 eV that was the minimum recommended energy gap between two spectral lines in the temperature measurement process [5]. Calculated electron temperatures were 1.5 eV and 2.5 eV at the peak arc current of 26 kA and 64 kA, respectively.

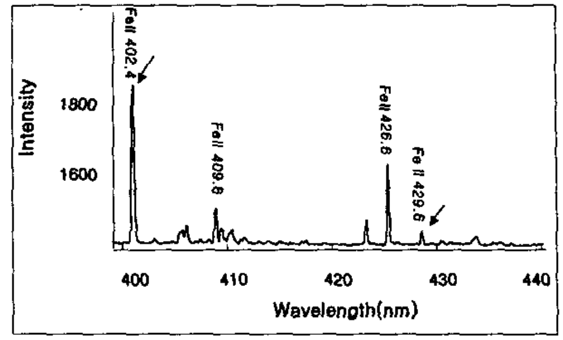

Figure 5. Typical emission spectra of vacuum arc plasma in the Fe electrode TVS in the 400 nm – 440 nm range. The peak current was 64 kA.

IV. CONCLUSION

A spectroscopic measurement was performed up to 150 kA peak current at the center of TVS electrodes. The TVS used in the experiment has a rod array electrode. The cross section of each rod has trapezoidal shape. Two different electrode materials were used for the experiment. Those were Fe and OFHC. Detailed analysis of the spectral data was performed only for Fe electrode since the OFHC line data were not adequate to analyze. Measurement result showed that more than 90 percent of the charge states were Fe II (singly ionized) and other 10% were Fe I (neutral) and By assuming a local thermal equilibrium (LTE), electron temperatures of the vacuum arc plasma in the TVS were determined from the relative line intensity ratio of Fe II. The electron temperatures at the center of electrodes were calculated as 1.5 eV and 2.5 eV with 26 kA and 64 kA peak currents, respectively. Further investigation is underway to gain more detailed vacuum arc plasma parameters, such as spatial and temporal behavior of electron temperature and density. Those parameters will provide more insight of the vacuum arc process and help to improve high coulomb transfer capability and controllability of the TVS.

V. REFERENCES

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