Analysis of Gliding Arc Discharge Plasma Using a High-speed Camera and Emission Spectroscopy Measurement

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Abstract: To study a basic process of a gliding arc discharge, high speed camera and optical emission spectroscopic measurements have been applied for the gliding arc discharge in the atmospheric pressure using several conditions. As the experimental results, it seems that two discharge domains exist in the upstream and downstream sides along with a gas flow. In the upstream discharge domain, emission spectra strongly depend on the gas, and emission peak intensities increased with increasing discharge power and gas flow rate. Although the spectra almost independent for the discharge power and gas flow rate, baseline of the spectra increases with increasing gas flow rate. On the other hand, emission spectra in the downstream discharge domain are different from that in the upstream. In the spectra, there are no emission peaks other than N₂ second positive band. The results suggest that a discharge kinetics of upstream discharge in a gliding arc discharge is different form that in the downstream.

Keywords: Gliding arc discharge, Optical emission spectroscopy, discharge in the atmospheric pressure

1. Introduction

Gliding arc (GA) discharge is one of the electric discharge plasma which can be generated to open air space[1-3]. The basic structure of GA and the operation are as follows. The high voltage is supplied to two-end spread electrodes arranged in a gas stream, arc discharge occurs between the shortest gaps. The arc discharge is passed by gas flow and glides to the downstream along with a spread electrode. The arc discharge disappear at arc maintenance voltage exceeds input voltage. This process of generating of an arc, movement (gliding), and disappearance is repeated continuously in the high voltage discharge [4-8]. Therefore, GA forms "plane plasma" in the two dimensional space between electrodes. GA generated using the direct current and the exchange power supply were applied to decomposition of the quality of an air pollutant [9-11]. Recently, the method which used the high frequency pulse power supply was also proposed, and they are applied to surface treatments, such as resin, glass and metal [9-14].

On gliding arc discharge, many studies had been accomplished, but, as for the most, there were many experiential elements about the constitution of the electric discharge part such as shape, geometry and materials of electrode, power supply system, plasma ignition and so on. In particular we thought that there was a big problem for management of an impedance of the power supply and a plasma ignition. Because there is a possibility that it is a current return path of a main power supply, the ignition system of high voltage is undesirable although it is used in many gliding arc experiment studies.

In this paper, two dimensional photographs of the gliding arc discharge were taken by high speed camera, and optical emission spectroscopic measurements were applied for the gliding arc discharge in the atmospheric pressure in the several discharge conditions, such as gas, gas flow rate, discharge power. As the results, a basic process of a gliding arc discharge was studied.

2. Experimental

A schematic for optical emission measurement is shown in Fig. 1. The electrodes of arc discharge were iron cylinder rods, and a 2mm in diameter, and 114 mm in length. The discharge part was covered
by the acrylics pipe of 100 mm in inside diameter in order to pass through the gases almost uniformly from the upstream side to the downstream side. The gases used for the experiment were argon, oxygen, and carbon dioxide. However, the atmosphere gases (nitrogen, oxygen, carbon dioxide etc.) were mixed these gases since the electric discharge domain is not sealed. Gas flow rate was controlled from 10 l/min to 50 l/min by the pressure regulator and the digital flow instrument. Discharge voltage was controlled by the voltage slide regulator (TAMABISHI: S-130-30), and increased by using the high voltage transformer (VIC international: 120:1), and then high voltage was applied to the electrodes. Therefore, the frequency of electric discharge is 60 Hz. Discharge voltage was measured using the high-voltage probe (IWATSU: HV-P60). Discharge current was measured using the clamp current probe (HIOKI: 9018-50). Two-dimensional photographs of the gliding arc discharge were taken by two type of high-speed camera (higher speed type: Photron, FASTCAM SA5, lower speed type: Casio, High speed exilim EX-F1). The flame rate speed was 1302000 and 1200 flame per second respectively. Optical emission spectra were measured by the USB small multichannel spectroscope (Fastvert S-2431: Soma optics). Wavelength resolution was 2 nm, the slit width of 50 micrometers and number of pixels 2048ch. In this measurement, exposure time was 20 msec and integration number was 30 times.

Fig 1. A schematic for optical emission measurement

3. Result and discussion

3.1 The structure of gliding arc discharge

The picture of gliding arc discharge for different discharge power at 50 l/min in Ar gas flow rate is shown in Fig. 2. As the result, it seems that two discharge domains exist in the upstream and downstream sides along with a gas flow. In the upstream side, emission intensity was strong and it increased with increasing discharge voltage. In addition, electric discharge area is small and it was increased with increasing the discharge voltage. On the other hand, emission intensity is weak and electric discharge area is large in the downstream side. Although emission intensity is almost constant independent for the discharge voltage, discharge area decreased with increasing discharge voltage in the downstream side as shown in Fig. 2.

Fig 2. The picture of gliding arc discharge for different discharge voltage at 50 l/min in Ar gas flow

Fig. 3 shows the photographs of gliding arc for different gas flow rate at 150 W discharge power.

Fig 3. The photographs of gliding arc for different gas flow rate at 60V discharge voltage

With increasing the gas flow rate, emission intensity increased in the upstream side. On the other hand, electric discharge area increased with increasing gas flow rate in the downstream side. These tendencies were observed in argon, oxygen, and carbon dioxide gas discharge. These results suggest that the an upstream area is a positive column of the main arc discharge which can be controlled by discharge power, and downstream
domain is a plasma jet plume which exists across between electrodes that depend on the gas flow.

Fig. 4 shows the photographs of gliding arc using high-speed camera. In this experiment, shutter speed was 1200 flame per second, ISO1600 in sensitivity, peak discharge power was 150W, and Ar gas flow was 50 l/min. As the results, arc discharge occurs between the shortest gaps and emission intensity is very high, like white-color emission. The arc discharge did not moved without gas flow, and it seems to one dimensional structure like needle to needle electrodes arc discharge as shown in Fig 4(a). The arc discharge glides from upstream to the downstream along with electrodes by Ar gas flow. The discharge spreads in two dimensions to the electrode and gas flow directions as shown in Figs. 2, 3 and 4(b)-4(d). There were a lot of discharge passes in the same flame of 0.83 ms gate time.

3.2 Optical emission spectroscopy

Optical emission spectra of upstream domains in the gliding arc using argon (Ar), oxygen (O₂), and carbon dioxide (CO₂) gas measured by the multichannel spectroscope were shown in Fig 5. The nitrogen molecular spectra (N₂ second positive band: C\(^{3}\)Π\(_{u}\) - B\(^{3}\)Π\(_{g}\)) were observed in all the spectra. This maybe due to the atmosphere gases (nitrogen, oxygen, carbon dioxide etc.) were mixed these gases since the electric discharge domain is not sealed. In the Ar gas discharge, many ArI emission peaks, such as 415 nm, 420 nm, 750 nm, 764 nm etc., can be observed without nitrogen molecular peaks. In addition baseline of the spectrum was higher than those spectrum in O₂ and CO₂ gas discharge. This may be due to increase gas temperature. In the O₂ gas discharge, several very strong O I emission peaks, such as 777 nm, 778 nm etc., can be observed in addition to the molecular spectrum of nitrogen. In the CO₂ gas discharge, CO molecular peaks (H band, 388nm) can be observed in addition to the molecular spectrum of nitrogen and oxygen discharge.

Dependence of optical emission spectra on discharge power at upstream area in the gliding arc using Ar gas were shown in Fig. 6. As the results, both of emission peak intensity and baseline of the spectra increased with increasing gas flow rate. These results agree well with the picture of gliding arc discharge as shown in Fig. 2. Dependence of optical emission spectra on gas flow rate at upstream area in the gliding arc using Ar gas was shown in Fig. 7. As the results, both of emission peak intensity and baseline of the spectra increased with increasing gas flow rate. These results agree well with the picture of gliding arc discharge as shown in Fig. 3. In our previous experiment, discharge current increased with increasing Ar gas flow rate. This may be due to promotion of Ar gas ionization by the gas flow rate increasing. In the gliding arc discharge, high electric power density was supplied to the 1 mm gaps electrode 2 mm in diameter. Therefore, ionization is promoted with the increase in a gas flow and electron density increased, and then discharge current may increases. Emission spectra at the downstream area and that at the upstream area in the same gliding discharge are shown in Fig. 8. In the upstream area N₂ molecular spectra (N₂ second positive band: C\(^{3}\)Π\(_{u}\) - B\(^{3}\)Π\(_{g}\)), CO emission and O I emission peaks can be observed. On the other hand, there is only N₂ second positive band in the spectrum and any other peaks are disappeared.

As the results, an upstream area is a positive column of the main arc discharge around the shortest gaps area. Almost all discharge power was consumed at the place and they can be controlled by discharge power. In the downstream domain, plasma behaves “plasma jet” or “plasma plume” which exists across between electrodes that depend on the gas flow.

3.3 Ultra high-speed measurement

The discharge was observed with the camera more than 1 million fps maximum frame speed type. The discharge parts were installed in a discharge tube by this measurement and did not have atmospheric mixture. Fig.9 shows a discharge path taken in
56000 fps on Ar flow rate of 50 l/min. The photos caught the moment when a current path was rebuilt by a consecutive phenomenon. The discharge did a kink from a simple shape rapidly at the same time to go up the upper part from the footing, and paths of discharge were changed with the segment which approached it and then reconnected. We still do not understand this reason well, but we considered that a large heat gradient is related because it did not happen if there was not a gas flow it requires cooling. As well as it, not only gas flow but also the shape of the current path strongly depended on the gaseous species.

Also a boggler that the reconfiguration of the current path happened was confirmed.

**References**


**Fig. 9** The photographs of gliding arc using ultra high-speed camera with 56000 fps and Ar flow rate of 50 l/min

**4. Conclusions**

Optical emission spectroscopic measurements for the gliding arc discharge in the atmospheric pressure suggests that two discharge domains exist in the upstream and downstream sides along with a gas flow. In the upstream discharge, emission spectra strongly depend on the gas, and emission peak intensities increased with increasing discharge power and gas flow rate. Although the spectra almost independent for the discharge power and gas flow rate, baseline of the spectra increases with increasing gas flow rate. On the other hand, emission spectra in the downstream discharge domain are different from that in the upstream. In the spectra, there are no emission peaks other than N₂ second positive band. As the results, an upstream area is a positive column of the main arc discharge around the shortest gaps area. Almost all discharge power was consumed at the place and they can be controlled by discharge power. In the downstream, plasma behave ”plasma jet” or ”plasma plume” which exists across between electrodes that depend on the gas flow.