Optical Emission Spectroscopy and Electrical Study of High Power Thermal Arc Plasma Switching Device

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In this work, an atmospheric thermal plasma arc generated from a laboratory scale high power arc switching device was investigated. In the presented study the typical voltage and current profiles from the arc switching device were measured by a high voltage probe and a Rogowski coil. It was shown that the volt-ampere characteristic of the arc plasma is directly related to the distance between electrodes. This switching device has a pulse width range of approximately 120 ns. Furthermore, the optical emission spectroscopy techniques were used to measurement of the arc temperature and to identify the plasma active species. The calculated arc temperature is about 14000 K.

Keywords: atmospheric thermal arc plasma, switching device, arc voltage, arc temperature

1 INTRODUCTION

Pulsed Power is the science of storing energy over a long period of time (usually seconds or minutes) and then discharging it as electrical energy over a much shorter period of time (usually microseconds or nanoseconds). Pulsed power has a wide range of applications such as materials processing, food processing, medicine and biology and they can also be used as power sources such as lasers, high power microwave devices, radar modulators, and accelerators for X-ray treatment devices [1]. Requirements for the pulse length, average and peak energies, and the repetition rate are highly application specific; however, compactness and portability are the common driving forces above these requirements for today's pulsed power systems [2].
The need for the compact pulsed power systems, for both military and civilian applications, has increased the researches on this field in recent years. The most important research subject for compact systems are dielectric media with better capacitive storage capabilities and high-power closing switches with less house-keeping requirements, and one of the best choices are plasma switch devices, most of the plasma switch devices like Spark Gap [3], Thyratron [4] and Pseudospark [5] work in the low pressure regime and they use glow discharge for working.
Arc discharges are intense, highly luminous, and high current density discharges. High current densities up to kilo amperes per square centimeter are easily achieved by arc discharges; however their concentrated nature causes a high erosion rates for the electrodes.
In this study, the laboratory scale high power pulse switching device with arc discharge in the atmospheric pressure was manufactured. Then, the effect of distance between electrodes on electrical pulse characteristics was investigated. The optical emission spectroscopy method was used to measurement of the arc temperature and to identify the active species in plasma.

2 EXPERIMENTAL

The apparatus used to study the thermal arc plasma characteristics comprised of two cylindrical tungsten electrodes, a high voltage ac power supply, a high current dc power supply and some diagnostic instruments.
The horizontal gap between electrodes is variable in the range of 2-8 mm. Each electrode has the same configuration with a cylindrical - shaped 7 mm in diameter. An AC high voltage power supply 30 kV and 30 MHz is used as a trigger to strike the arc be-tween electrodes. Furthermore, the dc electrical current was supplied from a high current dc power supply to electrodes. In this condition intensive thermal arc plasma is generated.
One of the most important electrical features of the plasma arc is its voltage-ampere characteristics, which depends on the electrodes configuration and some operational parameters of the plasma system. Time-resolved measurement of the arc voltage and arc current was measured using a high voltage probe and a

Rogowski coil, respectively. In order to calculate the plasma arc temperature and also to identify the reactive species, emission spectra of the arc jet in the range of 200-1100 nm were recorded by optical emission spectrometer (OES). The OES optical fiber was located at approximately 1 m distance from the electrodes gap.

Moreover, the picture of thermal arc plasma was taken with a digital polarized camera due to the intense light emitted from the plasma.

3 RESULTS AND DISCUSSIONS

In this study the line pair method was used as one of the most common spectroscopic techniques, to estimate the arc temperature in the high intensity region, which is considered to be in local thermal equilibrium (LTE). In this method, it is advised to choose two lines as close as possible in wavelength and as far apart as possible in excitation energy [6-7]. According to Fig. 1, two intensive spectrum lines of ionized nitrogen at the wavelengths of 383.42 nm and 395.84 nm emitted from the plasma arc was used and calculated via the following equation:

$$I/I' = (Ag\lambda')/(Ag'\lambda) * e([E - E']/KT) \qquad (1)$$

Where I refers to the line intensity, T is the arc temperature, g is the statistical weight factors, A is the transition probability, E is the energy of the excited state and k is the Boltzmann constant. Using this method, the calculated arc plasma temperature was about 14000 K at 6 mm gap distance.

Moreover, using the OES analysis, the excited species produced in arc plasma were studied. As can be seen in Fig. 1 the spectrum contains several transition lines corresponding to nitrogen atoms and ions 383.42, 395.84, 403.55, 485.66, 499.94, 517.51, 567.05, 744.2, 776.73, 821.15, 868.12 [nm], excited nitrogen molecules 265.57, 293.03, 358.88 [nm], excited nitrogen monoxide 226.47, 237.02 [nm], excited oxygen and ozone molecules 257.08, 308.36, 333.94 [nm], excited hydroxide 623.8 nm and excited tungsten atoms 655.18 nm.

Typical voltage and current profiles from the arc switching device are shown in Fig. 2.

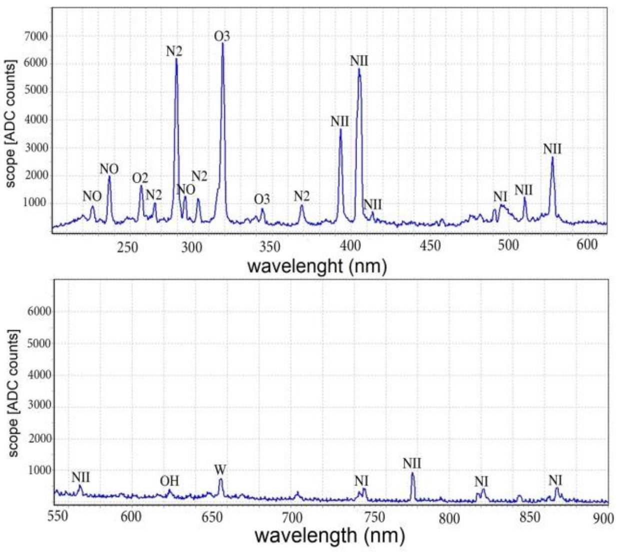

Fig. 1: 200-900 (nm) thermal arc plasma spectrum

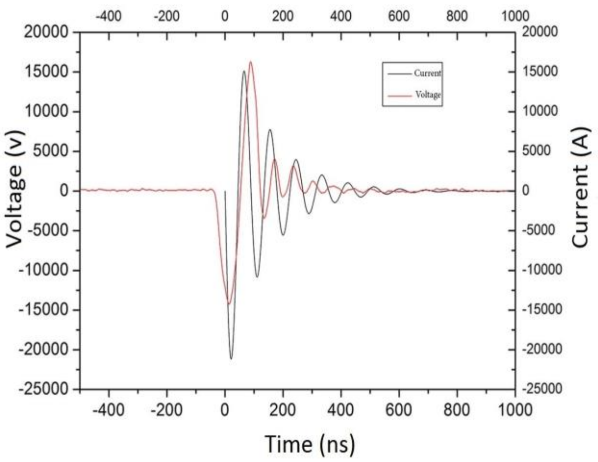

Fig. 2: Typical voltage and current profiles from arc plasma

As shown in this figure in 120 ns the main intensive pulse appeared and following that the arc voltage and the arc current damped rapidly. Distance between the electrodes was also an important parameter in arc discharges and also has an effect directly upon the arc voltage and the arc current. Therefore, if the distance between electrodes increases, consequently both the arc current and the arc voltage heighten. This behavior is shown in Fig. 3 and Fig.4.

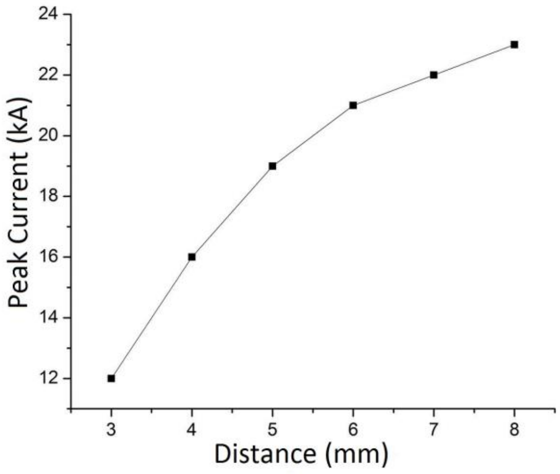

Fig. 3: Variation of the arc current with gap distance

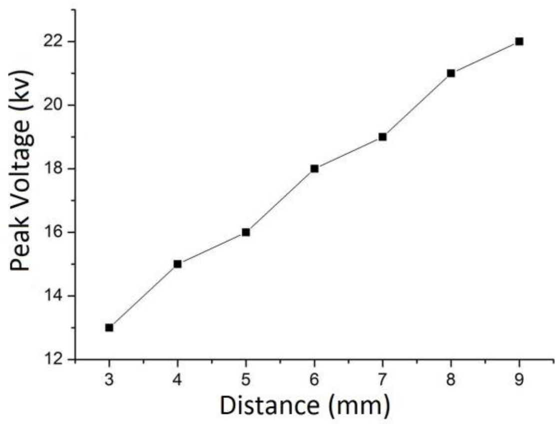

Fig. 4: Variation of the arc voltage with gap distance

Fig. 5: thermal arc plasma appearance

The photograph of Fig.5 is recorded using a high resolution digital camera. The picture of the arc configuration inside the electrodes gap was taken using a polarized lens. The appearance of an expended plasma cloud above the electrodes is probably due to Lorentz force exerted on charged particles of plasma.

4 CONCLUSION

Open air thermal arc plasma generated from a laboratory scale high power arc switching device with variable gap distance between two electrodes was investigated. The main arc plasma pulse length was about 120 ns which is appropriate in most high power switching device. Additionally, the arc voltage and the arc current increases with gap distance between electrodes. Therefore, with an increase in gap distance more electrical energy is consumed to sustain the arc plasma in high temperature regime.

On the other hand to prove that the arc plasma is in high temperature regime, the OES analyses were performed at a special experimental condition. The results of OES analyses showed that the arc temperature was about 14000 K. Moreover using the OES analysis it was obvious that there are various species in arc plasma such as nitrogen ion and atom, excited nitrogen, oxygen and ozone molecules and etc.

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