Time-resolved optical and spectroscopic study of the restrike mode in arc plasma torch

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Abstract: Simultaneous optical, spectroscopic and electrical measurements in the region of the arc anode attachment of the water-argon plasma torch are presented. A movement of the arc attachment along the anode surface together with its restrike mode is monitored. Temporal evolution of temperature during one cycle of the restrike mode is obtained. Resulting temperature profile shows importance of the position of the arc attachment on plasma properties.

Keywords: plasma torch, arc anode attachment, restrike, emission spectroscopy

1. Introduction

Measurement of plasma characteristics with high temporal and spatial resolution is of great importance in order to understand physics of the individual discharge as well as for various applications in plasma processing technologies. Time-resolved measurements are typical for discharges with well-defined time appearance, i.e. different types of AC and pulsed discharges. It is possible to find such cases also for arc discharges, which are of special interest in relation with present work [1 - 3]. As for DC discharges, measurements with high temporal resolution are more difficult because of technical properties of CCD chips. Moreover, it is often not expected any specific temporal behaviour of such discharges in relevant time scales. One of the special examples of time resolved pattern in DC discharge is so called restrike mode of the arc attachment (called also arc root) movement in plasma torches. In this work we present results of optical and spectroscopic measurement during one cycle of the restrike in the anode attachment of the water-argon plasma torch.

2. Experimental Setup

Schematic view of DC water-argon torch is shown in Fig.1. Details about this torch can be found also elsewhere [4]. The arc is stabilized by the argon in the cathode region and by the water vortex surrounding substantial part of the arc column. The arc current can be varied between 200 A and 600 A and the argon flow rate between 8 slm and 40 slm. Rate of water evaporation into the plasma is about 0.3 g/s. This work presents measurements for 400 A and 500 A and for 12 slm of argon.

Cathode, made of thoriated tungsten, is protected by the argon flow; therefore its erosion is negligible and its lifetime is long. On the other hand, anode is a copper disc with thickness 16 mm. It is rotating with the frequency 50 Hz in order to assure uniform erosion and is cooled by water. The anode is located outside of the torch body 2 mm from the exit nozzle in horizontal direction.

The gap of the nozzle connecting arc chamber with surrounding environment has diameter 6 mm. From this description and from Fig.1 it is evident that we are able to observe part of the arc between nozzle and anode, and also the arc root which is moving along the anode surface with the period in the order of tens of microseconds.

Measurement system consists of high speed camera Photron, voltage probe Rigol, PC oscilloscope (PicoScope) and spectrometer Jobin-Yvon Triax 552. Videos recorded by high-speed camera are synchronized with the cathode-anode voltage measurements and with spectroscopic measurements.

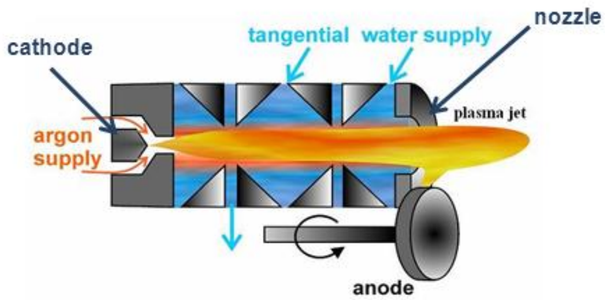

Fig. 1. Schematic view of water-argon plasma torch

3. Results

We present examples of measurement for two values of arc currents, 400 A and 500 A. In both cases argon flow rate was 12 slm. Fig. 2 shows saw-tooth pattern of cathode-anode voltage, which is typical for restrike mode of the arc root movement along the anode surface. Fig. 3 shows images of the plasma obtained by the high speed camera corresponding approximately to minimum (upper image) and maximum (lower image) cathode-anode voltage. The voltage monotonically increases from minimum to maximum as the arc attachment moves along the anode downstream the plasma flow. When the attachment reaches end of the anode, it disappears and new attachment is formed upstream. This event is accompanied by fast drop of the voltage. Thus new cycle of arc attachment movement begins and the process repeats.

Fig. 3 shows also positions in which we performed spectroscopic measurements; they are marked with the red rectangles and with numbers 1 and 2. In position 1 light is collected from the plasma above the central part of the anode, while in position 2 we measure region above the downstream edge of the anode surface. In all measurements the integration time of the spectra is 20 μs; as a typical period of the restrike is about 90 μs, we are able to monitor temporal behaviour during this period spectroscopically.

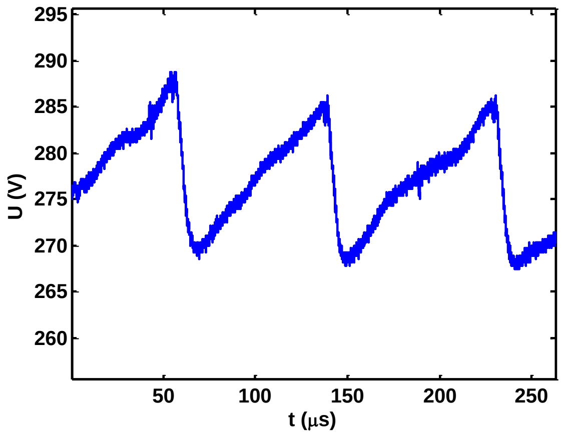

Fig. 2. Example of temporal evolution of the cathode-anode voltage

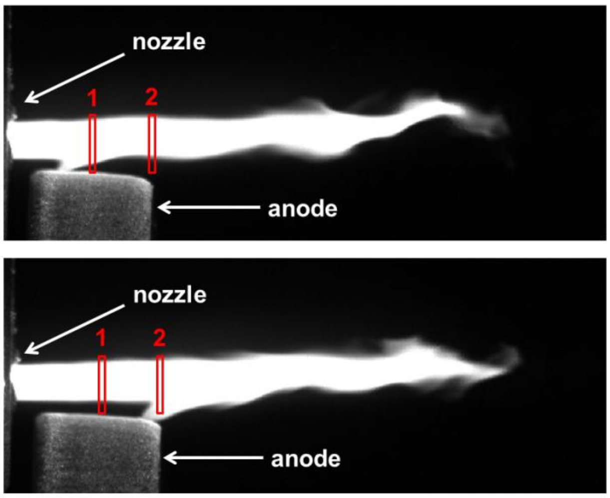

Fig. 3. High speed camera images of the plasma arc and jet for two cases: minimum voltage (upper) and maximum voltage (lower). Images come from a high speed movie with 20 000 fps and exposure time is 1 μs. Red rectangles show positions of the entrance slit for spectroscopic measurements

Fig. 4 shows typical measured emission spectrum in spectral window with the centre at Hβ line (486.1 nm). In spite of the fact that the spectrum is noisy, it is possible to see well-recognized Hβ, as well as two emission lines of singly ionized argon (476.5 and 480.6 nm). All these three lines were used for temperature determination. The method is based on the ratio of experimental and theoretical emission coefficients of Hβ and ArII lines; details about this method can be seen in [5].

Spectroscopic measurements were performed as follows: for given experimental conditions (arc current, argon flow rate and position of the measurement) we captured large number of spectra together with high speed camera images and voltage-time dependencies. From these data we chose only those, which did not include the restrike itself. Then we were able to specify in which moment during restrike period we measured spectrum. Moreover we excluded those data that were measured during periods, which were much longer or shorter than average one (90 μs). As a result we obtained temporal profile of temperature during the average restrike period.

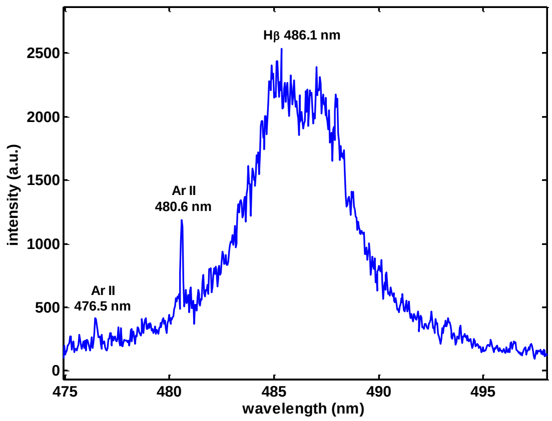

Fig. 4. A typical emission spectrum with the central wavelength at Hβ line

Results are shown in Figs. 5 and 6. Each point in these time profiles corresponds to the centre of the time interval during which spectra were acquired. It means, for instance, that point with time coordinate 40 μs was measured in the time interval from 30 μs to 50 μs. Time zero corresponds to the moment just after restrike process, i.e. it is the moment with minimum voltage when anode attachment is closest to the exit nozzle of the torch (Fig.3 upper image). Similarly, at the time 90 μs there is a maximum voltage (Fig. 3 lower image).

Fig. 5 presents measurement with the arc current 400 A and in the position 1 (above the centre of the anode). In this case the temperature reaches its maximum value in the middle of the time interval at about 40 μs. On the other hand, Fig. 6 shows the case with current 500 A and for position 2, where temperature monotonically increases up to the maximum value at the end of the interval. It seems that maximum value is connected with the presence of the arc attachment. As it moves along the centre of the anode surface, maximum temperature is measured.

Similarly the highest temperature at the edge of the anode is obtained in the moment when arc root gets there.

Interpretation of these results can be different. The region of anode attachment is characterized by interaction of plasma with the solid electrode. This phenomenon brings strong non-equilibrium effects into the thermal arc plasma behaviour. A drawback of these measurements is that we collect light from the whole plasma column. Better insight can be obtained if not only temporal but also spatial resolution will be high enough. Previously we have measured spectra with high spatial resolution but integrated in time scales of tens of milliseconds. In such a way we obtained local values of temperatures in different parts of the arc column, but we could not follow the arc root movement. Next step should be measurement with high temporal as well as spatial resolution at the same moment.

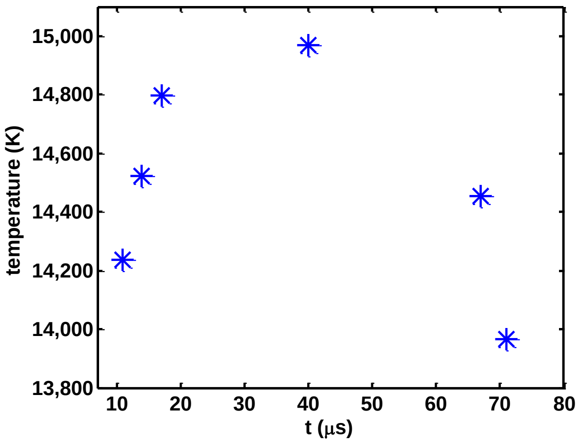

Fig. 5. Temporal evolution of temperature during one period of restrike mode (arc current 400 A, measured in position 1)

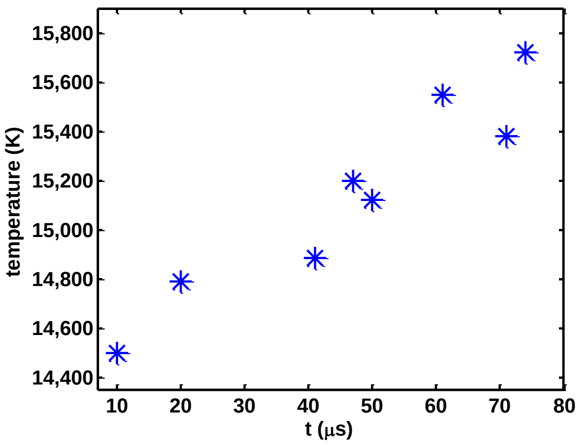

Fig. 6. Temporal evolution of temperature during one period of restrike mode (arc current 500 A, measured in position 2)

4. Conclusion

Time resolved measurements of arc discharge in the anode region are presented. We are able to follow movement of the arc anode attachment using high speed camera movies, arc voltage time evolution as well as by emission spectra. Results include temporal evolution of temperature during the restrike mode; it seems that temperature depends on the position of the arc root.

Acknowledgement

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