Electric probe diagnostics of low pressure dc arc steam-argon plasma jet

O. Hurba[1,2], M. Hrabovský[1] and J. Gregor[1]

[1] *Institute of Plasma Physics AS CR, v.v.i., Prague, Czech Republic*
[2] *Charles University in Prague Faculty of Mathematics and Physics*

Abstract: Thermal plasma jet under low pressure was investigated. Electric probes used as relatively simple and efficient tool for diagnostic of structure of flow field in thermal plasma jet. Were defined plasma potential and boundaries of the conducting region and their change with pressure change.

Keywords: thermal plasma, supersonic, plasma torch, arc plasma jet, electric probe

1.Introduction

Thermal plasma dc arc jets at low pressures have been studied intensively in recent years especially in relation with applications of jets in various plasma processing technologies such as plasma spraying, deposition of thin film or plasma synthesis. Effect of chamber pressure on a structure of a jet flow and deviation from local thermodynamic equilibrium in dc arc plasma jet was studied in [1] for pressure range of 6 to 39 kPa. Several studies of low pressure dc arc jets published recently [2-4] were related to the application of the jets to plasma spraying. Fast deposition of dense coatings with the reduction of possible oxidation is the main advantage of low pressure plasma spraying. The low pressure jet generated in a hybrid water-gas stabilized arc was studied in [5, 6]. When ambient pressure was lowered below several tens of kPa a transfer of flow regime was observed from the subsonic turbulent jet controlled dominantly by an entrainment of cold ambient gas to the supersonic expanding jet where plasma dynamic phenomena inside the jet are most important. Electric probe were used for diagnostics of low pressure jets in [7, 8]

In this paper we investigate, using moving electric probes, low-pressure expanding plasma jets generated in water/argon-stabilized arc [9]. The torches with this arc are used for plasma pyrolysis and gasification of materials as well as for plasma spraying. Potential of plasma in a free jet downstream of an arc anode was determined, which is given by a voltage drop on an anode attachment through which an arc current is conducted from a jet to an anode surface. The shape of an electrically conducting region of a jet was determined for various pressures for positions where materials are injected or substrates are positioned in plasma processing. Both these jet characteristics, plasma potential and an extent of conducting region, are important for performance characteristics in plasma processing applications.

2.Experimental system

The experiments were carried out with the hybrid plasma torch WSP®H 500 [9]. The cathode part of the torch is arranged similarly like in gas torches. Argon is supplied along the cathode; vortex component of the gas flow assures proper stabilization of arc in the cathode nozzle. Argon plasma flows through the nozzle into the second part of the torch where the arc column is stabilized by a water vortex. The vortex is formed in three cylindrical segments with a tangential water injection in the same way like in water-stabilized torches. The segments are separated by two exhaust gaps; water is exhausted out of the arc chamber. The interaction of an arc column with the water vortex causes evaporation from inner surface of the vortex. The steam is mixed with argon plasma flowing from the cathode section; the overpressure produced in the arc chamber accelerates the plasma through an exit torch nozzle. The anode of the torch is created by a rotating water cooled cooper disk that is located out of the arc chamber about 2 mm downstream of the exit nozzle. This type of cathode must be used to reduce strong erosion of the electrode in steam plasma. The scheme of the experimental arrangement is presented in Fig. 1. The torch was attached to the low pressure chamber, where pressure down to 1 kPa could be adjusted.

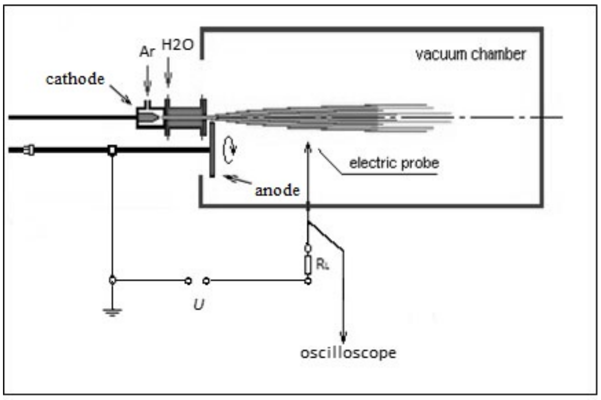

Fig. 1. Schematics of the experimental arrangement.

The electric probes made of tungsten Mo wire with 0.8 mm in diameter were moved across the jet in various distances from the torch nozzle exit. The length of the measuring probe tip was 3 mm. The spring system moved the probes through the plasma jet with a velocity 1.5 m/s. The probe movement was monitored by means of the angle position resistor sender and recorded together with the probe signal. The probes were connected to the earthed anode via resistor R_L, the probe potential was controlled by the voltage source U (Fig. 1). Due to the potential difference between an anode surface and plasma jet, given by a voltage drop on the anode attachment, plasma in free jet downstream of the attachment has negative potential against the anode (up to about 20 V depending on the jet conditions). The probe potential and current are determined by plasma potential, voltage U and resistance R_L. Thus, for voltage U = 0, electron currents flow to the probe. Measurements were performed for various values of the resistor R_L and the voltage U for several distances from plasma torch nozzle exit (30, 40, 60, 80 and 100 mm). The experimental arrangement is schematically shown in Fig. 1.

The measurements were performed for arc current 200 A, argon flow rate 12.5 slm, steam flow rate in plasma jet was determined by evaporation rate from stabilizing water vortex and was 0.2 g/s.

3.Experimental results

3.1.Plasma potential measurements

The plasma jet potential in a free jet, downstream of the anode, is determined by a voltage drop on an anode attachment region, which carries arc current from an arc jet to an anode surface through the gap between the jet and the anode. The non-zero plasma potential in positions of injection of materials or location of substrates can influence the processes decisive for results of plasma processing technologies. Thus knowledge of the plasma potential is crucial for exact description of physical conditions in arc jet applications.

In Fig. 2 the measured probe currents are shown in dependence on the probe position with respect to the torch nozzle axis (r = 0) for various values of the voltage U.

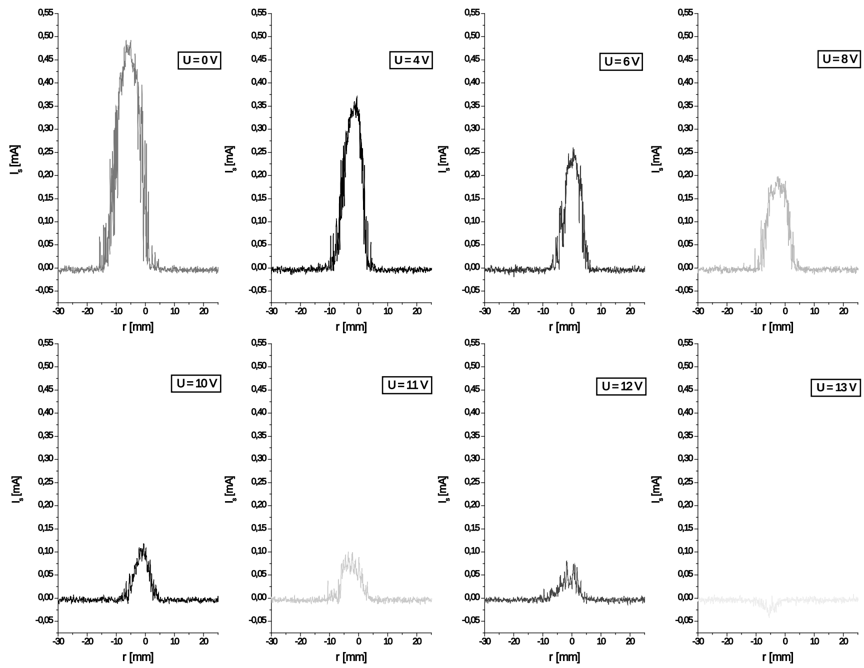

Fig. 2. Probe currents for various values of biasing voltage (I = 200 A, argon flow rate 12.5 slm, chamber pressure P = 30 kPa, axial distance from plasma torch 100 mm)

Positive values of the probe current correspond to electron currents flowing from plasma jet to the probe which is positive with respect to plasma due to connecting to the anode. The probe currents had maxima in the plasma jet centerline, which was slightly shifted from the nozzle axis due to the deflection of plasma jet in an anode region. As can be seen that increasing of voltage value U leads to the reduction of probe current. For certain value U the probe current is zero and thus the probe potential is equal to floating potential in plasma, which is equal to corresponding value U. Dependence of floating plasma potential on ambient pressure for several distances from the exit nozzle, determined from measurements of U corresponding to zero probe currents, is shown in Fig. 3.

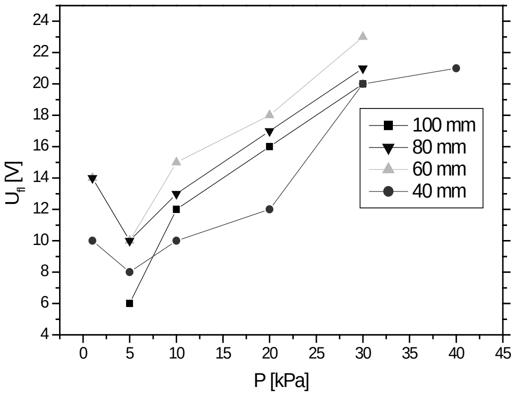

Fig. 3. Dependences of floating potential at jet centerline on pressure at several distances from the torch nozzle exit.

3.2.Measurements of diameter of plasma jet

It can be seen in Fig. 2 that that electric probe current falls to zero for some radial position independently on biasing voltage U. Thus the extent of electrically conducting region can be determined for various axial positions along the jet from the probe measurements. Fig. 4 presents probe currents for biasing voltage U = 0 V for various pressures, measured in axial position 100 mm from the torch nozzle exit.

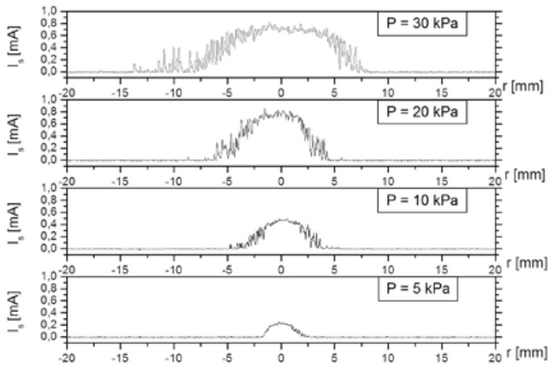

Fig. 4. Probe currents for biasing voltage U = 0 V for various ambient pressures. Axial position 100 mm.

Fig. 5 presents development of radial profiles of probe current along the jet for pressure 30 kPa.

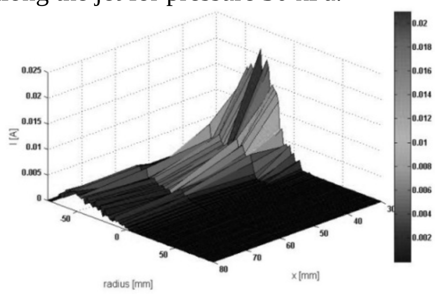

Fig. 5. Probe currents profiles for pressure P = 30 kPa and U = 0.

Similar measurements of probe currents were made for various axial positions and pressures. The diameters of conducting plasma zone were determined from these measurements. The dependence of diameter of conducting plasma zone on ambient pressure for several distances from the torch nozzle exit is shown in Fig. 6.

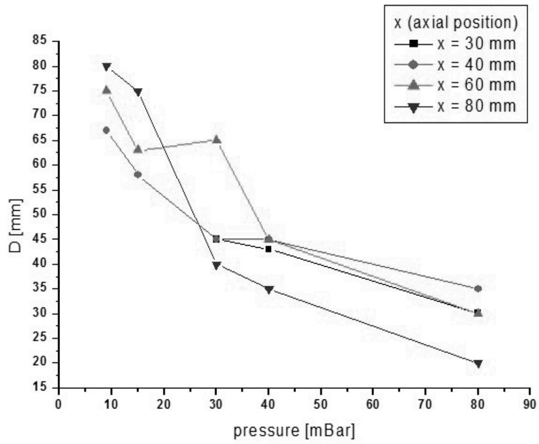

Fig. 6. The diameters of conduction area in dependence on pressure for several distances x from the torch nozzle exit.

4.Discussion and conclusions

Potential of plasma in a free jet downstream of the torch exit nozzle is negative with respect to the anode. As an anode is usually on the earth potential, an electron current can flow from plasma to an earthed substrate in plasma processing applications and it can influence processes on the substrate surface. Electron currents to a positively biased probe up to 5x10-4 A were measured which corresponds to the current density 7.5x10-6 A/m2. Plasma potential is determined by a voltage drop on an anode attachment which carries arc current from plasma jet to the electrode surface through the low conducting sheath between a jet and the electrode. Measured jet plasma potential was more than 20 V volts for pressure 30 kPa and decreased with reduction of ambient pressure (Fig. 3). The decrease of the plasma potential is caused by an expansion of plasma jet at lower pressures which leads to reduction of width of the sheath and shortening of an anode attachment [anode pressure].

The diameter of conducting plasma region in a free jet is strongly influenced by an ambient pressure (Fig. 6). Due to an expansion of the jet the conducting jet diameter increased almost four times when pressure was reduced from 80 kPa to 10 kPa. The shape of conducting area of plasma jet can be seen in Fig. 5.

4.References

[1] E. Selezneva, M. Rajabian, D. Gravelle, M.I. Boulos, Study of the structure and deviation from equilibrium in direct current supersonic plasma jets, *J. Phys. D: Appl. Phys.* 34 (2001) **2862-2874**.

[2] M. Gindrat, J.-L. Dorier, M. Loch, A. Refke, A. Salito, G. Barbezat, Effect of specific operating conditions on the properties of LPPS plasma jets expanding at low pressure, **Proc. of ITSC 2002**, Essen, Germany, **459-464**.

[3] J. Jodoin, M. Gindrat, J.-L. Dorier, Ch. Hollestein, M. Loch, G. Barbezat, Modeling and diagnostics of a supersonic DC plasma jet expanding at low pressure, *Proc. of ITSC 2002*, Essen, Germany, 2002.

[4] N. Singh, M. Razafinimanana, A. Gleizes, The effect of pressure on a plasma plume: temperature and electron density measurements, *J. Phys. D: Appl. Phys.* (1998).

[5] M. Hrabovsky, V. Kopecky, O. Chumak, T. Kavka, M. Konrad, Properties of plasma jet generated in hybrid gas/water torch under reduced pressures, *J. of High Temp. Mat. Process. 8* (2004), Issue 4, **575-584**.

[6] M. Hrabovsky, O. Chumak, V. Kopecky, M. Konrad And T. Kavka, Effect of pressure on behavior of anode attachment Of dc arc plasma torch, *J. of High Temp. Mat. Process. 9* (2005), Issue 3, pp **391-400**.

[7] M Hrabovsky, O Chumak, J Gregor and O Hurba, Electric Probe Diagnostics and Imaging of Expanding DC Arc Plasma Jet, *GD2006, Gas Discharges, Xi´an, China,* September 11-15, 2006, paper J28, **737-740**.

[8] M. Gindrat, J-L. Dorier, Ch. Hollenstein, A. Refke, G. Barbezat, Characterization of supersonic low pressure plasma jets with electrostatic probes, *Plasma Sources Sci. Technol. 13* (2004) **484–492**.

[9] M. Hrabovský, V. Kopecký, V. Sember, T. Kavka, O. Chumak, M. Konrád, Properties of Hybrid Water/Gas DC Arc Plasma Torch, *IEEE Trans. on Plasma Science 34* (2006), Issue 4, Part 3, **1566-1575**.

5.Acknowledgement

The authors gratefully acknowledge support of the Grant Agency of CR under the project number GA15-19444S.