Enthalpy Probe Diagnostics of Steam/Argon Plasma Jet

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DC plasma torch with argon/water stabilization features extreme properties of the exiting plasma jet. The plasma mass flow rate is very low while the temperature reaches very high values. Plasma properties were measured by enthalpy probe connected to a mass spectrometer. The measurements of enthalpy, temperature, density and dynamic pressure were carried out for three different arc currents and at atmospheric pressure. The dependences of plasma characteristics on arc current were shown.

Keywords: enthalpy probe, thermal plasma, plasma diagnostics

1 INTRODUCTION

Thermal plasmas at atmospheric pressure generated by electrical arc have been used in many areas such as spraying, welding, gasification etc. The advantage of the high enthalpy of plasma brings also the disadvantage in complicated plasma diagnostics. There are three common methods of thermal plasma diagnostics: optical emission spectroscopy, Langmuir probes and enthalpy probe measurements.

Enthalpy probe system

The technique of enthalpy probe measurement is known from early sixties [1] and is widely used in publications over past decades [2, 3 and 4]. An enthalpy probe consists of a water cooled stainless steel tube that is pointed to the flow of plasma. The measurement proceeds in two steps: 1) no plasma is sampled into the probe, only heat flux on the probe is calculated, 2) known flow rate of plasma is sampled (ideally at isokinetic conditions) and the sample is analyzed in mass spectrometer (sampling). The difference between the heat load on the probe cooling circuit in these two cases represents the energy associated with the extracted plasma sample. The specific enthalpy of the plasma at the sampling point can be calculated using the following equation [5]:

$$h = \frac{(\mathrm{Q_W \rho_W Cp_W \Delta T})_{\mathrm{sampling}} \pm (\mathrm{Q_W \rho_W Cp_W \Delta T})_{\mathrm{tare}}}{Q_{\mathrm{g}}\, \rho_{\mathrm{g}}} \quad (1)$$

where:

h: specific enthalpy of the sampled gas [kJ/kg]
Q_w: cooling water flow rate [m^3/s]
Cp_w: specific heat of water [4,18 kJ/kgC]
ΔT: temperature rise of cooling water [°C]
Q_g: sampling gas flow rate at SPT [m^3/s]
ρ_w: density of water [1000 kg/m^3 @ 20°C]
ρ_g: gas density at STP [kg/m^3]

STP = standard temperature and pressure (0°C and 101.3 kPa)

The analysis of the sampled gas and calorific measurement accordingly to equation 1 enable to calculate values of plasma enthalpy, temperature, density, dynamic pressure, velocity and heat fluxes.

The measurements were carried out by the enthalpy probe system ENP-04 produced by Tekna Plasma Systems Inc.

2 EXPERIMENTAL SETUP

A DC plasma torch WSPH (Water Stabilized Plasma Hybrid) with hybrid argon-water stabilization (Fig. 1) has been used as the source of plasma. The argon flow is supplied along the thorium-doped tungsten cathode tip and is injected tangentially assuring a proper stabilization of the arc in the cathode nozzle. From the cathode region the argon plasma flows to the water vortex stabilized part, where it passes through the water channel (Gerdien arc). The length of the argon stabilized arc column is about 6 mm (ArC), while the length of the arc column stabilized by water vortex is 50 mm (WC). Heated water together with some products of the dissociation and ionization of the argon and steam is exhausted at two positions along the arc chamber. The diameter of the cylindrical exit nozzle is 5.7 mm. The anode of the torch is represented by a rotating cooper disc located outside of the arc chamber downstream the exit nozzle. The torch, as is described and shown in Fig. 1, is connected to a water system, which maintains a water cooling and a circulation through both electrodes and the water stabilized torch part. The temperature and flow rate of the cooling water were measured together with the temperature and flow rate of the stabilizing water in the system.

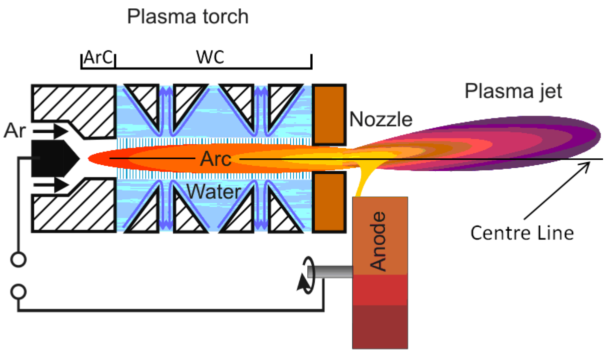

Fig.1: Schematic of the plasma torch

Produced plasma features extreme properties such as high enthalpy and temperature together with very low mass flow rate. These extreme properties and the possibility of the adjusting the plasma parameters within a wide range have led to the investigation of the WSPH torch and many papers about the torch have been published [6, 7].

The flow rate of argon was during measurement set up to 22 SLM (Standard Liter per Minute). The arc power can be controlled by the regulating of the arc current and it was set up to 300, 400 and 500 A and the axial distance of the probe (to the torch nozzle) was 200, 250 and 300 mm, respectively. The axial distance was the closest possible that was allowed due to the maximal heat flux to the probe that was stated as 1000 W. Every measurement for the particular condition had to be due to strong fluctuations carried out 5 times and mean value had to be calculated.

A DC power supply with a thyristor six pulse rectifier was used.

3 RESULTS AND DISCUSSION

Measured parameters were plasma enthalpy, temperature, velocity, density and dynamic pressure. Plots of these parameters for the current of 400 A (278 V) can be seen below:

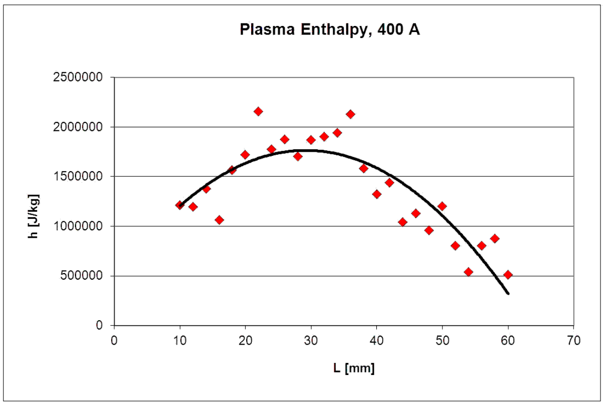

Fig. 2: Plasma enthalpy profile (current 400 A, axial distance 250 mm, centre line position 30 mm)

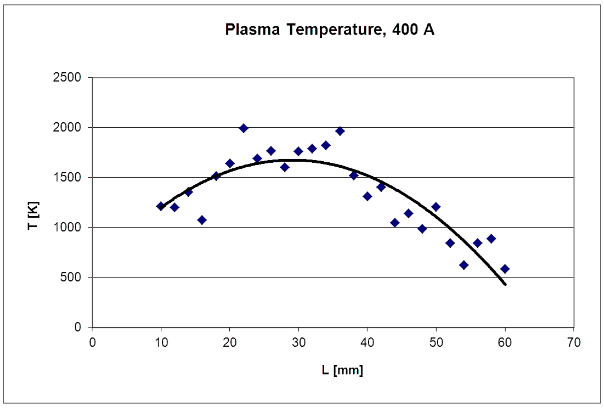

Fig. 3: Plasma temperature profile (current 400 A, axial distance 250 mm, centre line position 30 mm)

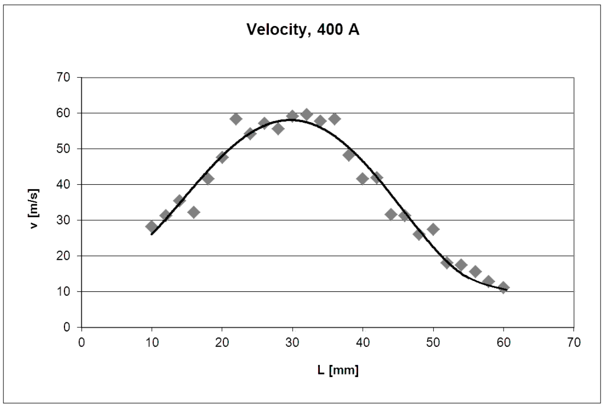

Fig. 4: Plasma velocity profile (current 400 A, axial distance 250 mm, centre line position 30 mm)

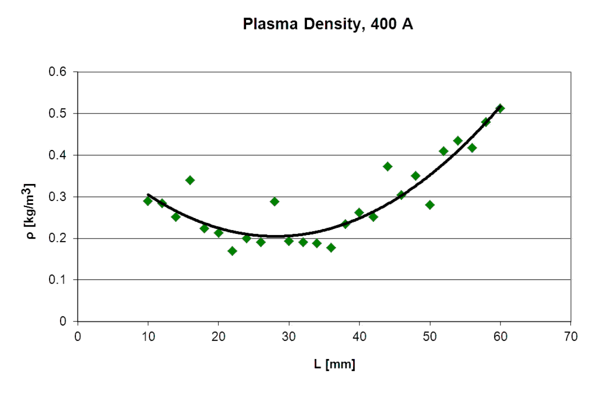

Fig. 5: Plasma density profile (current 400 A, axial distance 250 mm, centre line position 30 mm)

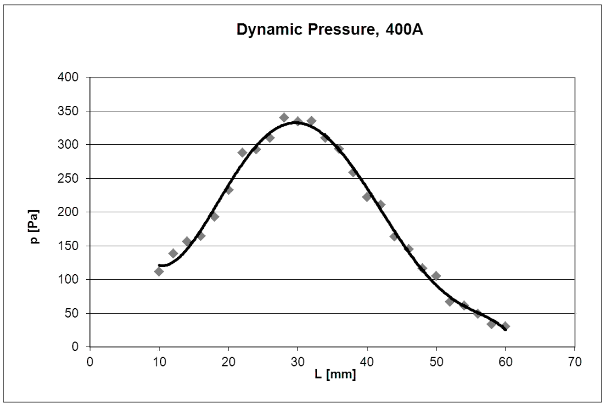

Fig. 6: Plasma dynamic pressure profile (current 400 A, axial distance 250 mm, centre line position 30 mm)

Plasma parameters were measured also for the currents of 300 and 500 A.

Previous experiment with torch using optical emission spectroscopy [8] revealed that the centre line temperature near the exit nozzle is roughly ten times higher than the temperatures measured using the enthalpy probe located further downstream the plasma flow. The decrease of temperature is caused by plasma-entrainment, the radiation of energy out of the plasma jet and jet expansion. Measured values of enthalpy and temperature are still comparable with nozzle conditions in conventional gas plasma torches at the order of magnitude.

The idea of the experiment was to carry out the measurements at the nearest possible distance to the torch nozzle that resulted in different axial distances between the torch nozzle and the probe tip for different currents. The comparison of some centerline values at different currents are summarized in Tab. 1.

Table 1. The comparison of some plasma parameters for different arc currents together with different axial distance between the probe tip and the torch nozzle, measured at a centreline position

Current	[A]	300	400	500
Voltage	[V]	243	278	306
Axial Distance	[mm]	200	250	300
Enthalpy	[MJ/kg]	12.5	17.8	19.8
Temperature	[K]	1290	1690	1780
Dynamic Pressure	[Pa]	220	335	325

It is obvious from presented results that enthalpy and temperature increase together with increasing arc power, even if the axial distance is getting larger. Dynamic pressure measurements have the smoothest course in the case of all set up currents which means the pressure is not influenced by the mixing of plasma and ambient air a lot. Pressure decreases fast within the axial distance.

4 CONCLUSIONS

The enthalpy probe measurement has proven to be a fast and simple way how to obtain interesting plasma parameters but it has also revealed some disadvantages – the maximum heat flux to the pro probe (in our case 1000 W), therefore it is impossible to get close to the plasma nozzle, at least in the case of the torch with Gerdien arc.

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