PLASMA JET VELOCITY MEASUREMENT OF A D.C. VORTEX PLASMA TORCH

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ABSTRACT:

The axial velocity of the plasma jet at the nozzle exit of a D.C. vortex plasma torch was deduced from the measurement of the time delay Δt between two power radiation signals recorded at a given distance d along the axis of the plasma jet. The used plasma torch was equipped either with a well or a button type cathode. The evolution of the jet maximum velocity was systematically studied versus the working parameters (arc current, gas flowrate and nature).

I.INTRODUCTION

In previous papers, it has been shown /1/, /2/, /3/ that the study of the static parameters (arc voltage U, arc current I, heat losses at the electrodes, gas nature and flowrate G) was not sufficient to characterize the behaviour of plasma torches. Running frames made with the help of a video camera with a high shutter speed /3/, shown up that the plasma jet at the nozzle exit which looked stable and axisymetric with the naked eyes was in fact continuously fluctuating in length and position. The investigation of the dynamic behaviour of the plasma torches is thus necessary for a better understanding of these fluctuations and their origins. For this an original method of diagnostic has been developed /3/. It allowed the measurement and the data processing of the fluctuations of arc voltage and current, light radiation and acoustic pressure. Based on the light fluctuations of the plasma jet at the nozzle exit, a measurement method of the axial velocity of the plasma jet has been developed in the laboratory /4/. The velocity v was calculated from the phase shift between two signals of power radiation recorded at two points separeted by a distance d. The delay between the two luminous waves was calculated by cross correlation between the two signals after adequate filtering, and the axial velocity was determined from the ratio between the distance d and this calculated delay.

The velocity measurements presented in this study were performed for D.C. plasma torches with a vortex injection of plasma gas. The tubular anode was coupled with two types of cathodes: a hot button type and a cold well type. The arc current ranged from 100 to 600 A, and three gases were used : air, nitrogen and argon (gas flow rates from 40 to 190 slm). For this range of parameters, the arc voltage varied between 30 V and 500 V.

II. DESIGNS OF THE TORCH.

The plasma torches used were already described in /5/ and the tubular anode used as nozzle (internal diameter (i.d.) of 7 mm) was coupled with two types of cathodes: a button type cathode (BTC) and a well type cathode (WTC). A vortex injection of plasma gas was made between the two electrodes. The hot BTC worked with argon and nitrogen as plasma gases, (gas flowrate G from 40 slm to 100 slm), the arc current I varied between 150 A and 600 A, and with such working conditions the arc voltage U ranged from 30 V to 100 V. The cold WTC worked with air (gas flowrate from 130 slm to 210 slm), for I ranging from 100 A to 200 A, and U varying from 300 V to 500 V.

III.SET UP AND DATA PROCESSING METHOD

This method already described in /4/, allowed the measurements of the delay between two light signals taken on the plasma jet axis. As the distance between the two points is known, the velocity of the plasma jet can be calculated. The optical bench used for the light measurement is composed of a lens, a prism, two optical fibers (i.d.=100µm) and two photomultipliers. An image of the plasma jet was focused by the lens on the tips of the two optical fibers after being separeted by the prism. The distance d between the two measurement points of luminous fluctuations was fixed by the relative position Δx between the two optical fibers, and by the magnification G of the optical system ($d = \Delta x / G$). The relative distance between the optical fibers was equal to 10 mm and the magnification G equal to 1.28. So the distance between the two measurement points along the plasma jet axis was equal to 7.8 mm. According to the size of the fibers and the magnification of the lens, the measurement volumes are about 78 µm in diameter and 78 µm in length. Thus a local measurement is performed (jet mean diameter 7 mm).

The delay (Δt) between the two signals was equal to the time lag between the origin and the time corresponding to the maximum of their cross correlation function (after adequate filtering) and $v = d / \Delta t$.

The luminous signals were detected by two photomultipliers and were recorded by a digitizing oscilloscope (LECROY 9314). Each signal was composed of 10000 running points. The sampling frequency used was 100000 samples/s, and the delay between two running points was 10 µs.

The delay Δt was calculated on sequences of 1024 points (windowing by a Hamming function), which were taken among the 10000 points recorded for the two synchronized signals. The 10000 points were broken up in about 140 sequences of 1024 points. So 140 velocities were calculated, and the variation of the velocity during the time of a record (10000 x 10µs=0.1s) was observed. A statistic study of the values of velocity was also made for each record, and both the mean value (vm) and standard deviation (dvm) were calculated.

IV.PLASMA JET VELOCITIES FOR A PLASMA TORCH WITH A HOT BUTTON TYPE CATHODE

IV.1. Argon as plasma gas.

In fig. 1, the statistical distribution for the 141 calculated velocity and the evolution with time (during the recording time of 0.1 s) of the plasma jet velocity are represented for I=282 A and G=80 slm, for which the corresponding arc voltage is equal to 35 V. A very slight scattering of the velocity around its mean value (vm=713 m/s) is observed, and the standard deviation is very low (dvm=35.4 m/s). The change of the mean velocity vm with working parameters was systematically studied (I varied between 150 and 600 A, G ranged from 71 to 100 slm). As shown in fig. 2, vm increases with the rise of I, and increases too with a rise of G.

IV.2. Nitrogen as plasma gas

With nitrogen as plasma gas for this BTC torch. The velocity scattering is larger than the one obtained previously with argon, fig.3 shows the same results as fig. 1 (for I=307 A, G=80 slm and U=117 V). The standard deviation (dvm=71.2 m/s) is greater compared to that calculated with argon. In a previous study /3/, it had been shown that the light fluctuations of the plasma jet were strongly linked to the undulations of the arc root and arc current. These electrical fluctuations (arc voltage and current) also recorded in this investigation, were greater with nitrogen than with argon. This is linked to the higher constriction of the arc in nitrogen (diatomic gas with a high dissociation energy at 7500 K at 1 atm). As the plasma jet fluctuations depend strongly on the arc root fluctuations and as the electrical diameter of the arc is smaller with nitrogen (inducing greater arc root fluctuations), it is not suprising to have more dispersed values for the velocity with nitrogen than with argon.

As observed with argon, the mean velocity increases when rising arc current and gas flowrate, but these variations are less steady (probably due to the greater fluctuations of the torch behaviour with nitrogen). The velocity change is depicted in fig. 4, and a slight increase of vm is observed for given I and G compared to the values obtained with argon. In fig.5, the evolution of vm versus G at given values of I (respectively 240, 300, 330 A) is shown, and is quite linear in the range of the nitrogen flowrates studied (40 to 100 slm). Successive measurements of jet velocity (with a time delay of a few minutes between each of them) at given I and G gave well reproducible results , and the variation of vm was less than the calculated standard deviation of each measurement.

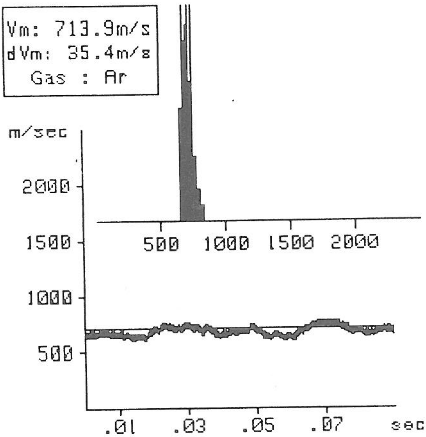

Fig.1: Statistical distribution and time evolution of v with Ar (I=282 A, G=80 slm, U=35 V)

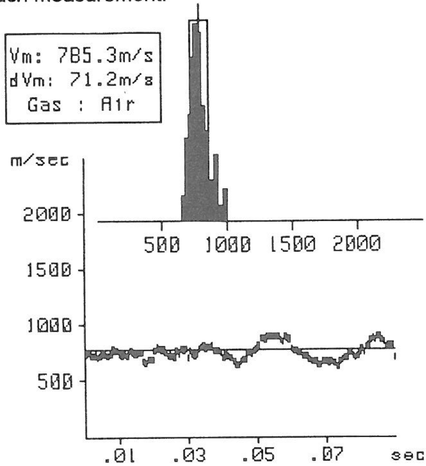

Fig.3: Statistical distribution and time evolution of v with N2 (I=307 A, G=80 slm, U=117 V)

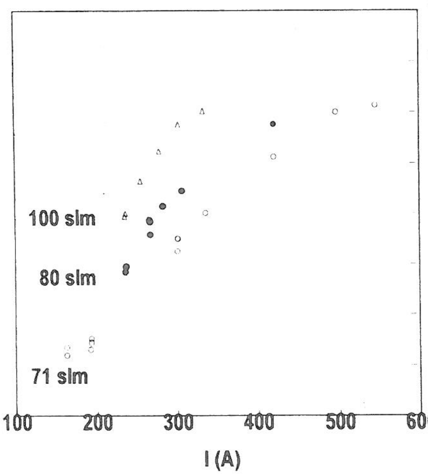

fig.3: Variation of vm with I and G with Ar as plasma gas (BTC)

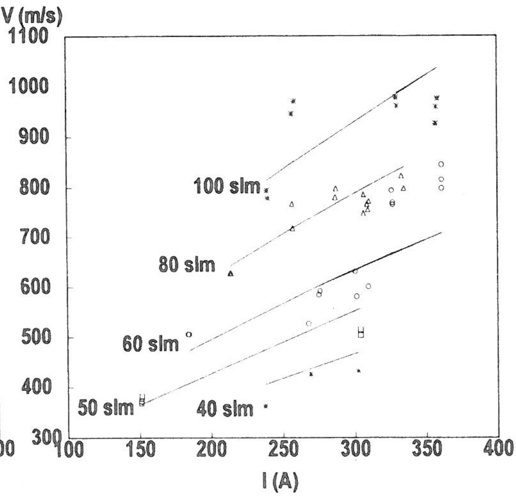

fig.4: Variation of vm with I and G with N2 as plasma gas (BTC)

V.MEASUREMENTS OF PLASMA JET VELOCITY FOR A TORCH WITH A WELL TYPE CATHODE

For this type of plasma torch with two electrodes made of OFHD copper, air was used as plasma gas (flowrate ranging from 130 slm to 190 slm). An example of velocity scattering is given in fig.6 for I=134 A and G=130 slm, and a rather sharp distribution of velocities (dvm=109 m/s) around their mean value (vm=1223 m/s) is observed even if it is larger than with Ar and N2. Compared to the BTC torch with nitrogen as plasma gas, the fluctuations of electric arc were stronger and acted upon plasma jet stability. Although the arc current range was lower compared to the BTC torch (100-200 A against 150-600 A), the mean velocities vm are greater with this WTC torch (from 1100 m/s to 1800 m/s against 400-900 m/s for the BTC torch) as it is shown in fig. 7. At the moment, no clear explanation was found for this phenomenon. The variations of vm with the working parameters already found for the BTC torch are also observed with this torch (rise of vm with an increase of I and G). The influence of G on vm seems to be the same, but the increase of vm with I is more important compared to the BTC torch.

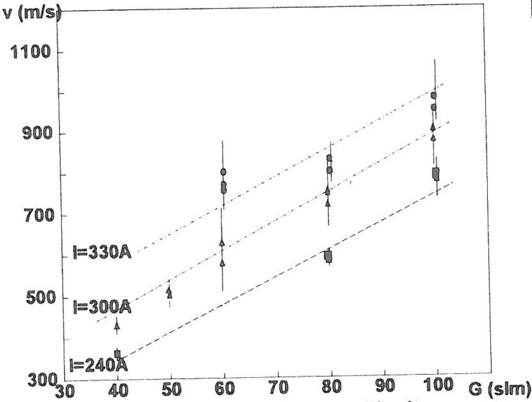

Fig. 5: Mean velocity change with nitrogen gas flowrate at given arc current (BTC)

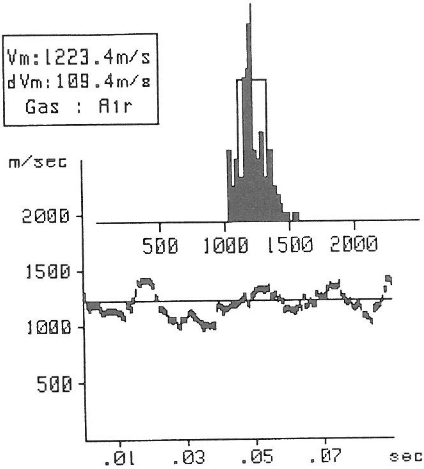

Fig. 6: Statistic distribution and time evolutialon of v with air (WTC) (I= 134 A, G=130 Slm, U=350 V)

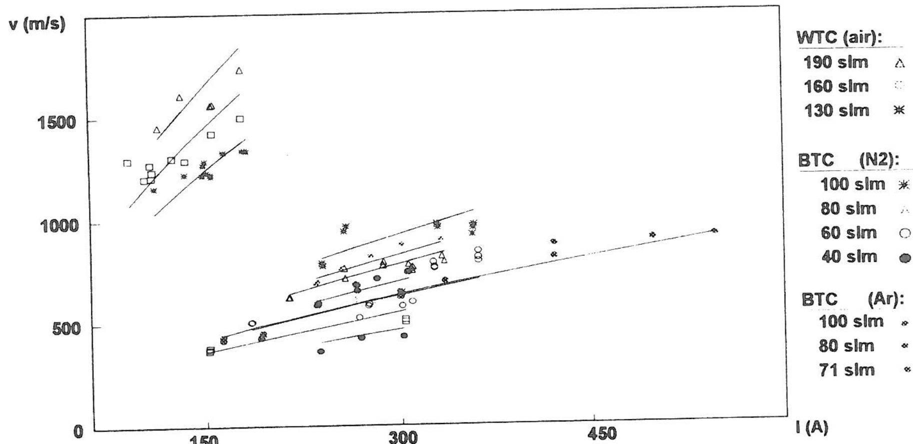

Fig. 7 : Mean velocities for the BTC and WTC torches

VI. SEMI EMPIRICAL RELATIONSHIP TO CHARACTERIZE THE CHANGE OF MEAN VELOCITY WITH WORKING PARAMETERS

In previous studies /6/, /7/, /8/, semi empirical relationships were calculated to characterize the variation of arc voltage U with the experimental parameters I, gas nature and G, and torch design. These relationships were calculated between dimensionless numbers /6/, which depended on the working parameters. The following numbers were used:

$$Su = \frac{Ud\sigma_0}{I}, \quad Si = \frac{I^2}{Gd\sigma_0 h_0}, \quad Re = \frac{G}{\mu_0 d}, \quad Pr = \frac{\mu_0 h_0}{\kappa_0 T_0}, \quad Sg = \frac{l_a d_c}{l_c d_a}$$

where $\sigma_0, \mu_0, h_0, \kappa_0$ were respectively the electrical conductivity, enthalpy, viscosity and thermal conductivity of the plasma gas at a mean temperature T_0 (reference temperature for which the electron concentration reach 1% in the plasma), and l_a, d_a, l_c, d_c were the anode length and i.d. and cathode length and i.d. For the torch with a BTC, the ratio l_c/d_c was taken equal to 1. A correlation /5/ calculated with these dimensionless numbers allowed to rebuilt the arc characteristics U-I of two torches very different in size and working conditions (WTC and BTC torches).
This method has been also used to characterize the frequency change of the arc root displacement inside the torch /5/, with I, G and torch design. For that a new relationship was calculated between Si, Re, Sg and a new dimensionless number Sf calculated by dimensionnal analysis to represent the frequency of the arc root fluctuations.

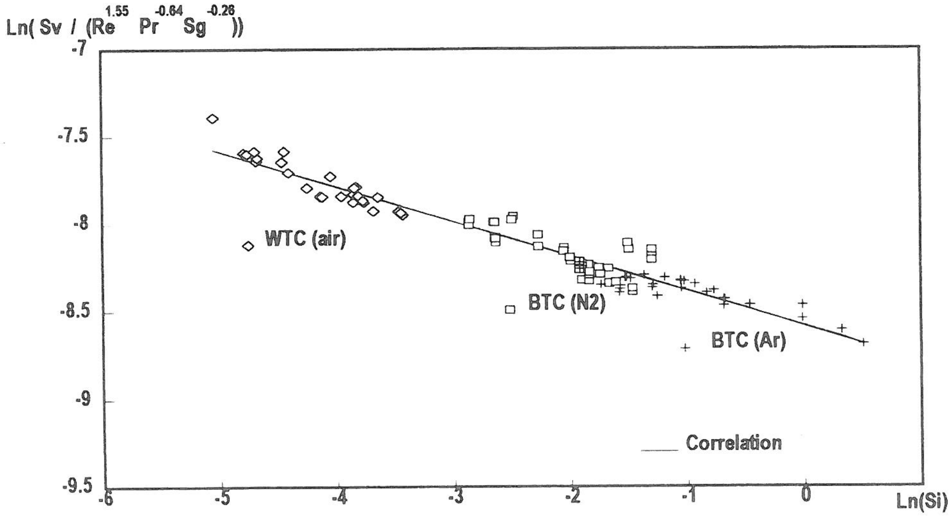

Fig. 8: Calculated correlation

This method was applied in this investigation in order to see, if the mean velocity change with working parameters could be characterized by a similar relationship. Another dimensionless number Sv was calculated by dimensional analysis:

$$Sv = \frac{vG\sqrt{\sigma_0 / \mu_0}}{I}$$

and was used with Si, Re, Pr and Sg, to calculate a semi empirical relationship with the experimental datas obtained with the BTC torch (with argon and nitrogen as plasma gases) and WTC torch working with air.

The following result was obtained:

$$Sv = 1.867.10^{-4} . Si^{-0.2} . Re^{1.55} . Pr^{-0.639} . Sg^{-0.257}$$

As it is shown in fig.8, there is a weak dispersion of the experimental points around the calculated correlation (standard deviation equal to 7%). Moreover, the correlation takes well into account the mean velocity change with I, gas nature and G, electrode designs as it is shown in fig.7, where experimental (represented by the different symbols) and calculated velocities (represented by the lines) are compared. So, the values of mean velocities can be predicted in a wide range of working parameters by using this relationship.

VII.CONCLUSION

The method of plasma jet velocity measurement previously described in /3/ and used to measure the velocities of the plasma jet at the outflow nozzle of a DC plasma torch with axial injection of plasma gas, was used in this investigation with two DC vortex plasma torches: one with a hot button type cathode (BTC) and another one with a cold well type cathode (WTC). The velocities obtained for the BTC torch with argon and nitrogen as plasma gases ranged between 400 and 1000 m/s, and this range was lower compared to the one observed for the WTC torch (1000 - 1800 m/s). Greater fluctuations of velocity around its mean value were observed for the BTC torch with nitrogen and for the WTC torch with air, compared to the BTC torch with argon for which the very stable behaviour of the torch led to very small fluctuations of velocity. For each torch, the mean velocity increased when rising arc current I and gas flowrate G. At given I and G, the mean velocity increased slightly when nitrogen was used as plasma gas instead of argon. All these variations were well represented by a semi empirical relationship calculated with dimensionless numbers previously used in other studies (Si, Re, Pr and Sg), and a new one Sv calculated with the help of dimensional analysis.

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