

# NUMERICAL SIMULATION OF THE POSITION AND ROTARY VELOCITY OF ARC SPOT IN A TUBULAR ARC PLASMA GENERATOR WITH DOUBLE STEPS

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## Abstract

A simplified axisymmetric turbulent arc model is used to simulate the position and rotary velocity of arc spot in rear electrode of a tubular arc generator with double steps. The regular patterns of arc spot position and rotary velocity changing with gas flux ratio of auxiliary and main gas ( $\bar{G} = G_1 / G_2$ ), the diameter ratio of inserted section and rear electrode ( $\bar{D} = d / D$ ), the nondimensional length ( $\bar{L} = L / D$ ) and arc current ( $I$ ) are discussed. The most optimum parameters are found. The results of calculation correspond to experimental results qualitatively.

## 1. Introduction

Tubular arc plasma generator has a great future for its advantages. The research of basic processes in tubular plasma generator with double steps is significant for designing the generator with high power, long life and high efficiency. Through numerical simulation and experimental studies, the regular pattern of the position ( $h$ ) and rotary velocity ( $w$ ) of arc root changing with  $\bar{G}, \bar{D}, \bar{L}$  and  $I$  has been discussed, and the most optimum parameters ( $\bar{G}, \bar{D}, \bar{L}$ ) are found. Under these parameters the rotary velocity of arc root has the highest value, and the resident time of arc root on the wall of rear electrode is less than 0.0001s. According to heat transfer calculation, when the resident time is no more than 0.0001s, the electrode will not be damaged, and the generator will be operated safely.

In this paper, the cold and heated flow fields in rear electrode are simulated numerically. In cold condition the position and rotary velocity of arc spot changing with  $\bar{G}, \bar{D}, \bar{L}$  are considered, and in heated condition  $h$  changing with  $I$  is also discussed. According to the results of numerical simulation, it exists

functional relationship between  $h$ ,  $w$  and  $\bar{G}, \bar{D}, \bar{L}, I$ . The most optimum parameters are found. Experiments show that calculation results are qualitatively reasonable.

## 2. Numerical Simulation of Arc Spot

The numerical simulation is based on the following assumptions:

(1) The process in rear electrode is determined by aerodynamic process of the flow. The cold state process is similar to heated state process. The axial zero velocity point in near-wall zone is regarded as arc spot [1];

(2) The gas flow is steady and axially symmetric;

(3) The electric arc is regarded as a line-shaped uniform heat source, and heat source intensity is determined by arc power;

(4) Mass force is negligible.

The calculation domain is sketched in Fig. 1. The flow can be described by the following equation:

$$\frac{\partial}{\partial x}(\rho u \phi) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v \phi) = \frac{\partial}{\partial x}(\Gamma_{\phi} \frac{\partial \phi}{\partial x}) + \frac{1}{r} \frac{\partial}{\partial r}(\Gamma_{\phi r} \frac{\partial \phi}{\partial r}) + S_{\phi}$$

In this equation,  $\phi$  stands for time - averaged dependent variables, including axial velocity  $u$ , radial velocity  $v$ , swirling velocity  $w$ , temperature  $T$ , turbulent kinetic  $k$  and its dissipation  $\varepsilon$ .  $\phi = 1$ ,  $S_{\phi} = 0$  correspond to the continuity equation.  $\Gamma_{\phi}$  is transport coefficient and  $S_{\phi}$  is source term, details of these two terms are given in table 1.

Table 1 The transport coefficients and source terms

$\phi$	$\Gamma_{\phi}$	$S_{\phi}$
1	0	0
$u$	$\mu_e = \mu + \mu_t$	$-\frac{\partial p}{\partial x} + \frac{1}{r} \frac{\partial}{\partial r}(r \mu_e \frac{\partial v}{\partial x}) + \frac{\partial}{\partial x}(\mu_e \frac{\partial u}{\partial x})$
$v$	$\mu_e$	$-\frac{\partial p}{\partial r} + \frac{1}{r} \frac{\partial}{\partial r}(r \mu_e \frac{\partial v}{\partial r}) + \frac{\partial}{\partial x}(\mu_e \frac{\partial u}{\partial r}) + \frac{1}{r}(\rho w^2 - \frac{2\mu_e v}{r})$
$w$	$\mu_e$	$-\frac{\rho v w}{r} - \frac{\mu_e w}{r^2} - \frac{w}{r} \frac{\partial \mu_e}{\partial r}$
$k$	$\mu_e / \sigma_k$	$G - \rho \varepsilon$
$\varepsilon$	$\mu_e / \sigma_{\varepsilon}$	$\frac{\varepsilon}{K}(c_1 G - c_2 \rho \varepsilon)$
$T$	$\lambda$	$\dot{Q}$

Notes:

$$(1) \mu_t = c_\mu \rho K^2 / \varepsilon$$

$$(2) c_\mu = 0.09, \quad c_1 = 1.43, \quad c_2 = 1.92, \quad \sigma_k = 0.9, \quad \sigma_\varepsilon = 1.22$$

$$(3) G = \mu_\varepsilon \left\{ 2 \left[ \left( \frac{\partial u}{\partial x} \right)^2 + \left( \frac{\partial v}{\partial r} \right)^2 + \left( \frac{v}{r} \right)^2 \right] + \left( \frac{\partial w}{\partial x} \right)^2 + \left( \frac{\partial w}{\partial r} - \frac{w}{r} \right)^2 + \left( \frac{\partial u}{\partial r} + \frac{\partial v}{\partial x} \right)^2 \right\}$$

The equation were solved numerically by finite difference technique and low relaxation line iteration method on a stagger grid system. SIMPLE procedure is used.

### 3.Results and Discussion

(1) Both calculation results and theoretic analysis indicate that there exist two recirculation zones near the entrances of auxiliary and main gas. The rotation of gas produces radial pressure gradient, and axial velocity can not make up the pressure gradient, thus recirculation zones will be formed. The axial zero-velocity point in the near-wall zone is regarded as arc spot, and  $h$  is the distance from arc spot to the entrance of auxiliary gas.  $h$  and  $w$  change with  $\bar{G}, \bar{D}, \bar{L}, I$ .

(2) Fig.2 shows how arc spot position changes with arc current. Because arc heating to main gas is larger than it to auxiliary gas, main gas has a larger temperature increment thus a larger momentum dissipation than auxiliary gas has, therefore arc spot moves to the direction of main gas. The larger arc current is, the greater  $h$  is.

(3) Fig.3 and Fig.4 show how  $h$  and  $w$  change with  $\bar{G}$ . Because of the existence of end wall, auxiliary gas rotation momentum transforms into velocity which points to the outlet of rear electrode. main gas rotation momentum transforms into velocity which points to the inlet of rear electrode because of the step's confinement. When  $\bar{G}$  increases, it means auxiliary gas increases and main gas decreases, and arc spot moves towards the outlet of rear electrode. The rotary velocity of arc spot has the greatest value when  $\bar{G}=0.6 - 0.8$ . It also shows if  $\bar{D}$  is too large,  $h$  and  $w$  get unstable; if  $\bar{D}$  is too small,  $w$  is also small. So it is feasible  $\bar{D} = 0.5 - 0.6$ .

(4) Fig.5 and Fig.6 shows how  $h$  and  $w$  change with  $\bar{L}$ . With the increasing of  $\bar{L}$ ,  $h$  increases and finally to a constant value and  $w$  decreases. The friction between gas and tube's wall gets weak when  $\bar{L}$  increases to certain degree, so  $h$  will be constant and  $w$  is very small. It is fitful that  $\bar{L} = 2.14 - 4.29$ .

(5) To examine the results of numerical simulation, the tubular plasma generator is designed by these parameters, and under these parameters the

generator is operated safely. To examine the relationship between the position of arc spot and arc current, the method is used, which is that after experiment the arc position and the damage condition in rear electrode are watched directly. It is found that with the increasing of arc current, arc spot moves towards the main gas.

#### 4. Conclusion

(1) Through numerical simulation, the most optimum parameters are:  $\bar{G}=0.6 - 0.8$ ,  $\bar{D} = 0.5 - 0.6$ ,  $\bar{L}=2.14 - 4.29$ . Arc spot moves to the outlet of rear electrode with the increasing of arc current.

(2) According to the results of numerical simulation, experiments are engaged with  $I = 200 - 400A$ . The results of experiments indicate that it is feasible for offering parameters in generator designed by numerical simulation.

#### Acknowledgment

This work is supported by National Natural Science Foundation of China.

#### References

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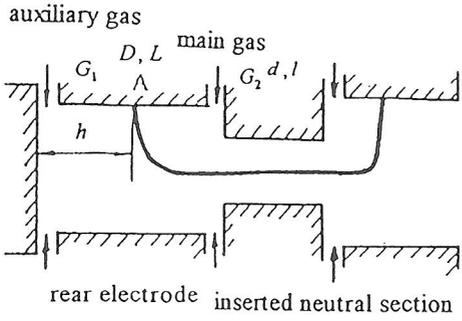


Fig.1

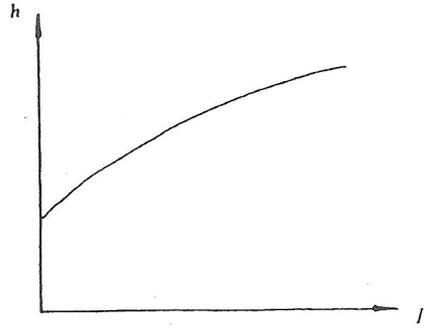


Fig.2

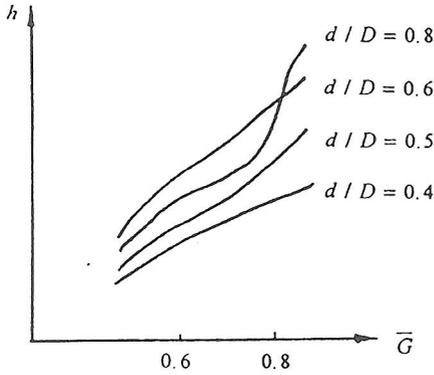


Fig.3

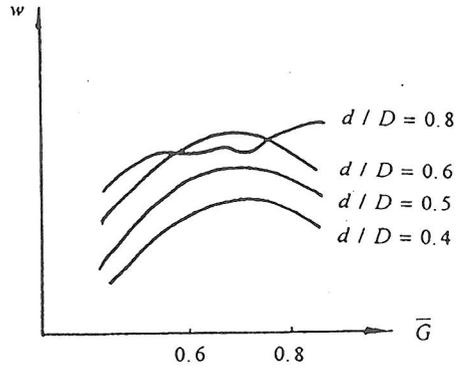


Fig.4

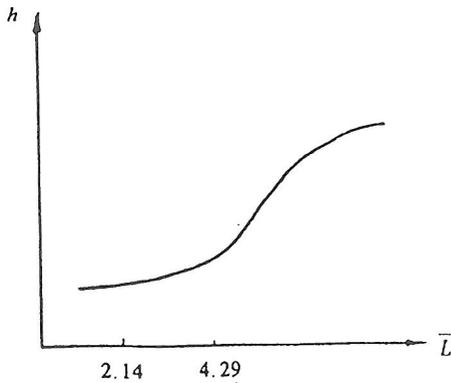


Fig.5

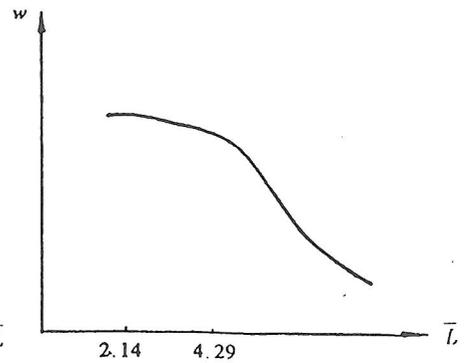


Fig.6