Two-Dimensional Velocity Field Interporation of Plasma Jet From Pictures Sequence captured by High-Speed Camera

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Abstract: An method for two-dimensional plasma flow field is developed based on the SSIV method. Experimental verification is conducted in atmospheric plasma jet produced by a direct current arc torch making use of a high-speed camera. The two-dimensional velocity distribution is calculated using the the proposed method by processing the image sequence captured by the camera. Moreover, the compression-expansion regions is clearly presented by manipulation of the two-dimensional velocity field.

Keywords: SSIV, two-dimensional, flow field, plasma, specific oscillation.

High-speed plasma jet/plume has been playing indispensable roles in various areas[1-6]. In those applications, the flow velocity field is important parameter for utilizations due to it decides the heating history and the moment transfers of injected particles in plasma spraying, moreover, it is the critical scaling parameters in plasma wind tunnels. Traditional velocimetric methods are difficult to apply due to the high temperature and other extreme conditions of plasma jet. The method tracing the optical flucutation of the emission has many advantages, such as no intrusive interruption on the flow and no tracing-problem like particle based methods. Recently, a new method named specific signal imaging velocimetry (SSIV) was proposed based on the analysis of optical images recorded with a high-speed camera[7]. The main idea in SSIV is tracing a specific intensity fluctuation which is written in the plasma source or in the upstream and follows the plasma flow. Due to the plentiful information contained in two-dimensional image sequences, it is possible to withdraw the two-dimensional flow field using SSIV. In this work, the ability of two-dimensional velocity measurement of SSIV is investigated.

In previous work[7], SSIV is successfully applied in low-pressure and atmospheric plasma jet/plume velocity measurement, and the one dimensional velocity distribution is obtained. In that work, the plasma plume is subsonic and relatively uniform, in which the propagation of the specific signal with specific oscillation frequency along the center axial is nearly straight. Hence,

In one-dimensional velocity measurements, such as the velocity along the central axis, the tempo-spatial propagation of the specific fluctuation is expressed as

$$I(x_i,t) = A(x_i)\sin\left[2\pi f_s\left(t-\int_0^{x_i}\frac{dx}{U(x)}\right)\right] \tag{1}$$

where $A(x_i)$ is the specific signal amplitude at x_i position, $U(x)$ is local velocity and f_s is the specific oscillation frequency.

For two-dimensional flow field, the velocity has two components, i.e., $\vec{U}=U_x\vec{e}_x+U_y\vec{e}_y=U\cos\theta\vec{e}_x+U\sin\theta\vec{e}_y$, the angle θ is the angle between the velocity vector and the x-axis, As illustrated in Fig.1. Considering three measuring points close enough that their velocities could be considered equal. Each point has individual initial phase of the specific oscillation. The oscillation propagation equation of equation (1) would be along the direction perpendicular to the isophase lines consisting with measuring points with the same initial phase. Thus, the relationship between U, θ and the measured time delay between each two measuring points, i.e., Δt_x and Δt_r could be established as

$$\left.\begin{aligned}\Delta t_x &= \frac{\Delta x\cos\theta}{U}\\ \Delta t_r &= \frac{\Delta r\sin\theta}{U}\end{aligned}\right\}\Rightarrow\left\{\begin{aligned}U'_x &= \frac{U}{\cos\theta}\\ U'_r &= \frac{U}{\sin\theta}\end{aligned}\right. \tag{2}$$

Therefore,

$$\begin{aligned}\theta &= \arctan\frac{U'_x}{U'_r}\\ U &= U'_x\cos\theta\end{aligned} \tag{3}$$

In which,

$$U'_x = \frac{\Delta x}{\Delta t_x},\ U'_r = \frac{\Delta r}{\Delta t_r} \quad (4)$$

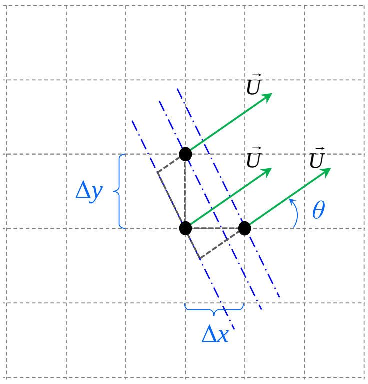

Fig.1 the spatial relationship between the measuring points, the velocity vector and the isophase lines (blue dotted line).

For verification of the two-dimensional SSIV method, denoted SSIV2D, experiments on atmospheric arc plasma jet is conducted. The image sequence of the jet is captured using an high-speed camera with framerate of 500 kfps (by a IX Camera, i-speed 513), and the image pixel size is 336x192, as shown in Fig.2. for the sake of optical satuation, only a small region is analyzed as marked yellow in Fig.2. The oscillation is produced by external circuit as described in [7]. The specific frequency is 1 kHz.

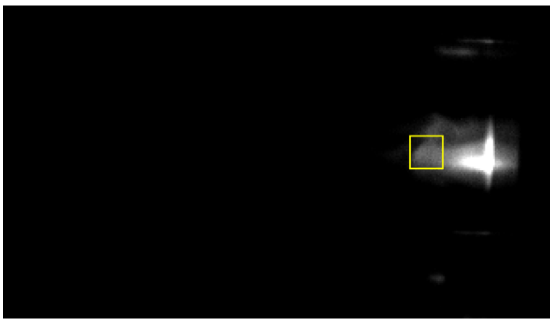

Fig.2 the picture of the atmospheric plasma jet produced by a dc plasma torch with the anode exit located at the right side. the pixel dimension is 336×192, and the region to be analysed (marked with yellow rectangle) is 21×21 pixels.

Using equations (2)(3)(4), the velocity field could be obtain through SSIV method, as shown in Fig. 3. The obtained two-dimensional velocity field could provide much more information than one-dimension case, such as the expansion-compression within the flow field, which is represented by the divergence of the velocity, as clearly shown in Fig.4.

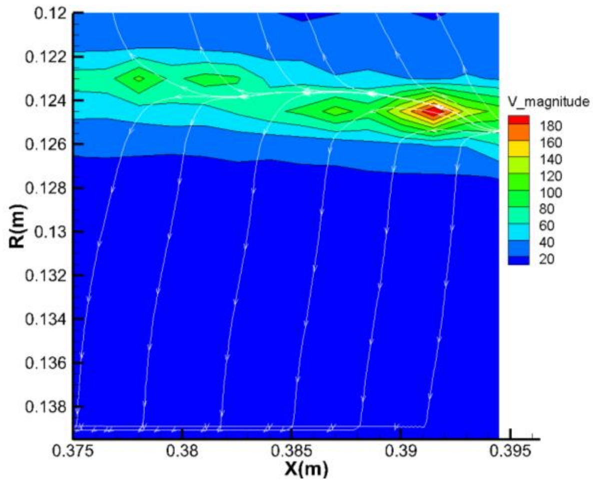

Fig.3 calculated magnitude of the velocity field and the streamline.

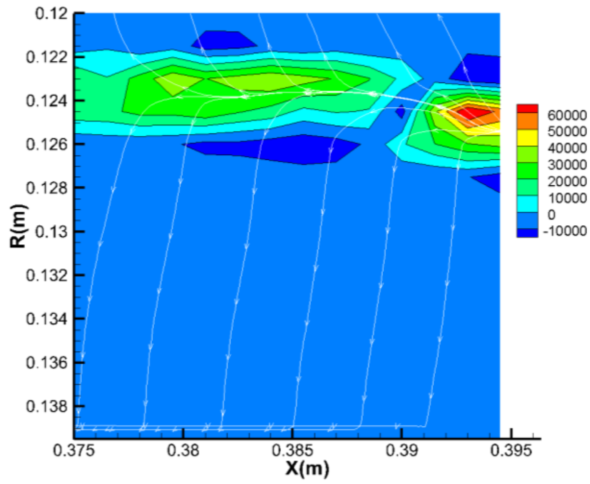

Fig.4 calculated divergence of the velocity field and the streamline.

In conclusion, the SSIV2D is suitable for two-dimensional field measurement of atmospheric plasma flows. The experimental verifications demonstrated that the basic field structure could be captured by SSIV2D. Theoretically, SSIV2D could be applied in high-speed/low-pressure directly, which would be realized in the near future.

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