Visualization of Thermal Plasma Jet Induced Turbulence Using Spatial-Frequency-Resolved Schlieren Sensor

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Abstract: Turbulence structure around argon thermal plasma jet was visualised by a novel technique using a spatial-frequency-resolved schlieren sensor. Regions which induced a phase-shift of the refractive index on the laser wavefront were observed distributing in the jet downstream. In particular, the fine phase-shifted regions at downstream of the jet corresponded to the structure caused by turbulent eddies.

1. Introduction

Thermal plasma jets have been used in industrial processes such as plasma spraying and environmental cleaning processes such as decomposition of persistent substances. Turbulence around the plasma jet causes entrainment of ambient air into the jet, which leads to a temperature drop in the plasma region and undesirable mixing of substances. Since these can harm the processes, it is necessary to elucidate the turbulence around thermal plasma jets in detail. Shigeta [1] presented the turbulence structure around a plasma jet by numerical simulation. On the other hand, in experiments, Pfender et al. [2] showed a snapshot using the shadowgraph method. No similar study has been reported since then.

The final goal of this study is to figure out turbulence induced by thermal plasma jets. As the first step, we captured the turbulence structures around an argon thermal plasma jet by a novel method using the spatial-frequency-resolved schlieren sensor [3].

2. Methods

Argon thermal plasma jet ejected from a plasma torch with an outlet diameter of 8 mm into the air at room temperature and atmospheric pressure. The spatial-frequency-resolved schlieren sensor was used to extract only the regions of the refractive index that induced a phase-shift of the spatial wavelength from 122 μm to 244 μm on the laser wavefront. In this paper, these regions are called “phase-shifted regions”. The center of the jet outlet was taken as the origin of the coordinate system, and the z-axis was taken in the flow direction. Two high-speed cameras were used to take the schlieren image and the plasma luminescence.

3. Results and Discussion

Figure 1 shows the instantaneous image of the plasma luminescence region (white) and the phase-shifted regions (red) taken with the spatial-frequency-resolved schlieren sensor. This image was stitched together from separated images taken at 10 mm intervals. The red regions represented the density gradient caused mainly by the turbulence structure because the refractive index gradient corresponded to the density gradient. It should be noted that these included the effects of refractive index gradients caused by not only pressure changes of eddies but also the temperature gradient. In the region of $z < 20$ mm, the phase-shifted regions around the plasma luminescence had a large wave-like shape. These regions corresponded to the fluctuations of the large temperature gradient regions. On the other hand, the phase-shifted regions that became finer in $z > 25$ mm were considered as the refractive index gradients induced by turbulent eddies. The distribution of the phase-shifted regions was expanded in $z < 35$ mm, while the distribution became thinner in $z > 35$ mm. This suggested that the turbulence decayed in $z > 35$ mm.

4. Conclusion

A novel technique using a spatial-frequency-resolved schlieren sensor successfully visualized turbulence structure induced by an argon thermal plasma jet. Fine phase-shifted regions were observed downstream of the plasma jet, which corresponded to turbulence structures. The present method is applicable to visualize turbulence structures induced by thermal plasma jets. It is noteworthy that a standard schlieren method could not capture the turbulence structure for the same condition.

References

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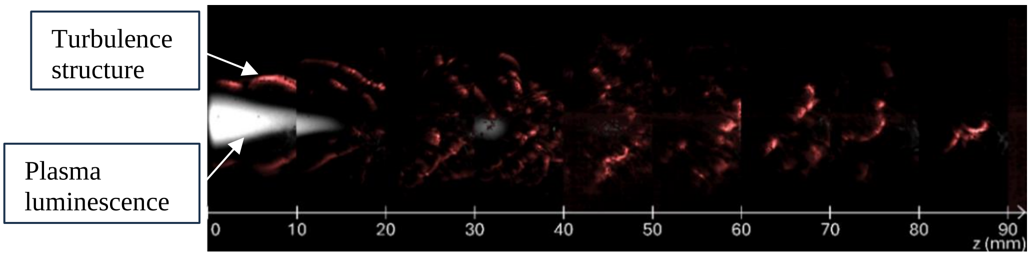

Fig. 1. Instantaneous image of plasma emission region (white) and phase-shifted region (red) at 0 mm $\leq z \leq$ 90 mm.