Application of Laser Holography and PDPA Technology in Spraying Fuel Particle Field Measurement

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1 Introduction

For starting and running an engine successfully, the fuel must be mixed with high-speed air rapidly and fully in the combustor. The atomization quality of fuel impacts on the fuel mixture. Therefore study on fuel injection, atomization, diffusion and mixing quality is important, and the measurement of fuel size and spatial distribution is the key to the engine research.

Both PDPA and laser holography can be used to measure aerosol particle field. However PDPA can't be used to deal with the particle field in the experiment wind tunnel where the flow speed is over 1000m/s, the size of atomized particle is in microns, and the running time of wind tunnel is less than hundreds milliseconds. Correspondingly the clear holograms of particle field can be captured by using laser holography instantly, just like the high velocity particles are "freezed". The holograms can provide the distribution, shape, size and other information of fuel particles. At first we measured fuel atomization particle field in this two methods in the circumstance of not having incoming flow. The results of measurement are compared with each other. The result of comparison confirms the reliability of laser holography method. So laser holography method is used to measure the fuel particle field in the wind tunnel experiment.

2 Measurement Theory

2.1 Principle of PDPA

Phase Doppler Particle Analyzer (PDPA) is a modern advanced flow field non-contact measurement method, which obtains the speed of particle by measuring the

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Doppler frequency shift and gets the size of fuel particle by measuring the phase of scattering light passing through transparent spherical particles. This method can be expressed as the formula.

$$\Phi = F(m)d_p \tag{1}$$

Where Φ is the phase difference, m is the particle refractive index, $F(m)$ is a transfer function which is based on different scattering types, and d_p is the particle diameter. The PDPA system consists of the optic launching system, the optic receiving system, signal processing systems, displacement system, computer and application software. Fig 1 is the schematic of a typical PDPA system.

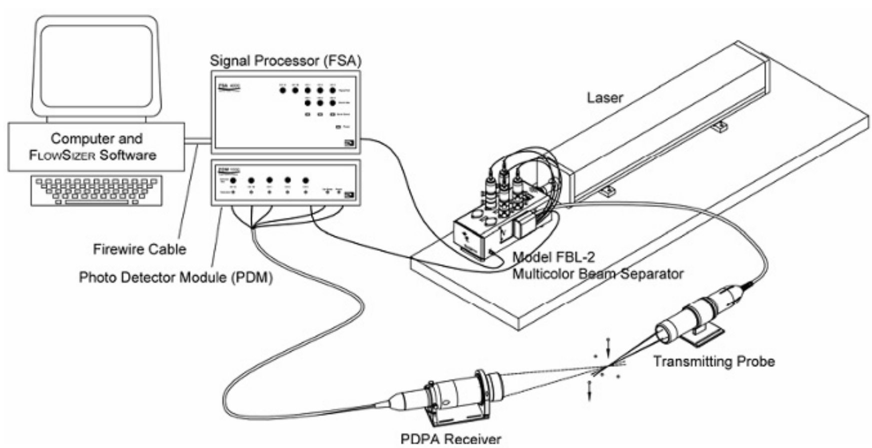

Fig. 1 Schematic of a PDPA system.

2.2 Principle of Laser Holography

When a high-coherence pulse laser beam irradiates the particle field, the information can be recorded by the holographic interferogram. During the process of holographic reproduce, images of particle field can be reproduced and recorded layer by layer according to the system field depth and particle far-field conditions. Then the relative size value can be obtained after computer image processing. In accordance with known size of calibrated silk thread or standard particle , the absolute size of atomized particle can be confirmed. With statistical analysis particle density and other parameters can be obtained.

Particle Field Holography measurement system consists of recording, reproduction and data processing parts. The recording system includes pulsed laser, synchronization signal controller, holographic optical system, etc. The reproduction system consists of a CW laser, the reproduce optical system, a fine-tuning device of stratified reproduction, CCD camera and computers of controlling and recording. Data processing system includes image analysis and processing, verification of particle in focus, particle size analysis and statistical analysis of atomization field. Fig 2 shows the holographic optical recording system (off-axis hologram), and Fig 3 is the holographic reproduction image acquisition system.

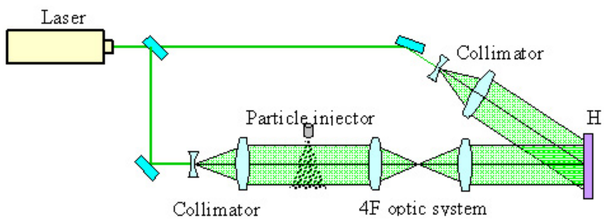

Fig. 2 Schematic of a laser holography system.

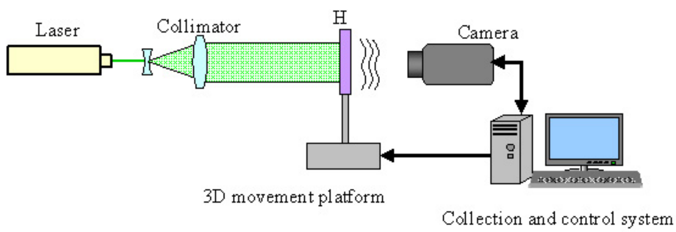

Fig. 3 Schematic of the holographic reproduction system.

3 Comparison Experiment

In the comparison experiment the water is atomized from the injector by the high-pressure gas. The atomization particle field is in the measuring area of PDPA or laser holography device. The main parameters of the test are as follows. The diameter of spray nozzle is 0.5mm. The pressure of gas is 4Mpa.The distance between the nozzle and the center of measuring area is 200mm.The spray liquid is water.

3.1 Measurement Results Based on PDPA

The injection time and the requirement of statistical analysis being considered, the statistical amount of particle measured by PDPA is set as 5000 in this experiment. Fig 4 shows statistical distribution results of particle diameter measured by PDPA. In the diagram the abscissa is the diameter of spray particle (unit um). The vertical axis is the statistical number of particle. According to the measured result of particle, the smallest particle diameter is about 3um, the biggest particle diameter is 267um (no more than 300um). The highest repetition frequency of particle diameter is 16um,which is about 200.The amount of particles whose diameters are less or equal to 20um is 1321. So the statistical particle diameter D_{32} is 94.91um. After repetitious measurements the D_{32ave}= 95.95um.

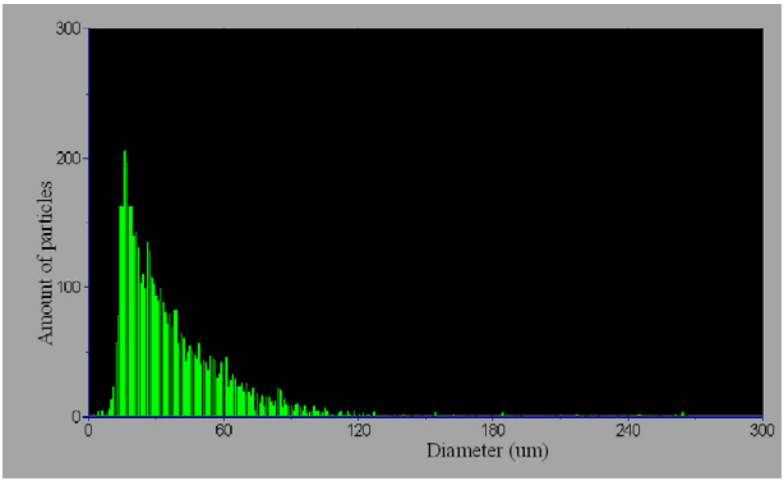

Fig. 4 Distribution of particle diameter measured by PDPA.

3.2 *Measurement Results Based on Laser Holography*

Fig 5 shows the statistical result based on 125 holographic reproduction images. In the diagram the abscissa is the particle diameter(um). Vertical axis is the particle amount.The volume of statistical area is approximately $2.5 \times 2.5 \times 0.4cm^3$, in which the particle amount is about 4700. As the interval between layered reproduction images along the optical path is defined as 1mm, the information of the particles between the two layers, especially small-size particles, is lost. Consequently the actual amount of particles is more than the statistical amount. Fig 5 shows the statistical distribution of particle diameter. The smallest particle diameter corresponding to the amount peak is 13um and the amount is 1458. There are 680 particles whose diameter are 21um corresponding to the second amount peak. The amount of big size particles shows a downward trend. The total statistical diameter D_{32} is 97.97um which is very close to the measured result based on PDPA.

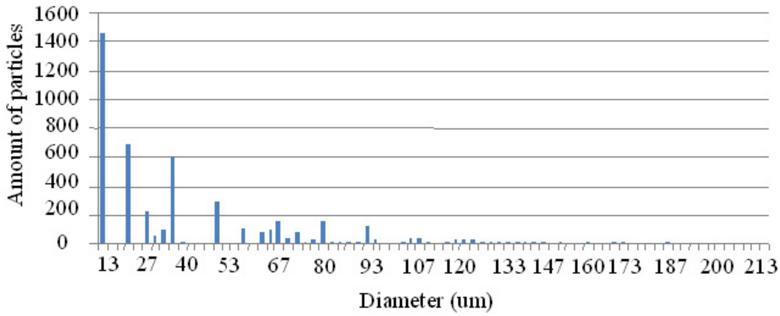

Fig. 5 Distribution of particle diameter measured by laser holography.

4 Experiments in Wind Tunnel

The comparison experiment of two methods on the same nozzle in the same condition indicates that the laser holographic measurement technique is feasible to measure the spray particle field. The error satisfies the requirement of engineering application. In view of the characteristics of two technologies, the laser holography can deal with the transient injection particle field in the shock wave wind tunnel only. Based on this method, the statistical information such as the diffusion of spray fuel and the particle size is easy to be obtained by holographic recording, latter stratification reproduction, digital image processing and identification of spray particles field. Fig 6(a) is a part hologram of the spray particle field acquired in the condition that Mach number is 2, the diameter of the spout is 0.5mm and the injection pressure is 2MPa. In Fig 6(b), the point (0,0) is the position of spout, x direction is corresponded to the flow, y direction is corresponded to the spraying and z is the optic axis. The sampling volume of mesurement area is 2mm×0.75mm×0.1mm.

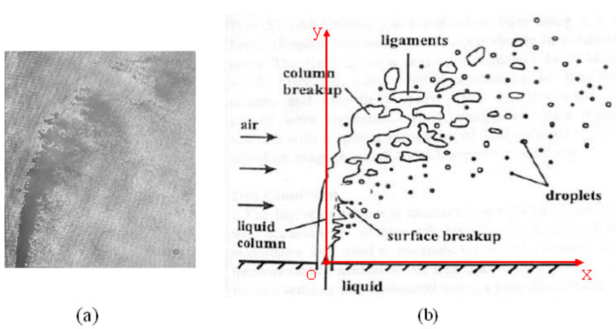

Fig. 6 Part hologram of spray field and schematic of the spray field coordinate.

After layered holographic reproduction of the hologram and spatial reconstructing, the spacial distribution of the spray particles can been obtained. Through statistical calculation, the analysis results show that D_{32} is less than 10 um in two serial samples mostly.

5 Conclusion

PDPA and laser holography are two completely different methods to measure particle field. As a sophisticated commercial instrument, PDPA can accurately measure and give the real-time result about the speed and diameter of particles. The error is generally less than 1um. However, it is a temporal statistical measurement, it requires a stable flow is long enough. The speed of particle is usually less than 500m/s. When laser holography is used to measure the particle size, the flow field can be recorded in an instant. For the laser pulse duration of this system is 150 picosecond, the velocity of particle and the stable duration of flow in wind tunnel test can fulfill the measure demand. Moreover three-dimensional spatial distribution of spray field can be obtained with this method. Although laser holography particle field measurement needs heavy work in data processing, with the development of computer technology, the processing time will significantly be shortened and the method will be more useful and reliable. In short, in the field of particle analysis, PDPA can provide higher precision and relatively simple operation. Laser holography can provide overall information. Especially it can be used in high speed or pulse wind tunnels. So it is more suitable than the PDPA for wind tunnel test.

References

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