Measurement of Diameter and Volume Density Distribution in Diesel Fuel Sprays by Means of Holographic Technique

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ABSTRACT

In this paper, the fundamental principle of the holographic measurement system in diesel fuel spray is described. Moreover, the application of measurement for the droplet size and its volume density distribution in diesel fuel sprays in actual single-cylinder diesel engine is discussed emphatically. Major technical parameters and key techniques are pressented.

INTRODUCTION

Because the pulsed laser holography has many good qualities, such as high time response and spatial resolution, great information capacity and being suitable for non-contact measurement, it gains more advantages over other measurement means in diesel spray field research. However, holography in practical application is still very difficult due to the complicated condition in actual diesel engine and the actual injected fuel jet being composed of many small droplets with very high velocity and wide range of the droplet size . In the past, most scholars studying diesel fuel sprays laid particular stress on the study of parameters such as depth of penetration L and cone angle, but didn't develop the research in droplet-size characteristics in fuel sprays until recently, and they did it isolatedly. Few searched for the essential relation between macroscopic characteristics and microscopic characteristics in spray field and studied the effect on the whole combustion process resulted from the coordination beween those characteristics and combustion chamber.

Generally, the number of droplets is enormous in a spray of diesel engine, e.g. for a millilitre diesel oil, the average diameter of droplets is 25μ after atomization, so there are 1.22 x 10^8 droplets. Therefore, it is meaningless and impossible to measure all or most of the droplets. The macroscopic distribution is very useful research goal.

Applying single pulse laser holography to record the spray region of sprays can analysize the droplet-size characteristics and evaluate the spray quality of spray system. In addition to process the droplet-size data with computer, d_{10} & ds of droplets and droplet frequency diagram can be obtained.

Applying double pulse laser holography can record whole region of sprays. By processing the interference fringe we can obtain the volume density distribution in vaporization and atomization regions of sprays, and we can obtain the volume density distribution in high concentration and core regions of sprays by pseud-color processing. Aided by the image processing system, we can draw the various concentration regions of sprays conveniently and catch the real sight of the spray parameters in actual diesel engine such as depth of penetration L and cone angle.

In summary, applying means mentioned above can analysize the diesel spray more completely and perfectly. They can be also applied to other type of spray study.

MEASUREMENT OF THE DIAMETERS OF SPRAY DROPLETS

In-line holography

In-line holography, with the advantages that its optical path is uncomplicated and convenient to adjust and the requirements for the coherence of light source and the resolution of record medium are low, compared with microphotography, can be three orders of magnitude higher in record depth of field and obtain the three-dimensional record and reconstruction of the spray droplet field. Therefore, it is very suitable for the measurement of diesel spray droplets. With the application of reconstructing and data processing system in dense droplet field, the application and development of in-line holography are improved and popularized.

In-line holography is interferential double imagery technique in which object light, reference light and illumination light are located in optical axis. The in-line holographic recording optical path diagram of droplets(the upper) and that of reconstruction (the lower) are shown in Fig.1. The droplet whose diameter is d is located in coordinate original point. When illuminated by the unit amplitude plane wave whose wavelength is and Zo , the distance from record medium plane to the droplet, meets the far-field condition, the droplet is recorded. The condition is as follows:

$$Z_o = N d^2/\lambda, \quad N > 1 \qquad (1)$$

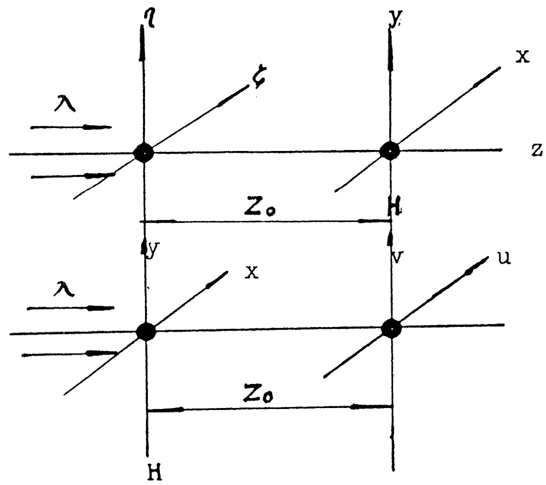


Fig.1. In-line holography

where N is the far-field number, whose sampling range is limited by reconstructed image quality. Generally this is proved by practice:

$$1 < N < 50 \qquad (2)$$

There is a limitation for the density of droplets. High density coold make the image quality poor even indistinguishable. The conception of density shadow is ordinarily used to describe the limitation. If the area of the transverse section of a recording space is S, there are a number of droplets in it, and the diameter of the ith droplet is di, the conception of density shadow is defined as the ratio of the sum of the cross-section area of all the droplets to S, i.e.

$$C = \frac{\pi}{4S} \sum_{i=1}^{n} d_i^2 \qquad (3)$$

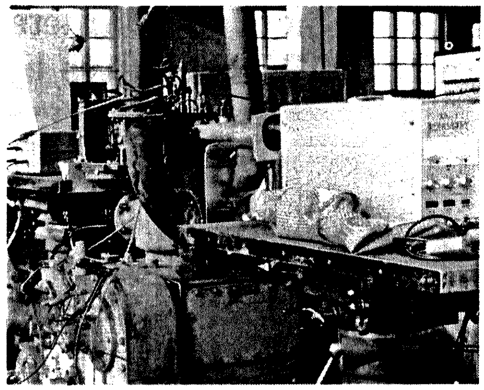
It is proved by practice that sampling C 5% is appropriate.

Recording system

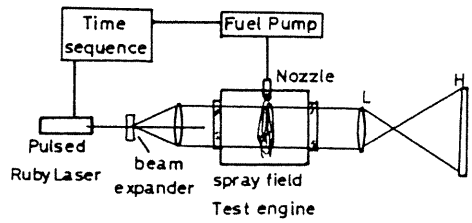
Holographic recording system is shown in Fig.2. The following should be taken into account while designation.

Choice of light source: we chose a pulsed ruby laser with an output greater than 50mJ generally, a impulse duration less than 30 ns, and coherent length greater than 0.5 m.

Choice of pick-up camera: in order to take pictures of whole spray field without moving the optical system and keep the enlargement factor constant, we adopted confocal system. The enlargement factor is 2-7. The resolution ratio is 3μm. The enlargement factor should be greater than 2 because of considering the resolution of coherent board, and nó more than 7 because the output of light source is considered and it's easy to give rise to air breakdown in confocal point. In the same time, in order to improve the resolution, decrease object distance and increase aperture as far as possible.



a) Test set up



b) Actual optical path

Fig.2. Holographic recording system

Droplet processing system

Reconstructing and data processing system is shown in Fig.3.

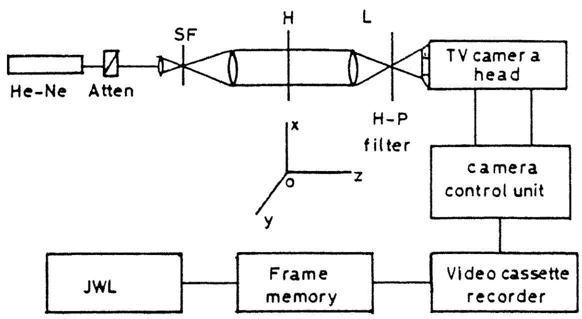


Fig.3. Reconstruction and data processing

The system includes an adjustable optical system, a TV camera system, a frame memory device and a JWL computer hondrometer with its periphoral equipment, etc. The hologram H is held on three-dimension adjustable mount and is illuminated through an extender len by a collimated He-Ne laser. The reconstructed image of the hologram magnified by len appears on the cathode of the camera and after remagnification, a clear oil droplet planar image is formed on the screen. When moving the hologram along the direction of laser beam i.e. the Z direction with the help of the mount, the different focused images of different layers can be obtained successively. When the hologram is moved in the X or Y direction, the images of different sampling regions are obtained.

The information about the droplet size over the planar image field is turned into digital signals which are sent to the frame memory. Data stored in the frame memory can be read to the computer for processing. JWL which classified the droplet with respect to their diameters prints out the results of diameter classification and their statistical values. Fig.4. give example of reconstructing and processing image.

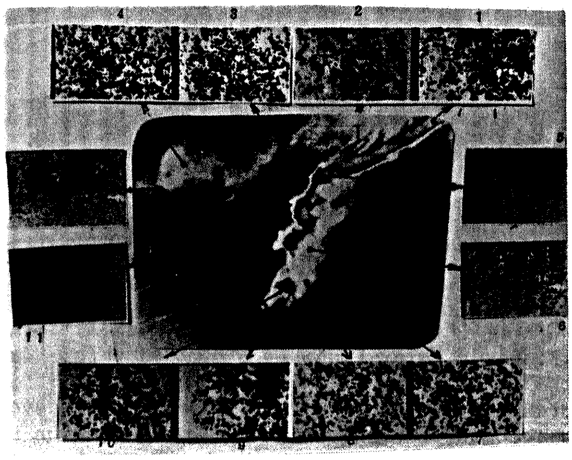


Fig.4. The reconstructed image of droplets

MEASUREMENT OF VOLUME DENSITY DISTRIBUTION IN DIESEL FUEL SPRAY FIELD

Double-exposure off-axis holography

Generally, there is a definite physioal correlation between volume density of spray field p(x,y,z) and refractivity field n(x,y,z). If we regard the vaporized oil spray as perfect gas, according to Gladstone-Dale equation, we can set up the following related equations:

$$\begin{cases} 2(n-1)/3\rho = \tilde{r} \\ \rho = p/RT \end{cases} \qquad (4)$$

where $\tilde{r}$ is characteristics refractivity, which is the funtion of medium and the wavelensth of light passing through the medium.

Applyinsm laser holography and interferential means i.e. double-exposure off-axis holography, we can obtain n(x,y,z) and then calculate ρ (x,y,z) by inversion. Since it is non-contact, the measurement has little influence on the spray field and can be quantitative.

Double-exposure laser holography usually record instantaneous object waves on the same medium and form hologram independently. While images are reconstructed, the interference fringe are produced because of the interference between two wave fronts.

When taking hologram, we record hologram i.e. expose for the first time while injection with a fixed rotation speed, then expose for the second time in the same condition. What is called double-exposure method.

When reconstructing the double-exposure hologram, we can observe the interference fringes on the double-exposure hologram.

Actual optical path

The diagram of the actual optical path is shown in Fig.5. The parameters of the engine and laser device on which experiment is performed are listed in the following tables.

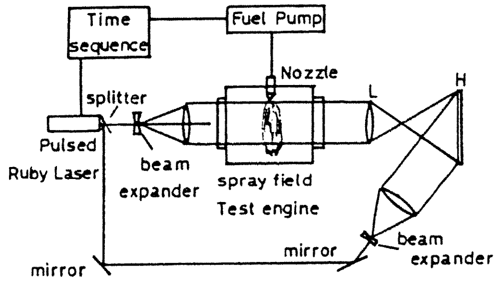


Fig.5. Double-exposure off-axis holographic system

Table 1 - engine parameters

type of the engine	E150
stroke number	2
scavenging pressure	0.12MPa
rotation speed	750rpm
cylinder diameter/stroke	150mm/225mm

Table 2 - laser device parameters

model	XJ-1
output	250mJ
impulse duration	30ns
coherent length	1m

Fringe processing technique

By reconstructing the double-exposure hologram, processing the interference fringe and calculating inversively, we can obtain volume density and temperature distributions of the spray field. The method has few problems in terms of theory, and performed by J.C.Dent in practice, but because they are obtained from actual diesel engine, the actual hologram carry a lot of noise information due to the limited condition. It brings difficulty to actual calculation.

Applying computer and what is called the skeleton method of slenderized fringe tracking, we can draw the fringes which are complicated and difficult to distinguish with computer convently, resulted in improving the preoision of inversive caloculation for an order of masnitude.

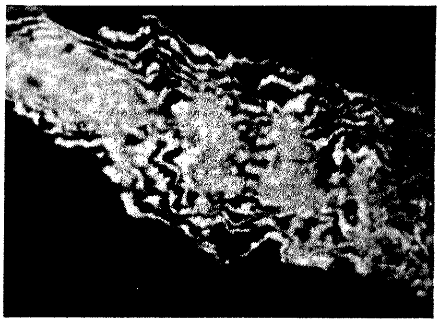
Fringe tracking criterion

a. Scan the images and search for the point meeting detection criterion. When the soal is achieved, take it as current point (h,k) in the curve being tracked.

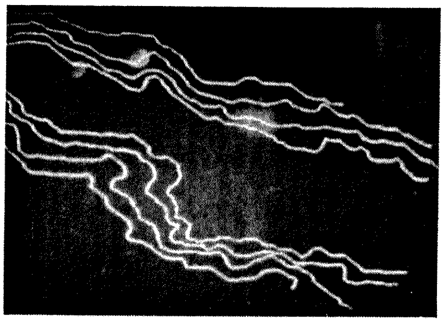
b. Detect the neishborhood of the point (h.k) and apply proper tracking algorithm, which depends on the grey scale of oandidate point, the distance from the current point and its direction. Once find a perfect candidate point, take it as the next current point.

c. If can't find the point meeting detection criterion, the frinse tracking is over. Then continue to track the next fringe.

Fringe tracking According to fringe tracking criterion, the skeleton curve of interference fringe obtained by fringe tracking really reflect the characteristics of interference fringe. Fig.6 is an example of fringe tracking.



a) The reconstructed image of spray



b) Fringe tracking image

Fig.6. Fringe tracking image

<u>Pseud-color technique</u>

Spray in diesel is atomization of flow with hish velocity, i.e. diffusive atomization and voporization in cylinder after air is compressed. The droplet size and distribution can be obtained by in-line holography, and the region of vaporization can be measured by double-exposure holography, but for the core region and high concentration region of the spray, both methods mentioned above are powerless.

This paper recommends to adopt pseud-color technique to carry out the concentration measurement of high density spray. The technique is one for display which pseud-colorizes hologram by coding image density with grating. It's a kind of information processing technique with white light.

Although spray is a flow with hish velocity, applying in-line holographic optical path, we can "freeze" the whole spray on holofilm instantaneously and make it turn into shadow image with hish resolution. Using grating as modulation cell, coding process the shadow image. After bleaching, phase coded film taking relief type is formed. With white light information processing systme (TBX-5 model), processing it with optical filter demodulation, we can get pseud-color image corresponding to light transmisson of the shadow image. Because resolving power of the eye to color image is much higher than that to the gray scale of black-and-white image, the pseud-color image can display every minute differences of the original black-and-white shadow image and different levers of spray concentration.

Since spray concentration D(x,y) meet the monotone-change correlation with photic optical path difference of the thickness of pseud-color coded relief, and time of exposure is decided by standard color curve, differend levers of spray concentration can be displayed according to the prios appointed color. Therefore, the spray volume density distribution can be obtained from the color images. A pseud-color image of spray is shown in Fig. 7.

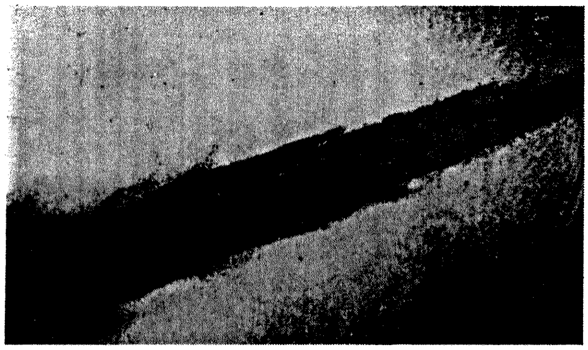


Fig.7. Pseud-color image of s pray

<u>Comprehensive measurement of volume density distribution.</u> Putting the methods mentioned above into use can take the pictures of spray distribution in cylinder.

They provide effective analytical means for studying combustion in diesel engine. A kind of spray distribution is shown in Fig.8,9.

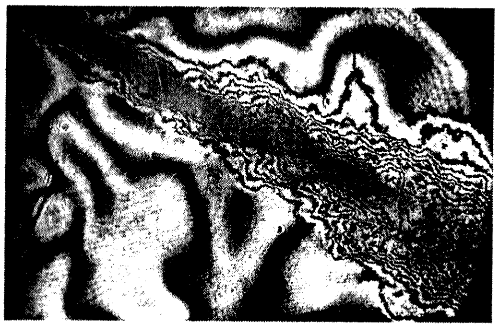
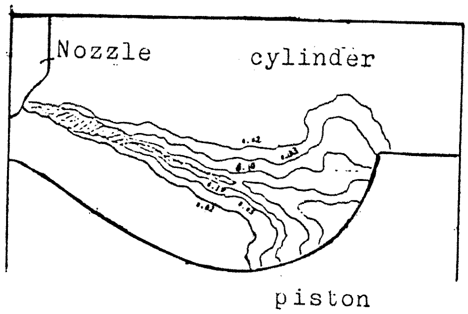
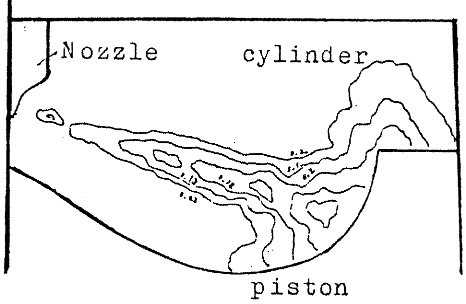


Fig.8. Vapour concentration.



(a)



(b)

Fig.9. The sprayvolume density distribution

CONCLUSION

a. Referring to the photoraphic parameters which is designating by author, can take the clear pictures of droplets in oil spray conveniently.

b. We can obtain droplet sizes and their distribution in spray field by applying JWL droplet size analytical system.

c. The interferentical images of volume density in spray vaporization region can be obtained by using double exposure interferentical holography.

d. Applying the skeletion method of interferentical fringe tracking, we can distinguish interferential fringes precisely, and make it easy to caloulate inversively.

e. The volume density distribution of high concentration spray can be obtained by using pseud-color technique.

f. Applying the three methods mentioned above, we can analysize spray distribution law and atomization characteristics comprehensively and provide important means for the research of combustion mechanism in diesel cylinder.

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