Study on Droplet Measurement of Unsteady Diesel Spray Using Phase Doppler Anemometry (PDA)

Tetsuma TAKEDA 1, Norimune OKUMURA 1 and Jiro SENDA 2

1 Graduate School of Engineering, Doshisha University, Email: dtfo376@mail4.doshisha.ac.jp
2 Department of Mechanical Engineering, Doshisha University

ABSTRACT It is very significant to obtain the information of droplets in an unsteady spray, that is, a diesel spray, to find the countermeasure against very sever regulation relating to the exhaust gas through a CI engine. One of useful technique is to apply the Phase Doppler Anemometry (PDA) to this kind of spray. However, there is some limit to measure the droplet diameter and its velocity because the number of droplets passing through a unit volume is too much dense and their velocity also passing through a unit volume is too much fast near the nozzle outlet. This paper describes this kind of limit of PDA.

Keywords: Phase Doppler, Laser Doppler, Diesel, Spray, Droplet, Measurement point, Number of measurement particle

1. INTRODUCTION

It is able to measure the droplet diameter in not only a steady spray but also an unsteady spray by use of the Laser Doppler Anemometry (LDA) and it is capable of detecting simultaneously both droplet diameter and droplet velocity by using the Phase Doppler Anemometry (PDA: DANTEC DYNAMICS, HiDense PDA System) as well known [1]. When both instruments are applied to an unsteady and dense diesel spray, it can understand the limit of measurement point. This is caused by the fact that there is the initial part [2] where the number density of droplets is too much dense and their velocity is too fast passing through a unit volume to measure. Some researchers presented the information of a diesel spray. However, this was at its leaner part and the case of a spray for an SI engine [3], [4]. It is very significant for the researchers and engineers relating to a diesel engine to know this kind of limit when they consider the characteristics of diesel spray and those of its combustion and design the combustion chamber of engine.

Figure 1 is one of examples of the time history of the count number of droplets and their velocity in the case of a diesel spray. There is the duration during the measuring period when the data are nothing. Thus, the objective of this paper is to find the limit of PDA technique when it applies to a diesel spray.

2. EXPERIMENTAL SETUP, PROCEDURE AND CONDITION

2.1 Laser and Phase Doppler system

Figure 2 illustrates the schematic diagram of the optics. The light source is Ar laser whose wave length is 514 [nm]. The light comes to a driver box where a optical fiber inserted and it oscillates by a transmitter (DANTEC 60X41) through the fiber. The diameter of the optical probe which is installed in the transmitter 60 [mm] and its focal length is 310 [mm]. The beam expander is also installed in the transmitter. Its magnification is 1.98, the beam diameter is 2.67 [mm] and the distance between two beams is 75.24 [mm]. It is necessary for the setting location of the detector to arrange as to be attenuated the reflected light at the surface including in the scattering light from the droplet and as to detect mainly the first refracted light. Thus, the setting
angle of the detector is 30 [deg.] against the axis of the detecting light. The detector has three sets of photomultiplier so that it is possible to obtain the two kinds of combination for the detection of the phase difference. As a result, it is capable of detecting two kinds of phase difference from a one droplet. Table 1 summarizes the main dimension of PDA.

Here, there are the non spherical droplets exist surely in a diesel spray. They affect the accuracy of measurement of PDA. Considering this fact, the data are eliminated when the sphericity is below 22.14 [%].

2.2 Fuel injection device and test nozzle

The fuel of JIS second class gas oil is injected into a constant volume chamber through an injection nozzle with a single hole connected with a common rail injection system. The dimension of injection nozzle is 0.24 [mm] in diameter, 1.2 [mm] in hole length and 0.35 [mm] in maximum needle lift, respectively. Table 2 is the specification of injection nozzle.

2.3 Experimental condition

The injection angle is 160 [deg.]. The experimental parameter is the injection pressure which is changed 60 [MPa], 80 [MPa], 100 [MPa] and 120 [MPa] under the constant injection quantity of 20 [mm³], the injection quantity which is changed 5 [mm³], 10 [mm³], 15 [mm³] and 20 [mm³] under the constant injection pressure of 100 [MPa]. The injection duration is prolonged as increase in the injection quantity. The ambient gas is carbon dioxide, the ambient density is constant at 39.5 [kg/m³] and the ambient temperature is 300 [K], in bots experiments. In the experiments to examine the effect of the ambient density it sets 1.17 [kg/m³], 18.6 [kg/m³] and 39.5 [kg/m³], and the ambient gas is air and carbon dioxide under the ambient temperature of 300 [K], and the injection pressure and the injection quantity are 100 [MPa] and 20 [mm³] constant. Table 3 is the experimental condition.

2.4 Measurement point

The experiments were carried out at 16 points beforehand. The distance, Z, from the nozzle outlet was selected 30 [mm], 50 [mm], 70 [mm] and 80 [mm]. The radial distance, r, from the spray axis was 0 [mm], 3 [mm], 6 [mm] and 9 [mm]. The fuel was injected during 4.0 [s] and the number of injection was 75 times.

3. DEFINITION OF EXPERIMENTAL RESULT

Figure 3 shows one of the results at the location mentioned above. The injection pressure \( p_{inj} \) is 100 [MPa], injection amount \( Q_{inj} \) is 20 [mm³], the ambient density \( \rho_a \) is 39.5 [kg/m³] and the injection period, \( t_{inj} \), is 1.66 [ms], respectively. The time, \( t \), from the injection start is equal to 2.49 [ms]. The empty round symbol means no problem in the measurement. The solid triangle means that the mean number of droplets detected is below 2 during 0.1 [ms], in other words, the number of droplets is below 150 during one time experiment. The cross symbol means that no count period appears during one time experiment because the attenuation of the scattering light occurs and non spherical droplets generates due to the high velocity of droplets and much droplets density at the measuring location. The asterisk means that the location is not suitable for measurement since the number of droplets passing through the location becomes smaller. The location of the asterisk locates mainly at the spray periphery.

4. EXPERIMENTAL RESULT AND DISCUSSION

4.1 Trend at spray axis

Figure 4 shows the result at the spray axis. The ordinate is the count number of droplets at every 0.1 [ms]. The case (a), that is, the case of the axial distance, Z, equal
to 30 [mm] shows that there is no count number about from 1.5 [ms] to 2.5 [ms]. Also the case (b) of Z = 50 [mm] indicates the droplets were not counted from 1.8 [ms] to 2.6 [ms]. The reason of trends is why the region where the number of droplets is much large in the unit volume and their velocity is much faster passing through the unit volume and the liquid phase is dominant goes across both locations. As the location goes father from the nozzle exit the atomization progresses, the droplets velocity becomes slower due to their momentum loss, the vortex with large scale becomes notable [5], as a result, the spray becomes leaner and the number of non spherical droplet reduces, thus, it is easy to obtain the information of droplets by PDA. The velocity at the axial distance, Z, equal to 30 [mm] where is near the boundary between the initial part and the mixing part [1].

4.2 Trend in radial direction

Figure 5 is the result in the radial direction at the axial distance, Z, equal to 50 [mm]. The other condition is the same as that of the case of Figure 4. There is no count in the case at the spray axis about at the time, t, 2.5 [ms] from the start of injection. As the location goes father goes from the spray axis the period of no count is not found. At the radial distance, r, equal to 9 [mm], in other words, at near the spray periphery and/or at the mixing flow region [2] the number of droplets becomes small and their velocity becomes slower. The reason of this tendency is as same as that in the case of the trend at the spray axis. Generally speaking, the farther the measuring location from the spray axis is, the slower the velocity is.

4.3 Effects of injection quantity

Figure 6 summarizes the result of the effect of the injection quantity, Q_{inj}, in other words, that of the injection duration, t_{inj}. The time, t, from the injection start is 0.80, 1.32, 1.77, and 2.49 [ms], respectively. The location where the capability of measurement is little shown by the symbol of solid triangle and that of cross appears near the spray axis. Their probability appears becomes large as the increase in the injection quantity due to the reason mentioned above. However, it is able to detect the information of PDPA at all the location inside the spray envelope and its surroundings.

4.4 Effects of injection pressure

Figure 8 is the effect of the injection pressure on the measuring against the injection pressure, p_{inj}. The ambient density, \rho_a, is 39.5 [kg/m^3] and the injection quantity, Q_{inj}, is 20 [mm^3], respectively. The time, t, from the start of injection is 2.49 [ms]. The symbol of the cross appears to 50 [mm] at the spray axis despite of the injection pressure. The symbol of the solid triangle is found to 50 [mm] at the radial distance, r, equal to 3 [mm] in spite of the injection pressure, and to 70 [mm] at the spray axis in the case of the injection pressure equal to 100 [MPa] and 120 [MPa]. The latter tendency is caused by the increase in the velocity of droplets.

![Figure 4](image-url) Temporal distribution of count number of droplets and their velocity at spray axis

![Figure 5](image-url) Temporal distribution of count number of droplets and their velocity in radial direction

\begin{align*}
p_{inj} &= 100 [MPa], \quad \rho_a = 39.5 [kg/m^3], \\
Q_{inj} &= 20 [mm^3], \\
t_{inj} &= 1.66 [ms], \\
r &= 0 [mm] \\
Z &= 80 [mm] \\
\end{align*}
Figure 9 shows the temporal distribution of the counter number of droplets and their velocity as a function of the injection pressure at the spray axis. When the injection pressure is over 100 [MPa] the count number of droplets is the minimum about at 2.5 [ms] due to the pass of the region of the high droplets density. The maximum velocity becomes faster as the increase in the injection pressure.

4.5 Effects of ambient density

Figure 10 displays the measuring capability against the ambient density at the time, \( t \), of 2.49 [ms] after the injection start. The injection pressure, \( p_{inj} \), is 100 [MPa] and the injection quantity, \( Q_{inj} \), is 20 [mm\(^3\)], respectively. It is found in the case of the ambient density, \( \rho_a \), equal to 1.17 [kg/m\(^3\)] that the no count of droplets shown by the cross appears at all the location measured at the spray axis. The symbol of the solid triangle appears at all the location at the radial distance, \( r \), of 3 [mm] and does at the axial distance, \( Z \), of 50 [mm], 70 [mm] and 80 [mm] at the radial distance of 6 [mm]. In the other case of \( \rho_a \) equal to 18.6 [kg/m\(^3\)] and 39.5 [kg/m\(^3\)] the capability of measurement is the same in each other out of the case of \( r = 3 \) [mm] and \( Z = 70 \) [mm]. The reason of the tendency mentioned above is why the spray tip penetration increases as the decrease in the ambient density. The droplets velocity is over the limit of the measurement system even at the axial distance, \( Z \), of 70 [mm] on the spray axis at about 2.0 [ms] when the ambient density is the lowest of 1.17 [kg/m\(^3\)] as shown in Figure 12.
The reason of the trend is why the velocity of droplets is too fast to measure due to the low ambient density.

5. CONCLUSION

The main conclusions are as follows:

1. There is the limit to measure the information of droplets existing in a diesel spray by means of PDA.
2. It is capable of detecting surely the information of droplets flowing at the periphery where droplets number density is small and their velocity is slow.
3. The capability to detect the information of droplets or not just depends on the structure of diesel spray itself which is affected by the injection pressure and the ambient density.

6. ACKNOWLEDGEMENTS

The experimental work were carried out in the Energy Conversion Research Center of Doshisha University which has been supported by Academic Frontier’ Project for Private Universities: matching fund subsidy from The Ministry of Education, Culture, Sports, Science and Technology, 2003-2007. A part of this work was supported by Grant-in-Aid for Scientific Research (C). No. 148560213, of Japan Society for the Promotion of Science.

The authors thank Mr. M. Matsumoto (DANTEC DYNAMICS K.K.) who lend them a part of experimental setup.

9. REFERENCES