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Research Article

Combined Laser Doppler Anemometer and Phase Doppler Anemometer System for Thermofluids Research at Ambrose Alli University, Ekpoma

Imaekhai Lawrence

Email: oboscos@yahoo.com

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Abstract

The thermofluids group laboratory of Ambrose Alli University (AAU) owns and operates a few high-end equipment in support of research and educational activities. The latest addition to the laboratory facility is the combined three-dimensional Lasler Doppler Anemometer (LDA) and Phase Doppler Anemometer (PDA) systems. The PDA system is capable of measuring diameter and concentration of spray droplets, while the LDA systems can measure droplet velocity for both temporal and spatial averages. The acquired system, which is supplied by Dantec Dynamics, is a non-intrusive measurement method with the ability to measure spray droplet velocities in three components. Thus, the system is the first of its kind used in Nigeria. With this high-end and state-of-the-art facility, UTP is ready to contribute towards technology development in various thermo fluids research in Nigeria, namely, in internal combustion, fluid dynamics, spray painting and chemical processes. This paper outlines the current research activities involving the use of 3-DLDA-PDA system, its functions, testing capabilities, and general characteristics, as well as an overview of the system.

Key word: Lasler doppler anemometer (LDA), phase doppler anemometer (PDA), research, internal combustion, fluid dynamics.

INTRODUCTION

The thermofluids research programs at UTP (Universities Technological Program) involves several areas of research where the studies of fluid and spray flow behavior are complicated, thus, this requires special measurement equipment. The research areas include the internal combustion Testing, Sprays studies and Wind Tunnel Testing. In these research areas, the measurement of fluid flow velocity is crucial and in some areas there is a need to study the spray droplet size and concentration. Therefore, it has been identified that a 3-D Combined Phase Doppler Anemometer (PDA) and Laser Doppler Anemometer (LDA) System is one of important equipment for the research in thermo fluids at UTP. The LDA system is laser-based equipment capable of measuring fluid velocity as well as the velocity of a flowing droplet or particle. The PDA system, which uses almost the same principles of operation as the LAD system, measures the droplet or particle size and concentration. The combination of these systems is referred to as the LDA-PDA system, which is able to measure velocity or droplet size, or both at the same time.

In an internal combustion system, droplet size and flow characterizes of the injected fuel can be varied through the design of the injector nozzle for better efficiency and reduced exhaust emission. In the past, the spray investigations were generically made using a rapid cinematography technique (Bates, 1992). However, the use of the LDA-PDA system enables quantification of the droplet properties to be more accurate and achieved in a very quick time. With three-dimensional LDA capabilities, the measurement could be carried out for all the three velocity components, thus enabling the detail study of turbulence in a combustion chamber. The PDA part of the system is very useful for the study of fuel evaporation behavior, as it could measure particle size, volume concentration is crucial as it determines the rate of fuel burning. Large droplets, for instance, is more difficult to burn and could also produce unburned hydrocarbon. Hence the LDA-PDA system capabilities could be extended to study the rate of atomization when using injection system.

In wind tunnel testing, before the emergence of laser-based equipment like the LDA system, velocity measurements in wind tunnels were carried out using the Pitot-static tube or hot-wire anemometer. Nevertheless, there are many disadvantages in using these types of measuring system since these equipments are of intrusive type. This means their sensors have to be placed in the flow field. The result of placing the sensors in the flow filed is the disturbance to the flow, which will alter flow properties. In addition, these devices require penetrations to be made through the walls of the wind tunnel test section. The number of penetration holes for this purpose is limited in order to assure that the test section of the wind tunnel is always airtight. As a result, the number of point measurement that can be made using these devices is limited. The pitot–static tube is inferior as it can only measure the total velocity, instead of components of velocity. Another disadvantage of the pitot-static tube and hot-wire anemometer, is that both of them are unable to detect reverse or backward flow (Yule, 1998), which is crucial in the study of flow behavior in wind tunnels. As for the hot- wire anemometer, the thin wire at its sensor is very delicate and it can break after a period of operation time in the wind tunnel, although it is capable of measuring up to three components of velocity. These weaknesses can be overcome by using the LDA-PDP system, which is a non-intrusive type measuring device, where no sensor or instrument penetration is required in the flow field, except for laser beams. Therefore, measurements can be made almost anywhere in the test section of the wind tunnel. However, only the LAD part of the system is normally required because wind tunnel testing is usually meant for the study of confined- flow behavior or for aerodynamic testing. Similarly, measurement can also be made for water tunnel testing.

Since commissioned at UTP in October 2002 the LDA-PDP system, which was supplied by Dantec Dynamics, has been operational to serve various research needs in the thermo fluids area. This paper provides an overview of the LDA-PDA system including its testing capabilities and general characteristics.

METHODOLOGY

Principle of operation

Measurement using LDA-PDA system requires the intersection of two collimated laser beams, which produces a fringe pattern or also known as the measuring volume. The measuring volume is actually an interference pattern consisting of light and dark fringes. Measurement occurs when a spherical droplet or particle passes through the fringe pattern. For LDA measurement of velocity, when a particle traverses the fringes, it is alternately illuminated by high and low light intensities. As a result, the scattered laser light frequency is shifted, with respect to the incident beam. The particle velocity, U is proportional to the frequency shift, f_D:

$$U = f_{D.}\, \Delta f \quad (1)$$

For which the fringe spacing, Δf is,

$$\Delta f = \lambda / (2 \sin \theta) \quad (2)$$

Where λ is the wavelength of the incident light beam, and θ is the half angle of the intersecting laser beams.

The basic configuration of the beams for the LDA-PDA measurements is illustrated in Figure 1. To produce the laser beam, a laser source is required. The LDA-PDA system at UTP uses a 5 W Argon-ion laser. The transmitting optics, which comprises of lenses and aligning mechanism, prepares the laser by splitting the source beam into two identical beams. Through the transmitting probe, the two beams are crossed and focused to produce the measurement volume. The scattered light, which is frequency-shifted, is collected by the receiver probe and sent to the photo detector, which is a transducer that converts the receiving light power into a current pulse signal (Becker et al., 1999). The signal processor converts the signal into an output voltage that is proportional to the particle velocity. For three velocity component measurements, three measuring volumes must be prepared therefore the number of transmitter and receiver detector must also be tripled.

For PDA measurement, the operation is almost similar to the one of LDA measurement. However in PDA the signals are used to measure the particle or droplet diameter, since they are linearly related when the receiver probe is

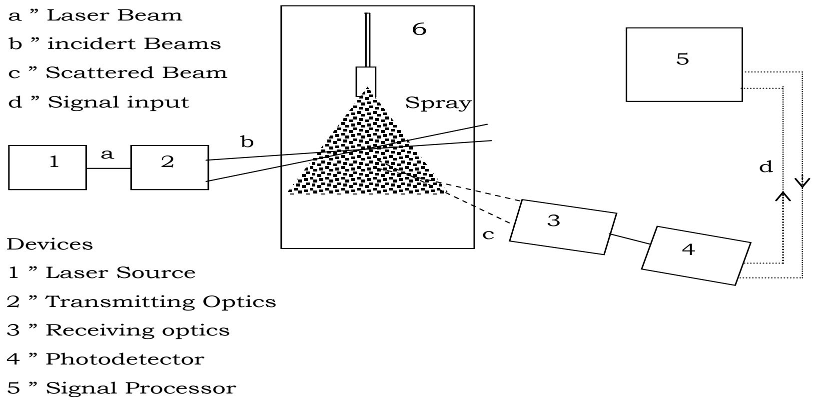

Figure 1. Basic configuration of LDA-PDA system.

positioned such that one light scattering mode dominates. The useful relationship between the droplet diameter and signal phase-sift, which enables the measurement of droplet diameter.

Because of the similarity in operation, both LDA and PDA measurements can be combined and performed simultaneously, thus allowing useful study of diameter-velocity relation in various researches. The LDA-PDA system installed in UTP is an integrated type for simultaneous measurements of diameter and velocities. The first probe comprises of two transmitters, which are built-in together for the light beams that measure the first and second velocity component. The second probe produces another measuring volume for the measurement of the third velocity component. The third probe is the receiving probe, which has all the receiving optics and photo detectors built-in together for velocities and size measurement. These signals are then sent to processor for conversion into understandable information that can be monitored in the computer software, which is supplied together with the systems. The software called BSA Flow is used to display results and to configure hardware settings for measurement control that suits the user’s requirement. The post-processing results include histograms, time-series plots, size-velocity correlation, etc. For particle size measurement, the presentation can be made using user defined size classes, for example, Sauter-Mean-Diameter (SMD).

A traversing system made of aluminum frames, which is also installed together with the LDA-PDA system, provides a mechanism for the mapping of proprieties of a given spray or particle flow, namely particle concentration or mass flux. With the availability of the traversing system, the transmitting and receiving probes can be mounted on the same frame to allow them to be shifted together. This means that the fringe pattern or measuring volume can be displaced anywhere in the x, y and z directions, thus allowing measurements to be made anywhere in a given space volume. The displacement increment can be low as 6.25 µ. The operation of the traversing unit may be controlled automatically or manually from the computer, thus making the measurement job very smooth and reliable.

System capabilities and advantages

Measurement using LDA-PDA system is a statistical measurement control technique. It is been agreed that single or double measurement is no longer conclusive for measurement of particle diameter (Svarovsky, 2000) as well as its velocity. Therefore statistical techniques can be used to evaluate precision and accuracy, which keeps the data measurement under statistical control. In this sense, large amounts of droplet population are collected, each measurement point in a short amount of time. The LDA-PDA system is also an online-measurement that allows a user to immediately monitor and evaluate the measurement data, thus minimizing the experiment time. The system is able to measure particle diameter of between 0.5 µ to several millimeters, and handle velocity measurement at a rate of up to 1440 m/s. In measuring velocity, the LDA –PDA system is also capable of detecting reversing flow, which is one of the outstanding features of the system. Another important advantage of the LDA-PDA system is the very high spatial and temporal resolution it offers, which makes an experiment more reliable and flexible. The high accuracy of the LDA-PDA system depends on a few basic parameters determined by the optical configuration and the principle of signal processing. The important parameters include the particle transmit time, number of optical interference fringes within the measuring volume and the processor bandwidth (Buchave, 1984). With good alignment, the accuracy of as low as one percent, while for the PDA the tolerance can reach around three percent (Rheims et al., 1999).

Among the important applications of the LDA-PDA system for UTP thermo fluids research are in the study of internal combustion (IC) engine and in wind tunnel testing. These are particularly due to the non-intrusive characteristic of the LDA-PDA measurement, which means no device or sensors are required to be in the flow region. The use of LDA measurement in internal combustion studies has probably started as early as in 1979 (Rask, 1979); and probably in 1988 (Saffman et al., 1988) for LDA-PDA. Previously velocity measurement were carried out using hot-wire anemometer, for instance in the work by Horvatin and Hussmann (Horvatin et al., 1969), where a few disadvantages were observed. In internal combustion chambers, LDA-PDA measurement have been made possible with the use of single cylinder optical access engine, as carry out in many previous and current works (Bates 2002; Pitcher et al., 1989; Brun et al., 1994). The engine is integrated with transparent sections made of quartz that allows penetration of laser beam, thus enabling the LDA and PDA measurements of the fuel spray. The 3-DLDA and PDA system at UTP can be connected with an engine system using an encoder to synchronize the measurement with the crank angle of the engine piston. Therefore the data acquisition can be set within a required portion of the engine cycle. With this feature the result can be presented in a more meaningful manner, for example by having velocity or droplet size versus crank-angle distribution profile.

In wind tunnel testing, only the LDA part of the system is required because normally the subject of study is only air, or water in the case of water tunnel. However, because a spherical particle or droplet must cross the fringe pattern or the measuring volume, artificial seeding is introduced in the flow to enable fluid velocity measurement the fluid velocity. Usually non-toxic smoke is used in wind tunnel testing; however the choice of suitable seeding particle depends

Table 1. Seeding particles used in LAD-PDA applications.

Type	Name	Material	Mean diameter, (μm)	Application
PSP	Polyamide Particles	Polyamide 12	5,20,50	Water flow
HGS	Hollow Glass Spheres	Borosilicate Glass	10	Liquid flow
S-HGS	Silver Coated HGS	Borosilicate glass	10	Liquid flow, with increased reflectivity
FPP	Fluorescent Polymer particles	Melamine resin based polymer	10, 30, 75	Applications with high background light level

specifically on the type of application (Saffman et al., 1988). Table 1 shows the list of some seeding particles and their applications. LDA system has been used extensively for wind tunnel testing although hot-wire anemometer and Pitot-static tube are still in use in some relatively simpler measurements. Some of the examples of research that use LDA for wind tunnel testing can be found in (Geropp et al. (2000) and Becker et al. (1999). Among the distinguished capabilities that LDA could perform are three dimensional boundary layer, separation and wakes measurements. If only velocity is to be measured, the PDA receiver probe can be deactivated so that the backscatter mode may be used for better data acquisition rate and simplicity.

The use of the acquired LDA-PDA system is not limited only to Automotive IC engines and Wind Tunnel Testing. There are various other applications where this measurement system could contribute to research works, among others include spray forming, spray painting, agriculture sprays, gas turbine fuel injection and pharmaceutical sprays, where in each of these areas there are always opportunity for improvement in terms of efficiency and cost through the optimization of sprays.

CURRENT RESEARCH ACTIVITIES

An experiment was conducted using water sprays produced using an air gun at UTP laboratory to demonstrate the application of LDA-PDA system. The purpose of this experiment was to experiment the measurement capability of the LDA-PDA system while studying the spray and flow behavior by using an air gun. At the same time, this experiment also serves as a learning platform for all new users at UTP in understanding the basic functions and problems in the operation of the equipment, before venturing into more complicated studies. The experiment setup is shown in Figure 2. Water sprays were produced consistently using the air gun, which was connected to a 2-hp air compressor. Water was fed into the spray discharge nozzle, while air pressure was regulated at a constant pressure of 0.4 bar gauge. Two pairs of laser beams were transmitted from the transmitting probe which was installed at an angle of 30° from the main axis. This configuration was set for two velocity-components together with droplet diameter measurement.

Thirty sets of measurements at 2 mm increments were taken along the horizontal axis located at 100 mm below the nozzle outlet on the middle plane of the spray cone. This was done by shifting the measurement volume using the traversing unit control after each measurement. The measurements at each location were taken for 10 s or 5000 data counts, whichever came first. A sample data set for one location indicating the frequencies for the droplet size measurements is shown in Figure 3. The average values were also calculated for all the 30 locations. From these

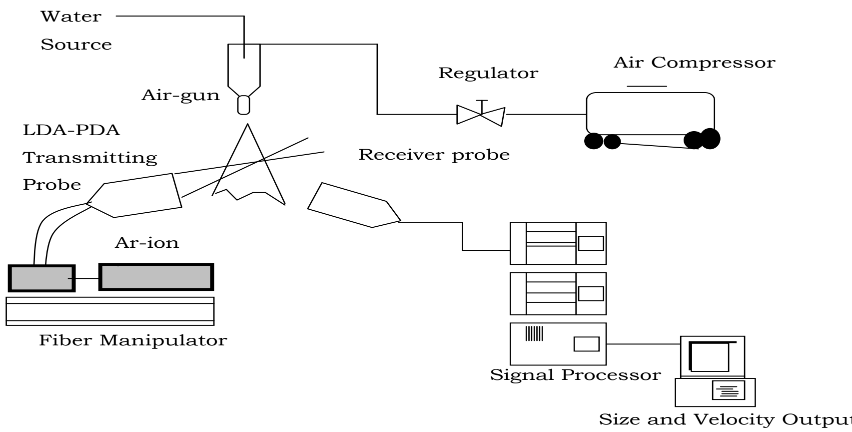

Figure 2. Experimental setup.

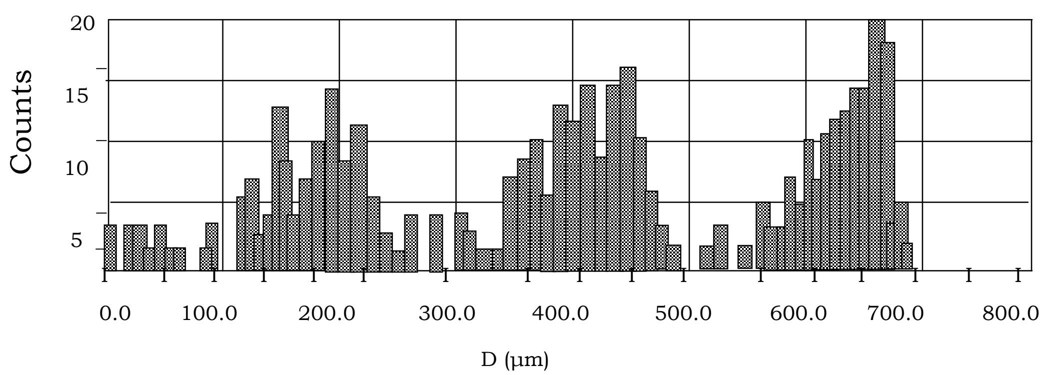

Figure 3. Sample droplet size measurements at one location.

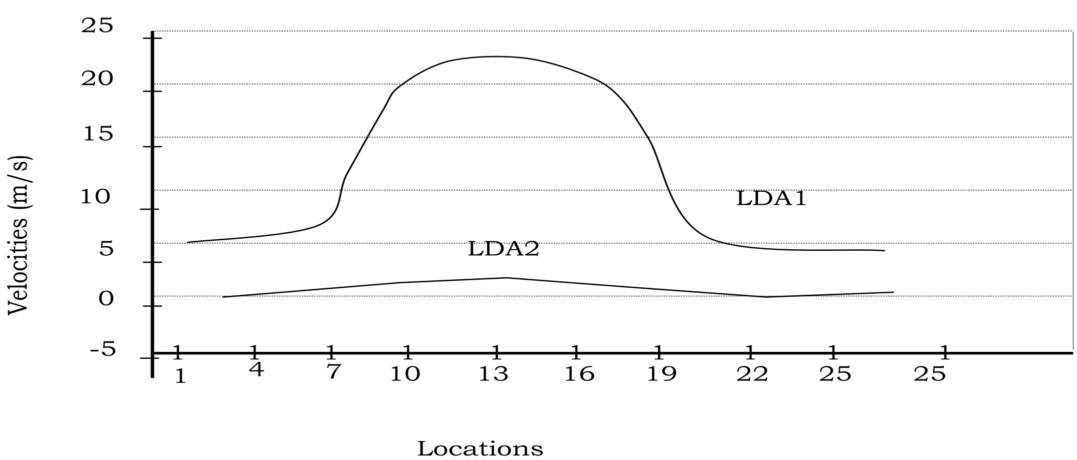

Figure 4. Velocity profile plots.

average data, the velocity profiles are plotted as shown in Figure 4. The experimental data presented in this research was selected to demonstrate the palatability of the diagnostic techniques for the LDA-PDA system to study spray characteristics.

Further research activities using the experimental setup are progressing. This includes, among others, the study of turbulence and fuel droplet behavior in internal combustion engine.

CONCLUSION

The UTP's combined 3-dimenisonal Laser Doppler Anemometer (LDA) and Phase Doppler Anemometer (PDA) system which is the first of its kind in Nigeria. The LDA-PDA system has the capability to measure fluid or spray flow properties. The LDA part can measure three velocity components of moving fluid, while the PDA is used to measure the size and concentration of flowing droplet or particle. The combination of LDA and PDA provides a very useful measurement tool for flow cases that are complicated to quantify, like in the combustion chamber of an automobile engine, which is the main purpose of its existence in UTP. The diagnostic techniques of the LDA-PDA system described here can be used to study combustion chamber geometry, flows at inlets and spray interactions to allow combustion systems to be selected and optimized. In the research of direct injection combustion, the LDA-PDA system has become the essential tool to obtain high quality data of the injector characteristics with different parameters of pressure, temperature and timing. In addition, the system has a wide range of application in other research, which includes wind tunnel testing, spray forming of metals, and fundamental spray studies. Besides high temporal and spatial resolution capability, measurement using the LDA-PDA system gives high accuracy. With this advanced technology measurement facility, UTP will contribute towards technology development in thermofluids research in Nigeria.

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