FE-15601
Topical Report 9

**LASER DOPPLER VELOCIMETER
PARTICLE VELOCITY MEASUREMENT SYSTEM**

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Prepared For The
U.S. Department of Energy
Contract No. DE AC02-80ET-15601

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ABSTRACT

This report gives a detailed description of the operation of the Laser Doppler Velocimeter (LDV) system maintained by DIAL at MSU. LDV is used for the measurement of flow velocities and turbulence levels in various fluid flow settings. This report details the operation and maintenance of the LDV system and provides a first-time user with pertinent information regarding the system's setup for a particular application. Particular attention has been given to the use of the Doppler signal analyzer (DSA) and the burst spectrum analyzer (BSA) signal processors and data analysis.

INTRODUCTION

The purpose of the report is to give the reader a reasonably complete description of the Laser Doppler Velocimeter (LDV) system developed for field use by the Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University (MSU).

PROJECT HISTORY AND OBJECTIVES

History

The development program for magnetohydrodynamics (MHD) is a phased sequence of projects and facilities, having as a goal the demonstration of the practicality and commercial viability of MHD for electric power generation in this country. This method of direct energy conversion will use our vast coal resources to generate electricity at highly attractive efficiencies in an environmentally acceptable manner.

The early MHD research and development work (1965-1975) was mainly concerned with evaluating the performance of MHD channels. Additional research and development efforts were initiated on advanced channel designs, channel insulator and electrode materials, combustors, and superconducting magnets. It has only been in recent years that some attention could be focused on the downstream portion of the plant.

In April of 1976, an interdisciplinary group of MSU engineering faculty members initiated a project entitled "Testing and Evaluation of MHD Materials and Substructures" sponsored by the Department of Energy from 1976 to March of 1980. As a part of this research project, Mississippi State University constructed a test stand for simulation of the gas-slag-seed stream and the thermal conditions that will exist in various substructures of the coal-fired baseline MHD power plant. This test stand is used for a variety of MHD engineering studies, as well as to evaluate and debug various diagnostic instrumentation systems that are being developed for use in characterizing MHD system parameters.

The Department of Energy initiated the design and construction of the Heat Recovery/Seed Recovery system (HRSR) for use in studying the operation of downstream MHD components and the various slagging, fouling, and corrosion/erosion processes that occur in these components. The operation of these facilities will eventually lead to the design, construction, and operation of a commercial demonstration facility in the late 1990's.

Objectives

Diagnostic and special instrumentation beyond what is normally required for appropriate control and operation of an electrical power production facility is required for a magnetohydrodynamic (MHD) power system. The DOE coal-fired MHD proof-of-concept program will serve as the precursor to larger-scale demonstration facilities and commercially implemented plants. In order that the transition to commercially feasible plant designs be made as quickly and effectively as possible, it is essential to determine as much as possible about the detailed component operation of the MHD power train and the HRSR system.

Conventional diagnostic sensors are of limited use in characterizing the MHD gas stream, and special diagnostic instrumentation systems are needed to monitor and collect engineering data that will determine specific parameters, both baseline values and fluctuations, and provide background information for continuing MHD development, solutions to technological barriers, and a basis for future plant designs. The accurate characterization of the thermal, chemical, and flow properties is essential for future design optimization.

The scale-up process is a nonlinear extrapolation because many of the physical processes are nonlinear. To decrease the uncertainties in this nonlinear extrapolation to a new, larger design, it is necessary to rely not only on engineering experience with smaller systems, but also on mathematical models which describe the physical processes and their behaviors as design variables are changed. Mathematical models require the input of

detailed data; the greater the quantity and quality of data, the more accurate the model and smaller the uncertainty in the extrapolation to larger designs.

The baseline data obtained by diagnostic measurements at the Component Development and Integration Facility (CDIF) and the Coal-Fired Flow Facility (CFFF) are providing important engineering experience and data for developing appropriate analytical models. Tests of these models, as well as information to further develop these design models, will be provided by diagnostic measurements on these facilities. These measurements are essential in minimizing the technological risks associated with the ultimate construction of a retrofit MHD facility or a commercial MHD power plant.

Measurements of selected parameters, coupled with empirical correlations or an accurate model, can contribute significantly to improved control strategies and the selection of control instrumentation. The direct measurement of a particularly useful parameter for system control may be very difficult, if not impossible. However, another parameter that can be correlated to the parameter of interest may be much easier to measure. The application of advanced instrumentation promises to produce fundamental advances in this area. This type of information will be very important in the selection of control instrumentation for a commercial MHD power plant.

MHD flows represent possibly the most severe environment encountered by gasdynamic diagnostics; special state-of-the-art techniques and instrumentation systems are required to monitor and collect data for MHD component systems. Additionally, these systems are operating under severe environmental and magnetic-field conditions. The Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University is developing and applying advanced optical diagnostic techniques and instrumentation systems that provide nonintrusive, remote, real-time measurements and that are designed to operate successfully in the industrial-like environment of large-scale facilities. Such diag-

nostic instrumentation can provide the information required to more clearly characterize the various processes involved in the ash/seed-laden gas stream of the coal-fired MHD flow.

NEED FOR THE INSTRUMENT

One of the most important parameters for determining the properties of a combusting system is mass flow at various spatial locations within the experimental train. Estimates of the flow velocities are often made directly by intrusive measurements (Pitot tube) or indirectly by model calculations. A more sophisticated, nonintrusive method for obtaining velocity information makes use of laser scattering technology. One version of this method, called laser Doppler velocimetry (LDV), has become widely recognized as the premier tool for studying fluid flow phenomena. The LDV method is especially well-suited for the harsh MHD environment where high velocities, extremely high temperatures, magnetic fields, and hard-to-reach measurement locations are common. Indeed, there is presently no other analytical tool that can as accurately and completely characterize such flows in a nonintrusive manner as can the LDV system. In fact, it is often the only way that reliable experimental estimates of the flow velocities and turbulence can be obtained.

PERFORMANCE CAPABILITIES

The MSU LDV system has the following performance capabilities:

- a) Portable.
- b) Remote control of measurements at distances of up to 30 m from control site.
- c) Backscatter and forward scatter measurements possible.
- d) One velocity component measured at a time. The other component obtained by rotation of optics at measurement site.
- e) Particle velocities measurement range from 0 to 1000+ m/s.
- f) Minimum particle size needed for backscatter measurements about 0.5 μm .
- g) Velocity profiles automatically obtained by traverse mechanism.
- h) On-site velocity histograms produced.

TECHNICAL APPROACH - PHYSICAL/SCIENTIFIC PRINCIPLES

Laser Doppler velocimetry measures the velocity of small, scattering centers in a fluid by detecting the Doppler shift in the scattered laser light. This is usually accomplished by crossing two focused laser beams to form an interference pattern. When a particle traverses these interference fringes, it scatters light. By the collection and detection of the scattered light, one can measure the frequency of the Doppler burst and use that frequency which is then used to determine the velocity of the particle.

Consider a particle moving with a velocity U and irradiated by a laser light of frequency f_0 and wavelength λ . Figure 1 shows a dual beam fringe system for LDV in which the Doppler frequency is given by the equation

$$f_D = \frac{U}{\lambda} (\hat{S}_1 - \hat{S}_2) \quad (1)$$

where f_D is the Doppler frequency and $\hat{S}_1$ and $\hat{S}_2$ give the directions of propagation of the incident beams.

Since $\hat{S}_1 - \hat{S}_2 = 2 \sin \kappa$ and $U_x = U \cos \alpha$, Equation 1 becomes

$$f_D = \frac{2U_x \sin \kappa}{\lambda} \quad (2)$$

where U_x is the velocity component along the x-axis and α is the angle between the velocity vector U and x-component of velocity. The measurement volume is defined as the region where the intensity is e^{-2} of the intensity on the bisect axis of the two beams.

Figure 1. Dual beam detection system for LDV.

The measurement volume can be determined directly from the beam width at the crossing point as long as the cross angle remains constant. The size of the measurement volume can be calculated using the following equation:

$$d_m = \frac{4\lambda f}{\pi D_{e-2} E} \quad (3)$$

where d_m is the diameter of the measurement volume, D_{e-2} is the diameter of the laser beam entering the cell, f is the focal length of the focusing lens, and E is the beam expansion ratio. The length of the measurement volume (l_m) is related to the diameter of the measurement volume (d_m) as follows:

$$l_m = \frac{d_{r,i}}{\tan \kappa} \quad (4)$$

The relationships between fringe spacing (d_F), Doppler shifted frequency and the perpen-

dicular component of the velocity of the particle are given by the following equations:

$$d_F = \frac{\lambda}{2 \sin \kappa} \quad (5)$$

Combining equations (2) and (5) we can write the equation for the Doppler frequency as follows:

$$f_D = \frac{U_x}{d_F} \quad (6)$$

The number of fringes (N) in the measuring volume is given by:

$$N = \frac{d_m}{d_F} \quad (7)$$

LDV SYSTEM DESCRIPTION

DIAL's LDV System consists of three parts: the Laser System, the Optics System, and the Data Collection and Processing System. Operation of each of the systems is described below.

Laser System

Consists of: a laser head Coherent 5-watt Argon Ion
a power supply Laser System (Class IV)
two 50-foot standard garden water hoses,
a pump with water filter and pressure gauges,
and two accessory kits and laser instruction manual.

1. See that eight positioning/adjustment screws (1/8" dia.) in the laser head are loose before turning on or hooking up the laser. If not, remove the laser cover using a 1/8" Allen or Hex key (or ball driver) to loosen the screws and replace the cover. (These screws are usually secured before transporting the laser.)
2. Connect the laser head to its power-supply and hoses contained in the umbilical. (If in doubt, refer to the instruction manual.) Connect the water hoses between the source and power supply through the water filter/pump. Connect the drain hose and run it to a nearby drain. Keep the hoses where they won't be stepped on. (If the hoses are stepped on, the laser trips off automatically because of water flow interruption.) Check for water leaks. Water pressure should be between 30-50 psig. (i.e. a minimum 25 gals/min water flow through a standard garden hose.) Check this on the downstream side pressure gauge of the filter. If the upstream side pressure gauge shows

the correct pressure, but the downstream one does not, replace the water filter. Connect the laser control unit to the back of the power supply.

3. Check the 3-phase power supply voltages. [208V between lines, 120 between ground and line—the odd pin (vertical with a green wire) is the ground or earth.] The 3-phase source should supply at least 45 amps. Make sure of these requirements (including proper water supply above) from the facility authorities.
4. Plug the power supply to the 3-phase source. Refer to the manual for laser turn-on procedure. (Make sure the laser beam does not hit anyone's eyes). Block all stray reflections. Have the 'LASER CAUTION' board nearby. If needed, place a metal block in front of the laser beam. Otherwise, the beam may burn holes in plastic parts. Set the laser aperture to '12.' Check the power on the laser control meter. If the power is low, or the laser is not lasing at all, refer to the instruction manual. The laser may need its optics cleaned or its tube realigned. If operating with prism (at the rear end of the laser) on green line (514.5 nm), the laser power should be nearly 2 watts at 40 amps. If everything is satisfactory, set laser power to a low value, about 50 mw or less for LDV optics alignment purposes.

Optics System

Optics at laser side[†]

1. Turn the laser beam through 180° using the two mirrors inside the black box at one end of the laser table (or base). Use two alignment blocks—one near and another at a far distance on the base—to get the beam in line at the

[†]. You may want to use a neutral density filter in front of the laser before you start the alignment. Also, you may refer to TSI manuals for LDV optics alignment procedure.

required position on the optics mounting plate. (Beam should be passing through the two center holes in the level blocks.)

2. Mount the beam splitter (for green) on the plate so that the beam splits into two beams of nearly equal intensity 50 mm apart. Check that the beams pass through the 50 mm holes on the two level blocks. Make the necessary adjustments. (You may want to take out the nearby level block now).
3. Mount the Bragg cell next to the beam splitter. Connect it to its driver (frequency shifter) through the yellow triaxial cable. (Refer to the TSI manual of operation of the Bragg cell and frequency shifter.) Let the shifted beam be towards you. (You can rotate the Bragg cell unit in and out of the beam. This is useful when you don't want to shift the beam but want this unit in place.)
4. Next mount the dummy tube (about 10" long). This maintains well-separated, shifted beams.
5. Mount the beam stop unit. Adjust the two screws on the Bragg cell (refer to the TSI manual) so that the shifted beam (the beam with the highest intensity) passes through the 50 mm hole in the level block. (The other beam remains undisturbed.) Adjust the beam stop to allow only the beam you want.
6. Mount the (fiber) translator unit. See that the laser beams are coming out 50 mm apart (use the alignment mask or the block).
7. Mount the fiber input coupler next to the translator. Attach the fibers. Mark the fiber receiving the shifted beam. (Handle fibers carefully! They are 30 m long. Leave the caps on the fiber connectors when not in use.)
8. Place the unattached ends of the fibers on a flat base. Put a white card or screen in front of the fiber ends.

9. Adjust Z-X-Y screws (in z-x-y order) on the input coupler for each of the beams until you get the highest intensity possible through each fiber (refer to the fiber manual). Use only 50 mW (or less) of laser power during these adjustments. The intensities of the beams through each fiber should be about the same. You will reach a stage when you can no longer improve the power/intensity through the fibers. (The present fibers have only about 25-30% transmission.) You can set the laser power to whatever value you want. You may want to use a laser power meter to do some fine tweaking on each of the fibers.
10. When done, replace protective fiber end caps.

Optics at port side

(Backscatter Alignment)

1. Measure the window to window (or wall to wall) distance on the test section and record it. Note the window thickness and the center line distance; these data will be helpful in selecting the focal length of the lens you want in your setup and in making velocity profile measurements. Note the type of window (its material, etc.) you are going to use.
2. See that the proper rails are mounted below the ports at required heights—usually about 9" from top of the rail to the center of the window/port. (Present LDV optical axis height is about 9".) If long rails are used, support the end of the rail suitably.
3. Present LDV optics are mounted on a traverse system. Before mounting the system on the rail, basic alignment of the LDV optics is done at a convenient place on the ground near the port site. First, mount the fiber output coupler at the rear of the traverse frame. Carefully route the fiber optics

cable from the laser site to port site and avoid any damage to the fiber. Don't bend the fiber too much (minimum radius of bend ~6"). Connect the fibers next. Connect the fiber carrying the shifted beam to the side opposite the flow direction.

4. Using the alignment mask, level blocks, and the x-y adjustment knobs on the output coupler, adjust the beams to be 50 mm apart in the horizontal or vertical plane. See that the beams are travelling parallel (50 mm apart) for a distance of several feet.
5. Next, mount the receiving unit with the eye piece on it (the signal fiber will be mounted here later) and the desired beam spacer (9 mm or 22 mm) in line. The beams should emerge from the spacer at the desired beam separation.
6. Mount the beam expander next to the spacer. Center it properly. The beams should emerge from the beam expander at 'D' distance apart, where $D = \text{expansion ratio} \times \text{beam spacing}$. For example, if a 9 mm spacer and a 3.75 x beam expander are used, then $D = 3.75 \times 9 = 33.75$ mm.
7. Mount the focusing lens separately on the traverse platform in line with the beam axis.
8. Adjust the Z-knobs to get nice round beam spots, with a thin 'halo' around the spots, at the focal plane. Using the objective microscope and a white screen, adjust for 'good' crossing of the beams—slide the objective microscope in and out of the focal plane to check this. Adjust only the Y-knobs on the output coupler. Don't touch X-knobs, for they will change the beam spacing already established.
9. Measure and note the focal length; it should equal the manufacturer's specified value. If not, use the measured value in your later calculations.

10. Put a stationary scatterer (a black metal piece) at the focal point, and looking through the eye piece, adjust the lens in the receiving unit so that a sharp image is seen at the center of the cross hair. Lock the lens in place.
11. Without disturbing the lens, and taking care of the fibers, carefully place the setup on the rail to face the window. Carefully adjust the x-y-z position of the setup so that the beams pass symmetrically through the windows. Make the necessary adjustments on the traverse position to get the desired profile measurement. Preferably, you want to start from the center of the gas stream/channel. Lock the system in place. Note the position of the traverse.
12. If possible, place a stationary scatterer inside the channel at the focal plane. Have the window in place. Look through the eye piece and adjust the lens and the x-y screws on the receiving unit for a sharp image at the cross hair. Lock it.
13. Set the laser power as you would want it during the measurement (or a little less). Looking through the eye piece, identify stray reflections which might come on to the signal fiber. Avoid any bright spot or reflection in the central region of the cross hair. To block the stray light, you may have to use masking/black tape pieces on front face of the lens or the beam expander. Don't block the incident beams! Sometimes you may have to slightly offset the optical axis to avoid a reflection's affecting the signal fiber.
14. Using the manual traverse control, check the reflections for all positions of the traverse you are going to make during the profile measurements.

(Forward Scatter Alignment)

15. The preceding alignment procedure is for backscatter LDV setup. If a forward scatter experiment is to be set up, make sure a rail at the proper height

is available on the opposite port side. You need a scatterer inside the channel. (Sometimes, you can do this with the gas flowing by looking up at the crossing point of the beams.) Placing the window on both sides of the channel (test section), look through the eye piece and move the forward optics (assuming that a proper receiving/focusing lens is already mounted in front of the optics) until you find a sharp image of the crossing point. Secure the optics system in place. A slight offset with respect to the axis of the incident beams will help avoid strong bright spots or reflections affecting the signal fiber/PM tube (there is only one signal fiber, so if you are using both the back and forward scatter at the same time you have to use the PM tube at one position). At the proper holes, attach the two motors that control the x-y movement of the cross hair remotely (it is very difficult to keep the proper alignment of the cross hair on the forward scattering side during traverse). The x-y adjustments can be done inside the mobile laboratory using the remote control and watching the signal strength on the oscilloscope. Use a mask or tape to block stray light in front of the lens.

16. Connect the PM tubes to their power supplies. One of the PM tubes should be kept inside the mobile laboratory. Attach the signal fiber adapter to this PM tube and connect the signal fiber to it. Attach the PM tube/signal fiber on the backscatter and the forward scatter side. Plug the power supplies and the traverse control to standard 120 V outlets. Protect the instruments from both water and fire hazards.
17. At this stage, you can maximize the signal coming from the PM tube, which is focused on a stationary scatterer, by looking at the signal on an oscilloscope and tweaking the x-y screws on the PM tube receiving units.

Secure the PM tube position and remove the stationary scatterer. Put the windows in place and protect them from getting dirty.

18. Mark the long backscatter and forward scatter signal cable/signal fiber, remote traverse control cable, and remote x-y control cables and run them to the signal processing/computer unit inside the mobile laboratory or wherever they are situated. Route all cables carefully to avoid any damage. Check the condition of the end connectors before connecting.
19. At the port site, connect the signal cable to the PM tube, and connect the traverse control cable to the traverse power supply/control.
20. At the signal processor/computer side, connect the signal cable (the signal processor is either BSA or DSA and it takes only one input at a time) to the back of the BS. marked 'input signal' or to the receiver of the DSA marked 'signal in' (if a signal carrying no frequency shift or a 40 MHz shift is to be connected). Connect the traverse control cable to the back of the computer (parallel port, marked 'traverse'). Connect the x-y control cables for the forward scattering setup to the two, hand-held controllers.
21. If a frequency shift is used and a downmixed frequency is selected, the signal cable goes through the frequency shifter first and then continues to the BSA. Note that if (frequency shift) the Bragg cell is not used or moved out of the beam, the signal goes directly to the BSA (without going through the downmixer).

Data Collection/Processing System

Consists of:

a BSA (Burst Spectrum Analyzer) and a DSA (Doppler Signal Analyzer).

BSA system consists of:

the Burst Spectrum Analyzer, an IBM-AT compatible PC, and a Lecroy 9450A 300 MHz digital oscilloscope).

1. Read the BSA instruction manual to become familiar with the front and back control panels.
2. Read about the PC. The system disks, BSA control/data collection/analysis programs, and traverse control software are already loaded.
3. Become familiar with the oscilloscope operation (refer to manual).
4. Connect 488 cable from the BSA to the PC. Connect all power cables to a 120 V power strip. Connect the 'Doppler' output on front panel of the BSA to the oscilloscope.
5. You can also connect a printer to the PC system to get a hard copy of the graphical presentation of the LDV results or any other information.

System initial check

1. Turn on the system. The Date and time are automatically set by the PC. Check them anyway.
2. Go to the directory BSATRV. Hit RETURN.
3. Type BSAMSU. Hit RETURN. Wait for the main menu to show up on the screen.
4. Move the cursor to 'Test of Instrument' and hit RETURN. (If this results in an error message, check the 488 connections. Make sure the 488 board is

installed in the PC.) The next screen will show the cursor at 'BSA1' (in yellow color). Hit RETURN. Then the cursor will move to 'Manual' (in yellow). Use the + or - key to change this to 'Automatic.' When in automatic, hit RETURN. The system will automatically go through a systematic check of the BSA system (about 5 mins.). If o.k., all checks will turn green, except one labeled 'Data Collection.' Then the PC will ask for 'hard copy (y/n)?' Type 'n'; hit RETURN. Go to the main menu by hitting the 'F9' key. The instrument check is over.

Traverse movement check

1. Go to the main menu and move the cursor to 'Traverse' and hit RETURN.
2. Make sure the traverse connections are o.k. Ask someone to check the traverse movement at the port site when you are ready.
3. You can select either 'move forward' or 'move backward' by moving the cursor. Give the number of inches to move.
4. After checking the traverse, bring it back to the original position set during alignment (or your starting position of the profile measurement).

Data Collection[†]:

1. Go to the main menu. Set the cursor to 'setup of instruments' and hit RETURN.
2. Under this submenu, select 'optical parameters' and set the values accordingly. Note the fringe spacing value. (This will translate directly into velocity in m/s per MHz Doppler signal).

[†]. Make sure all the instruments are turned on and the PM tube current is set properly, about 3/4 or less.

3. Hit the 'F8' key. You are still under the submenu 'set up of instruments.' Select 'BSA setup' by moving the cursor. Hit RETURN.
4. The screen will show a set of parameters to be set up: center frequency (Hz or m/s), span, frequency shift etc. You can change some values by using the + or - key. Others, you have to enter. These values are all based on the expected velocity range, signal strength, frequency shift used, etc. You can change them later, if needed. Note that the frequency shift value is given a negative sign if the shifted beam (or the movement of the fringes) is opposite the direction of the flow. You enter the value selected on the front panel of the frequency shifter (downmixer). If no frequency shift is used, select 0 Hz. If a 40 MHz shift is imposed on the signal, use that value here. You can set the range of velocities to measure when the cursor is on 'center frequency' or 'span.'
5. Hit the 'F4' key. All the parameters selected will be transferred to the BSA. Some of them you can see on the BSA front panel. You can save the parameter in a file if needed.
6. Go back to the main menu and select the 'measurements' submenu. Here, you have two choices, 'On-line histogram' or 'data logging to disk.' If you want on-line analysis of data, select 'On-line histogram.' Refer to the manual or the menu at the bottom of the screen, which is very user-friendly. Get some practice here. Make sure the data are good. In the mean time, monitor the filtered Doppler output on the oscilloscope. They should look good. If they are noisy, or there is no Doppler signal at all, check the alignment of the optics again or check the signal cables, gain setting, etc.
7. If everything is satisfactory, go to the data logging mode. Here you set parameters: the number of bursts, filename, ID, etc. After entering the val-

ues, hit the 'F4' key. You are ready to collect data under the file name you gave.

8. Hit the 'F2' key. The system starts collecting data and stops automatically after the desired number of bursts is collected. Or, you can interrupt the collection by hitting the 'F2' key.

Data Analysis

1. Go to the main menu. Select 'graphic presentation/calculations' submenu. You have three choices: 'Graphics presentation,' 'alphanumeric calculation,' or 'show from setup file.' Select 'graphic presentation.'
2. The system will ask for the file name. Type the file name and hit RETURN.
3. Look at the menu at the bottom of the screen. You can select 'Draw.' Hit RETURN. The histogram presentation of the data with the mean value and standard deviation will be seen. Note the values.
4. If a hard copy of the results is needed, move the cursor to hard copy and hit RETURN. (The printer should be 'on' before this.) It takes a few minutes to print the results. You can do this off-line also, saving some time during the measurements.
5. The file containing the data is on the hard disk. You can retrieve it later.

Profile Measurement

Traverse the probe volume (measurement point in the gas stream) to the desired spatial positions in the flow. At each position, collect data (1000 points or so), analyze it, and note the mean velocity and standard deviation (rms velocity). Plot them later as functions of the distance from a reference point.

DSA system consists of:

the Doppler Signal Analyzer, a Gateway 2000, 486/33C personal computer, and a Lecroy 9450A 300 MHz digital oscilloscope.

1. Read DSA instruction manual to become familiar with the front/back panel controls and operation.
2. The DSA control, and the data collection and analysis programs are already loaded on the computer.
3. Become familiar with the oscilloscope operation. If you want to save the Doppler signals on the computer, connect the 488 cable from the oscilloscope to the IBM AT compatible computer. The program for this is already loaded in the directory c:\lecroy.
4. Connect the data transfer/control cable from the back panel of DSA to the 486/33C PC and connect the other cable from the back of the DSA to the receiver. Connect all the power cables to 120 V strip. Connect the signal cable from the PMT to the 'signal in' position on the receiver, and connect the 'signal out' from the receiver to the back panel of the DSA ('1A'). Connect 'out' on the front panel on the DSA to the oscilloscope.

System initial check

1. Turn on the system.
2. Go to directory DSA. Type CD\DSA, hit RETURN.
3. Type DSA. Hit RETURN. Wait for the main menu to show up on the screen.

Traverse movement check

Complete as described under the operations of BSA. The traverse is still controlled by the IBM AT compatible computer, and the traverse control program is in the directory of C:\BSATRV.

Data Collection

1. While you are in the main menu of the DSA control program press selection 'A' (On-line data analysis). This will take you to the DSA velocity setup menu.
2. The screen will show a number of parameters to be set up: frequency shift, DC offset, mixer frequency, etc. These values are based on the expected velocity range, frequency shift used, signal strength etc. Read the DSA operation manual for a detailed description of these parameters.
3. Once you are finished with the velocity setup page, press the 'F4' key. This will take you to the page named 'User Setup.' On this page you can set up the file name, the number of samples you want to collect, the position of the measurement volume etc. You can also select the kinds of data files you want to select (standard files, raw data files etc.). At the option 'K' on this page, input the focal length of the transmitting lens.
4. Press 'ALT-F4.' Factory configuration page #1 appears on the screen. Here you need to change the value of 'beam separation' in accordance with your optical setup. At the options 'K' and 'L' you need to input the focal length of your receiving and transmitting lenses respectively. Pressing 'ALT-2' will take you to the 'factory configuration page #2'—nothing needs to be changed here. 'ALT-3' gives you page #3 where you can turn the 'auto setup' option on or off. Keeping the auto setup on will select the parameters

on the 'velocity setup' page automatically for given velocity range. Pressing the 'F3' key will take you to the 'velocity setup' page.

5. Once you have finished setting all the parameters, press 'CTL-F4.' This will show you the 'Internal variable display' screen. Check the value of fringe spacing. If this value agrees with the value of fringe spacing for the optical system you used, you set the parameters correctly. If the value doesn't agree, go back to the different pages and check all the parameters.
6. Once you are sure that the parameters are correct, and you see good Doppler signals on the oscilloscope, you are ready to collect data. Press 'F9' and you will see the histogram building up on the screen. If you want to abort the data collection, press the space bar twice. Once the required number of samples is collected, the data collection process will halt automatically. Pressing the 'F8' key will let you save the data. Collect different data sets for a given position. Pressing 'ALT-X' from any page will take you to the main menu, and pressing the 'F1' key will take you to the help screen.

Data Analysis

1. Go to the main menu. Press 'Off-line data analysis.' Select the drive and the data file you want to analyze. Select a particular run and press 'ENTER.' This will give you the histogram, the mean velocity, and the rms velocity for that run.
2. To get a hard copy of the histogram press 'ALT-F6'; for a listing of the velocity values press 'CTL-F6.'
3. To go from the histogram page to the off-line data analysis page, press 'F8.' There you can analyze a different run.

Profile Measurement

Traverse the probe volume (measurement point in the gas stream) to desired spatial positions in the flow. At each position collect data, analyze it, and note the mean velocity and the rms velocity. Plot them later as a function of the distance from the optical window.

Transverse Velocity Measurements

1. Rotate the beams through 90° , which can be accomplished by rotating the fiber output coupler in place. Also, make sure you rotate the beam spacer to be in line with the beams.
2. Check for proper beam alignment and beam crossing by using the level blocks and the objective microscope.
3. With the windows in place, align the beams through the ports as described earlier.
4. Check the BSA or DSA setup. Use proper frequency shifting. Collect data, analyze them, and plot them.

Copying/Backup of Data Files

After the experiment is over, before packing up, copy (save) all the files onto formatted floppy disks.

1. To copy a file:
Type file name (space) A: (or B:), hit RETURN.
2. To copy all BSA data files at one time:
type *.BSA space A: (or B:), hit RETURN.

3. The best way to copy the DSA files, is to use the copying options in the 'Off-line data analysis' menu of the DSA software. Go to the file copying option and follow the commands.

Important Safety Points to Remember Before Packing the LDV System

1. Park the hard disk on the IBM AT compatible PC by typing PARK, hit RETURN.
2. Remove all the water in the laser head and its power supply by blowing with mouth or using compressed air (not more than 30 psig pressure).
3. Lock all eight 1/8" set screws inside the laser head before transporting.

TEST/EVALUATION METHOD AND RESULTS

Test Method

The LDV setup is tested for the proper alignment by measuring the velocity of a wheel rotating at a known speed. A pin is attached to the surface of the wheel, and the wheel is placed so that each time it rotates, the pin cuts the beams' crossing point. The velocity of this rotating wheel is 16.6 m/s for the given r.p.m of 1800. A velocity histogram obtained with this method is shown in Figure 2.

Figure 2. Velocity histogram from wheel.

The mean velocity measured with the LDV setup for the wheel was 16.4 m/s and it agrees with the calculated velocity value.

Experimental Results

Laser Doppler velocimetry measurements were performed in the aerodynamic duct of the Coal Fired Flow Facility at the University of Tennessee Space Institute (UTSI) during August 13-15, 1992. The experiment was done in the forward scatter mode. A composite plot of the profiles is shown in Figure 3. The mean velocity (x-component) measured at the centerline position (2.4" from the west wall) of the duct was around 950 m/s. The

velocity profile is almost flat excepting the positions near both port openings.

Figure 3. A composite plot of velocity profiles.

Figure 4 shows the x-component velocity histogram at the centerline of the duct. The y-component velocity profile is shown in the lower portion of Figure 3. The mean values were close to zero at every measurement position, and they displayed a range from about -100 m/s (down direction) to +100 m/s (up direction).

Figure 4. X-component velocity histogram at duct centerline.

Figure 5 shows a y-component velocity histogram at the centerline of the duct. The mean velocity value (y-component) was only 2.00 ± 37 m/s at this position.

Figure 5. Y-component velocity histogram at duct centerline.

CURRENT STATUS

Performance

The current LDV system is set up to measure a single component (horizontal or vertical) of velocity at a time. The measurement of the other velocity component is achieved by rotating the laser beams through 90°. When the signal qualities are good and the scattering particles are large, the backscatter mode is used for the measurement. In the case of poor signal quality and small particles, a forward scattering unit is employed.

Availability

The LDV system is available for measurement of particle velocities as needed at different facilities.

Future Development

As mentioned earlier, the current LDV system is a one-component system. Future development involves upgrading the LDV system to a two-color system enabling the simultaneous measurement of two components of velocity. The system also needs a small-diameter fiber-optic probe system to measure velocity in hard-to-reach locations.

REFERENCES

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