Outline

- Fluid flow measurements: pitot tubes, HWA, LDA
- Introduction to LDA: Doppler and fringe model
- Optical system set up
- Electronic systems
- Applications of LDA
- Limitations of LDA
Fluid Flow Measurements

Using Pitot Tubes

- Uses the concept of Bernoulli’s equation
- Other techniques using pressure difference: Venturi tube, Rotameter, Flow nozzles, Orifice plate etc.

LASER DOPPLER ANEMOMETRY
Fluid Flow Measurements

**Hot Wire Anemometry**
- Measures the convective heat transfer occurring due to flowing fluid
- Sensor having higher temperature

**Limitations**
- Indirect measurement
- Dirt is deposited resulting in insulation
- Disturbs the flow
- Fluid may decompose due to high temperature
Optical Techniques

- Do not disturb the flow
- Almost direct measurement
- Need particles for measurements
- For transparent fluids
- Particles small enough to follow the flow
- Measure displacement of a small particle in the fluid in unit time

LASER DOPPLER ANEMOMETRY
Optical Techniques: Examples

- Particle Image Velocimetry
- PLIF

LASER DOPPLER ANEMOMETRY
Introduction to LDA

DOPPLER EFFECT

- Change in frequency of a wave as perceived by an observer moving relative to the source of waves.
- Moving source – \[ f' = \left( \frac{v}{v \pm v_s} \right) f \]
- Moving observer – \[ f = f_0 \left( 1 - \frac{v_0}{v} \right), \]

\( v_s = \) velocity of source,
\( v = \) velocity of waves, and \( v_0 = \) velocity of observer.

LASER DOPPLER ANEMOMETRY
Introduction to LDA

Doppler Model

\[ \Delta \nu = \nu_A - \nu_B = \left( \frac{1}{\lambda} \right) U_i (k_i - m_i) \]

Fringe Model

LASER DOPPLER ANEMOMETRY
Dual Beam Anemometer

Doppler Model:
By superimposing the scattered beams in “k” direction, we get:

\[ \Delta \nu = \frac{1}{\lambda} U_i \left[ (\ell_2)_i - (\ell_1)_i \right] = \frac{U_{\perp} 2 \sin \phi}{\lambda} \]

Fringe Model:

\[ \Delta x = \frac{\lambda}{2 \sin \phi} ; \quad \Delta t = \frac{\Delta x}{U_{\perp}} \]

\[ f = \frac{1}{\Delta t} = \frac{U_{\perp} 2 \sin \phi}{\lambda} \]
Dual Beam Anemometer

- Explanation using beat frequency

- Detected frequency being independent of the observing direction is advantageous because a larger aperture can be used.
Drawback of Fringe Model

- Intensity as square of electromagnetic energy integrated over time
- Only squared value detector can see intensity
- Eyes and photodetector can see intensity
- Particle cannot see the intensities and hence the fringes
Direction of flow

- Bragg cells
- Diffraction grating

**LASER DOPPLER ANEMOMETRY**
Direction of flow

Laser-Doppler system based on rotating diffraction grating
Multidimensional Measurement

Using one pair of beam per measured flow direction

Two Beam Anemometer

LASER DOPPLER ANEMOMETRY
Effect of size of particles

- Different modulation depths are obtained with different sized particles.
- For very small particle, signal path ‘A’ is obtained.
- For increased particle size, ‘B’ is obtained.
- For particle size comparable to the distance of the interference fringes, modulation disappears as shown in ‘C’.
Optical System Setup

- Mainly 3 types of optical system setup
  - Reference beam anemometer
  - Two beam anemometer
  - Two scattering beam anemometer
- For reliable LDA measurement ensure that-
  - Parallel interference fringes
  - High modulation depth

\[ N_{ph} = \frac{2}{M \lambda} d_{ph} \sin \varphi \]

Two beam anemometer

\[ d_m = \frac{d_{ph}}{M} \]

\[ d_{in} = \frac{d_s}{\cos \varphi} \]
Optical System Setup: Mathematical Analysis

To ensure parallel interference fringes and high modulation depth

- For the lens in front of photo detector
  \[ d_{ph} = \frac{N_{ph} M \lambda}{2 \sin \phi} \]

- Quantity of effective measuring volume can be computed as
  \[ d_m = \frac{\lambda N_{ph}}{2 \sin \phi} \]

- Effective diameter of measuring volume
  \[ d_{in} = \frac{5 \lambda \left( \frac{f_1}{D_1} \right)}{\pi} \frac{1}{\cos \phi} \]

- Number of fringes within the cross section area
  \[ N_{ph} = \frac{10 f_1}{\pi D_1} \tan \phi \]

LASER DOPPLER ANEMOMETRY
Electronic Systems for LDA Measurement

- Signal comprising two parts
- Low Frequency—due to Gauss Intensity Distribution of Laser
- High Frequency—Part of Laser Doppler signal
- High Frequency portion is of interest.

Output Signal

LASER DOPPLER ANEMOMETRY
Electronic Systems for LDA Measurement

**Spectrum Analyzer**
- VCO signal triggered by a saw tooth wave.
- Mixer to mix VCO signal and Input signal.
- IF filter to pass components around stable frequency.
- Switching circuit for squaring and smoothing of output signal.
- Saw tooth wave is used for triggering X axis.

LASER DOPPLER ANEMOMETRY
Electronic Systems for LDA Measurement

Offset Heterodyne Tracker

- Input Signal mixed with mixer.
- Band pass filter to pass components around center frequency.
- Frequency discriminator to generate signal proportional to modification around center frequency.
- Integrator controls transient behavior.

Offset Heterodyne Tracker
Electronic Systems for LDA Measurement

- High Pass input signal in form of bursts.
- Whenever input is greater than threshold we get output.
- Tracker changes the frequency of preceding signal measured at exit.
- Thus output is in form of steps.
- Integrate over several frequency changes to get lower noise signal.

Input and Output signal
Electronic Systems for LDA Measurement

Period Measurement System

- Counter system has two level detectors and one zero detector.
  - Pulse 1 – Upper level and zero position
  - Pulse 2 – Zero position only
  - Pulse 3 – Lower level and zero position

Laser Doppler Counter System

LASER DOPPLER ANEMOMETRY
Electronic Systems for LDA Measurement

- Take only those zero passages in which either 1 or 3 is set.
- This avoids multiple zero passages.
- Use this to get number of time pulse passes zero.
- Divide that by time taken to get Doppler frequency.

Laser Doppler Counter System
Applications of LDA

- Multiphase flows
- Turbulent flows
  - Through rectangular duct
  - Separated air flow
- Supersonic flows
- Flow near the wall
Applications of LDA

Turbulent flow through rectangular duct
Applications of LDA

Turbulent flow through rectangular duct
Applications of LDA

Turbulent flow in form of separated air flows
Applications of LDA

Supersonic flows

LASER DOPPLER ANEMOMETRY
Limitations of LDA

- Particles do not always follow the fluid flow accurately.
- Heating of fluid
- Always needs particles
- Applicable for transparent fluids only
Conclusions

- Conventional techniques like HWA have limitations
- LDA can be explained using
  - Doppler model
  - Fringe model
- Direction of flow and other components of velocity of fluid can be measured using some modifications in setup.
- Offset heterodyne tracker is better than spectrum analyzer.
References

- “Principles and Practice of Laser-Doppler Anemometry” by F. Durst, A. Melling and J. H. Whitelaw
- Chapter-21, “Fluid flow measurements”,
THANK YOU