Particle Image Velocimetry
Part - 1

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Announcement

• Room 1058, Sweeney Hall for Lab#4 (LDV laboratory)

• Sweeney Hall is where Chemical and Biological Engineering Department is located.
Particle-based Flow Diagnostic Techniques

- Seeded the flow with small particles (~ μm in size)

- **Assumption**: the particle tracers move with the same velocity as local flow velocity!

\[
\begin{align*}
\text{Flow velocity} \quad V_f & = \quad \text{Particle velocity} \quad V_p \\
\text{Measurement of particle velocity}
\end{align*}
\]
**Frequency-shift based methods**

- **Frequency-shift methods:**
  - Based on the Doppler phenomenon, namely the shift of the frequency of waves scattered by moving particles.
  - Laser Doppler Velocimetry (LDV) or Laser Doppler Anemometry (LDV)
  - Planar Doppler Velocimetry (PDV) or Planar Doppler Anemometry (PDA)

\[ v_\perp = \frac{\lambda}{2} \cdot \frac{f}{2 \sin \frac{\theta}{2}} \]
Particle Image Velocimetry (PIV) technique

- **Particle displacement method**: to measure the displacements of the tracer particles seeded in the flow in a fixed time interval.

\[ U = \frac{\Delta L}{\Delta t} \]

\[ t = t_0 + \Delta t \]

- a. \( T = t_0 \)
- b. \( T = t_0 + 4 \text{ms} \)

**Corresponding Velocity field**
PIV System Setup

**Particle tracers:** to track the fluid movement.

**Illumination system:** to illuminate the flow field in the interest region.

**Camera:** to capture the images of the particle tracers.

**Synchronizer:** to control the timing of the laser illumination and camera acquisition.

**Host computer:** to store the particle images and conduct image processing.
Tracer Particles for PIV

- Tracer particles should be *neutrally buoyant* and *small enough* to follow the flow *perfectly*.
- Tracer particles should be *big enough* to scatter the illumination lights *efficiently*.
- The scattering efficiency of trace particles also strongly depends on the ratio of the *refractive index* of the particles to that of the fluid.

*For example:* the refractive index of *water* is considerably larger than that of *air*. The scattering of particles in air is at least one order of magnitude more efficient than particles of the same size in water.

![Diagram showing light scattering by particles of different sizes](image)

- \( d = 1 \mu m \)
- \( d = 10 \mu m \)
- \( d = 60 \mu m \)
A primary source of measurement error is the influence of gravitational forces when the density of the tracer particles is different to the density of work fluid.

\[ U_g = d_p \left( \frac{\rho_p - \rho}{18\mu} \right) g \]

The velocity lag of a particle in a continuously accelerating fluid will be:

\[ \vec{U}_s = \vec{U}_p - \vec{U} = d_p \left( \frac{\rho_p - \rho}{18\mu} \right) g \]

\[ \vec{U}_p(t) = \vec{U}(1 - \exp(-\frac{t}{\tau_s})); \]

\[ \tau_s = d_p \frac{\rho_p}{18\mu} \]

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**Fig. 2.1.** Time response of oil particles with different diameters in a decelerating air flow
Tracer Particles for PIV

- Tracers for PIV measurements in liquids (water):
  - Polymer particles ($d=10\sim100 \ \mu m$, density $= 1.03 \sim 1.05 \ \text{kg/cm}^3$)
  - Silver-covered hollow glass beams ($d =1 \sim10 \ \mu m$, density $= 1.03 \sim 1.05 \ \text{kg/cm}^3$)
  - Fluorescent particle for micro flow ($d=200\sim1000 \ \text{nm}$, density $= 1.03 \sim 1.05 \ \text{kg/cm}^3$).
  - Quantum dots ($d= 2 \sim 10 \ \text{nm}$)

- Tracers for PIV measurements in gaseous flows:
  - Smoke ...
  - Droplets, mist, vapor...
  - Condensations ....
  - Hollow silica particles ($0.5 \sim 2 \ \mu m$ in diameter and $0.2 \ \text{g/cm}^3$ in density for PIV measurements in combustion applications.
  - Nanoparticles of combustion products
The illumination system of PIV is always composed of light source and optics.

Lasers: such as Argon-ion laser and Nd:YAG Laser, are widely used as light source in PIV systems due to their ability to emit monochromatic light with high energy density which can easily be bundled into thin light sheet for illuminating and recording the tracer particles without chromatic aberrations.

Optics: always consisted by a set of cylindrical lenses and mirrors to shape the light source beam into a planar sheet to illuminate the flow field.
Double-pulsed Nd:Yag Laser for PIV

Fig. 2.17. Double oscillator laser system with critical resonators

Figure 4.8: Gemini with Extended Base Plate for UV Operation
Optics for PIV

Side view

Light sheet

-50 mm  200 mm  500 mm

Top view

Thickness

-50 mm  200 mm  500 mm
Cameras

• The widely used cameras for PIV:
  - Photographic film-based cameras or Charged-Coupled Device (CCD) cameras.

• Advantages of CCD cameras:
  - It is fully digitized
  - Various digital techniques can be implemented for PIV image processing.
  - Conventional auto- or cross- correlation techniques combined with special framing techniques can be used to measure higher velocities.

• Disadvantages of CCD cameras:
  - Low temporal resolution (defined by the video framing rate):
  - Low spatial resolution:
Interlaced Cameras

- The fastest response time of human being for images is about ~ 15Hz.
- Video format:
  - PAL (Phase Alternating Line) format with frame rate of $f=25$Hz (sometimes in 50Hz). Used by U.K., Germany, Spain, Portugal, Italy, China, India, most of Africa, and the Middle East.
  - NTSC format: established by National Television Standards Committee (NTSC) with frame rate of $f=30$Hz. Used by U.S., Canada, Mexico, some parts of Central and South America, Japan, Taiwan, and Korea.

![Interlaced Camera Diagram]

- 480 pixels by 640 pixels
- 1 frame $F=30$Hz
- Even field (2, 4, 6... 640)
- Odd field (1, 3, 5... 639)

Interlaced camera diagram:
- 1st field: Odd field
- 2nd field: Even field
- One complete frame using interlaced scanning
Progressive scan camera

- All image systems produce a clear image of the background
- Jagged edges from motion with interlaced scan
- Motion blur caused by the lack of resolution in the 2CIF sample
- Only progressive scan makes it possible to identify the driver

Note: In these examples, the cameras have been using the same lens. The car has been driving at 20 km/h (15 mph) using cruise control.

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