Time-Resolved Particle Image Velocimetry Measurements in an Internal Combustion Engine

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Definitions

\[ K(\theta) = \frac{1}{2} \left[ \frac{1}{RC} \sum_{r} \sum_{c} (u^2 + v^2) \right] \]

\[ K_t = \frac{1}{2} \left[ \frac{1}{RC} \sum_{c} \left( (u - \bar{u})^2 + (v - \bar{v})^2 \right) \right] \]

\[ U_p = \text{Mean Piston Speed} \]

\[ R = \text{Total number of rows in image; } r = \text{row index} \]

\[ C = \text{Total number of columns in image; } c = \text{column index} \]

Experimental Apparatus and Conditions

Engine: GM/ERC CRL Optically Accessible Engine
Compression Ratio: 10.95
Bore: 86 mm
Stroke: 94.6 mm
Displacement: 550 cm³
Engine Speeds: 600, 1200, 1800 rpm
Intake MAPs: ~60, ~100 kPa
Light Source: Dual Headed Nd:YLF Laser
Light Wavelength: 527 nm (2nd Harmonic)
Laser Energy: 12 mJ/pulse
Laser Rep Rate: 1 kHz
Camera: TSI HS3000 Frame Straddling CMOS Nikon 85 mm, f/1.4 Lens
Seeder: TSI Six-Jet Atomizer, Olive Oil Seeding
Mean Particle Size = 0.6 µm
Image Processor: TSI Insight 3G

Framing Rate Limit

- The maximum framing rate for a PIV system is given by the laser pulse separation required to obtain sufficient particle separation for correlation purposes.
- There is an inherent spatial averaging in the image processing by assigning a single velocity to an interrogation region.
- This smallest discernable length can be used, with Taylor’s hypothesis and the chosen velocity scale, to describe a upper limit for the high frame rate PIV.
- For the present system:
  - The maximum possible framing rate of the laser is 10 kHz.
  - The smallest discernable length is 1.2 mm.
  - At 600 rpm, this led to a upper framing rate limit of 3.4 kHz, well below that of the PIV system.

Relationship Between Temporal and Spatial Filtering

- Using Taylor’s Hypothesis, the relationship between temporal and spatial filtering was investigated.
- Scaling relationship:

  \[ f_{eq} = \sqrt{2K_L} \]

  \[ f_{eq} = \text{equivalent temporal filtering cutoff frequency} \]

  \[ L = \text{spatial cutoff frequency} \]

- While using Taylor’s hypothesis and the aforementioned scaling relationship there is excellent agreement between the temporally and spatially filtered mean turbulent kinetic energy when compared at the same cutoff and effective cutoff frequency, respectively.

- Excellent level of agreement between temporal and equivalent spatial filtering using Taylor’s hypothesis and the chosen velocity scale.

Filtering Effects on Velocity Field

- Spatial and temporal filtering were performed with Gaussian kernel-type convolution filters.
- Equivalent cutoff frequency for spatial filter chosen defined in using Taylor’s hypothesis and scaling relationship shown to the left.
- Selected cutoff frequency corresponds to integral time scale.
- Spatial filtering results in slightly smoother mean flow contours because it includes a larger number of data points (kernel size squared) than the temporal filter (kernel size).

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