Velocity Interferometer System for Any Reflector (VISAR)

Foundational Physics and Applications
What is VISAR?

**Velocity Interferometer System for Any Reflector**
- Measures change in Doppler shift of light reflected off a moving surface
- Used to calculate velocity of surface
Interferometry Principles

Superposition of two beams
- Calculate Doppler shift by analyzing interferometer fringes
- Desired: fringe phase

- Express as sample function
  \[ f(x,t) = b(x,t) + a(x,t)\cos[\phi(x,t) + 2\pi f_0 x + \delta_0] \]

\[ I^2 = I_1 + I_2 + 2E_1 E_2 \cos \theta \]

\[ \phi(x,t) \quad \text{fringe phase} \]
\[ 2\pi f_0 x \quad \text{phase ramp} \]
\[ \delta_0 \quad \text{initial phase} \]
Interferometry Principles

Fourier method to resolve fringe phase

- Base equations
  \[ f(x,t) = b(x,t) + a(x,t)\cos[\phi(x,t) + 2\pi f_0 x + \delta_0] \]

- Convert functional forms
  \[ f(x,t) = b(x,t) + c(x,t)e^{i2\pi f_0 x} + c^*(x,t)e^{-i2\pi f_0 x} \]
  where
  \[ c(x,t) = \frac{1}{2} a(x,t)e^{i\delta_0}e^{i\phi(x,t)} \]

- FFT
  \[ F(f,t) = B(f,t) + \int_{-\infty}^{\infty} c(x,t)e^{i2\pi f_0 x}e^{-ifx}dx + \int_{-\infty}^{\infty} c^*(x,t)e^{-i2\pi f_0 x}e^{-ifx}dx \]
  \[ F(f,t) = B(f,t) + \int_{-\infty}^{\infty} c(x,t)e^{i2\pi (f_0-f)x}dx + \int_{-\infty}^{\infty} c^*(x,t)e^{-i2\pi (f_0+f)x}dx \]
  \[ F(f,t) = B(f,t) + C(f-f_0,t) + C(f+f_0,t) \]
Interferometry Principles

Signal Isolation

\[ F(f,t) = B(f,t) + C(f-f_0,t) + C^*(f+f_0,t) \]

Signal filtering for single-shift term; Smith (J. Appl. Phys. 2013)

- Inverse FFT
  \[ c(x,t) = \frac{1}{2} a(x,t) e^{i\delta_0} e^{i\phi(x,t)} \]
  \[ f(x,t) = \int_{-\infty}^{\infty} C(f-f_0) \left[ \cos(xf) + i \sin(xf) \right] df \]

- Euler’s formula

Used to solve for wrapped phase

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Interferometry Principles

Phase Extraction

- Wrapped phase

\[
\begin{align*}
\text{Re}[f(x,t)] & \propto \sin(\phi(x,t) + 2\pi f_0 x + \delta_0) \\
\text{Im}[f(x,t)] & \propto \cos(\phi(x,t) + 2\pi f_0 x + \delta_0)
\end{align*}
\]

\[P(\phi(x,t) + 2\pi f_0 x + \delta_0) = \arctan\left(\frac{\text{Re}[f(x,t)]}{\text{Im}[f(x,t)]}\right)\]

Discontinuity Resolution

- Occurs as arctan() goes through full rotations

- Also observe “fringe-hopping” (algorithm misidentifies fringe shifts)

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Velocity Calculation

Velocity proportional to fringe phase

- Once phase determined, use VPF (velocity per fringe) to calculate velocity

  - Normalized phase difference
    \[ F(x,t) = \frac{\phi(x,t) - \phi(x,t_i)}{2\pi} \]

  - Velocity (VISAR approximation)
    \[ v(t - \tau_0) = v_i + \kappa F(x,t) + O(\tau_0) \]

- Constant VPF

  \[ \kappa = \frac{\lambda_0}{2\tau_0(1 + \delta)} \]

  - \( \lambda_0 \): wavelength
  - \( \tau_0 \): etalon time delay
  - \( (1 + \delta) \): etalon dispersion correction

 Velocity time evolution at single x
Smith (J. Appl. Phys. 2013)
**Example: Shock Physics**

VISAR measures shock “breakout time”
- Elastic/Plastic shockwaves
- Plasma expansion

Target configuration

Experimental setup for shock compression
VISAR Limitations

Amplitude-sensitive system

Sources of error

- **Beam**
  - Spatially-varying beam
  - Optical component alignment and back reflections

- **Camera**
  - Camera thermal noise + background pattern
  - Distortion “Speckle pattern”

- **Target**
  - Surface roughness -> non-uniform reflectivity

Velocity time evolution at all x locations
Smith (J. Appl. Phys. 2013)
Summary

**Velocity Interferometer System for Any Reflector**
- Measures change in Doppler shift of light reflected off a moving surface
- Used to calculate velocity of surface

Used Fourier analysis to isolate & resolve wrapped phase signal

\[
P(\phi(x,t) + 2\pi f_0 x + \delta_0) = \arctan\left(\frac{\text{Re}[f(x,t)]}{\text{Im}[f(x,t)]}\right)
\]

Converted phase change to velocity via VISAR approximation

\[
v(t - \tau_0) = v_i + \kappa F(x,t) + O(\tau_0)
\]

\[
\kappa = \frac{\lambda_o}{2\tau_0(1 + \delta)}
\]

Applied to shock breakout time in warm-dense Mo

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**Velocity vs. time at all x locations**

Smith (J. Appl. Phys. 2013)
Questions?