Embedded Fiber Optic Probes to Measure Detonation Velocities Using the PDV

D.E. Hare, R.G. Garza, O.T. Strand, T.L. Whitworth, LLNL
D.B. Holtkamp, LANL
Outline

• Previous work with the Fabry-Perot Velocimeter
• Description of the Embedded Fiber Optic (EFO) probe
• Background of the PDV
• Experimental Setup for EFO Measurements
• Examples of the data
• Issues
• Conclusions
Previous work with Fabry-Perot Velocimeter

The physics: laser Doppler velocimetry of the detonation wavefront

Detonating HE sample

EFO probe

Fabry-Perot velocimeter with special EFO filter

(This work was presented at the 13th International Detonation Symposium, Norfolk, VA, July 23-28, 2006.)
Previous work with Fabry-Perot Velocimeter

- Shock wave creates / maintains a refractive index discontinuity in probe core
- Index discontinuity:
  - Reflects laser light
  - Imparts a Doppler shift because it is moving
- In the case of steady flow:
  - The Doppler shift should be exactly the same as the steady shock or steady detonation speed

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Previous work with Fabry-Perot Velocimeter

Pellet junctions:
Make good position fiducials

booster  LX-17 or 9502 column

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EFO probe used with the Fabry-Perot Velocimeter has an aqueous solution of CsCl as its core

EFO-FP probe
- Used with FP velocimeter at 532 nm
- PTFE (Teflon) cladding (1.6 mm OD, 127 µm ID)
- Aqueous CsCl solution core (127 µm OD)
- Will measure wave speeds > 1.9 km/s

Note the angle polish on the end of the fiber inside the EFO probe
EFO probe used with PDV has a single mode fiber inserted into the Teflon tube

EFO-PDV probe
- Used with PDV at 1550 nm
- PTFE (Teflon) cladding (1.6 mm OD, 127 µm ID)
- Single mode fiber (125 µm OD, 9 µm core)
- Will measure wave speeds > 5 km/s

Note the angle polish on the end of the fiber inside the EFO probe

Weapons & Complex Integration
The index discontinuity of the shock front inside the core reflects the laser light back to the PDV.

Approximately $1 \times 10^{-4}$ efficiency.

The measured velocity is the time rate of change in the optical path length, which is the actual distance $\times$ the index of refraction.
The PDV operates by generating a beat frequency proportional to the velocity.

Develop velocimetry by mixing undoppler-shifted light with Doppler-shifted light and measuring the beat frequency.

\[
\text{Beat frequency } = f_b = f_d - f_o = 2(v/c)f_o
\]

**Example:** at 1550 nm and 1000 m/s:

- \( f_o = 193414.49 \text{ GHz} \)
- \( f_d = 193415.78 \text{ GHz} \)
- \( f_b = 1.29 \text{ GHz} \)
We use a 3-port optical circulator as the heart of the PDV

The circulator directs the light into the desired directions.

The fiber laser is easy to use.

The beat signal is generated at the detector.

We order the probes to have -40 dB return of the input light.

We choose probes to have $1 \times 10^{-4}$ efficiency.
High bandwidth electronics allow the PDV to measure velocities over 12 km/s

- IPG Photonics, ELD-2-1550-SF
- JDS Uniphase, CIR-230031000
- Corning, SMF-28
- Oz Optics, various types
- Laser
- OPM
- Detector
- Digitizer
- Attenuator
- Eigenlight, A4-LLNL01-01A
- Miteq Corporation, SCMR-100K20G, 3dB = 20 GHz
- Tektronix, Model DSA72004, 50 GS/s, 20 GHz
- Oz Optics
We package each 4-channel PDV system in a roll-around rack.

LANL has a modular format for the PDV chassis and can package 8 channels per rack.
We use a variable reflector to provide the reference signal.

Variable reflector provides our source of undoppler-shifted light.

The EFO probe provides only Doppler-shifted light, so we need an external reference source.
Over-driven LX-17 with on-axis detonator
Divide the measured velocity by the refractive index (1.4682) to obtain the actual velocity.

Many thanks to Jim Crain of LANL for loaning us his TDS-6154 for this 1st set of shots.
Under-driven PBX-9501 with off-axis detonator

No data from 1\textsuperscript{st} two pellets
We believe the oscillations are caused by the granularity of the HE.

This data is from the PDV EFO probe.

We see the same type of oscillations with the Fabry-Perot EFO probe, also.

Note: This level of detail is not possible using electrical pins for detonation velocity.
We observe that LX-17 detonates after a 2.78-mm gap.

No data from 1st 4.5 pellets.
Issue #1:
Detonation front must be nearly normal to the probe axis

We still need to experimentally determine the maximum angle that returns data.

Computation by Ray Tolar, LLNL
Issue #2:
What are the time response and time lag of the PDV EFO?

\[ \text{Time lag} \]

HE
Teflon
Glass
Teflon
HE

\[ 8 \text{ mm/\mu s} \]

\[ 12 \text{ mm/\mu s} \]
Conclusions

• We have developed an embedded fiber optic (EFO) probe for use with the Photonic Doppler Velocimeter.
• We have successfully obtained data with the PDV on several different HE stack-ups.
• The EFO-PDV probe has a Vmin of 5 km/s. We are investigating the use of plastic fibers with lower sound speeds.
• We still need to determine such parameters as time response, time lag, maximum angle with shock front.
• We wonder whether the normal index of refraction is the proper correction factor to use.