Photonic Doppler Velocimetry for Dynamic Experiments

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Summary: Photonic Doppler Velocimetry (PDV) is a new method of measuring the velocities of high-speed materials in dynamic experiments. It has been successfully used on a wide variety of experiments, including the recently completed R-Damage series at RFNC-VNIIEF (Sarov). Several examples of shock and magnetically driven experiments are discussed, illustrating the flexibility and robust nature of the diagnostic. A high pressure EOS experiment being designed in a collaborative activity with Sarov is also discussed.

The measurement of the velocity of fast-moving materials is essentially important to several areas of scientific and technical investigations, including shock physics and the study of the behavior of materials at high pressure and at high strain rates. Strand, et al [1] at LLNL developed a new method that we have adapted at LANL for use in a wide variety of experimental settings [2].

Photonic Doppler Velocimetry (PDV) is fundamentally a Michelson interferometer operating at very high speed and is completely enclosed in optical fiber. The reflected light from a moving surface is combined with the light from a reference source (typically at $\lambda = 1550$ nm) producing fringes, each of which correspond to the displacement of the surface by $\lambda/2$. These signals are detected and recorded with high-speed digitizers producing a record of displacement as a function of time. Typically these records are analyzed using Fast Fourier Transform techniques producing a record of frequency vs. time. The velocity is obtained by multiplying this frequency by $\lambda/2$. The telecommunications industry has produced marvelous lasers, detectors, digitizing oscilloscopes, and optical components that comprise a typical PDV system and because the optical system is enclosed entirely in fiber it is compact, lightweight, and easily fielded.

Because PDV data is analyzed in the frequency domain, rather than the amplitude domain as with a VISAR or Fabry-Perot velocimeter, the dynamic range available is enormous, resulting in a robust diagnostic that can operate successfully under a wide variety of experimental conditions with small inefficient optical probes.

Like our colleagues at LLNL and Sandia, we have successfully obtained velocimetry data using PDV in a variety of flyer plate and gun driven shock experiments, as well as with high explosive drive. In applications where very high absolute accuracies are required, PDV has been shown to have an accuracy of < 0.1% [3].

Recently a series of collaborative experiments, conducted by RFNC-VNIIEF (Sarov) and LANL, were completed that employed PDV as one (of several diagnostics) to measure the shock induced damage and spall of cylindrical targets impacted by magnetically accelerated cylindrical liners. Using a miniature multi-point optical probe aligned with the axis of the imploding systems, we successfully measured the acceleration and impact of the liners on aluminum target shells. PDV was able to track the spall, recollection and subsequent radial deceleration of the cylindrical targets until they stopped, slowed by their own material strength [4].

PDV is also capable of measuring very high velocities as well. A recent experiment at Los Alamos accelerated a liner to ~9 km/s [5]. The liner was successfully measured with an axial miniature optical probe over a velocity range spanning almost 5 orders of magnitude.

Our partners (National Security Technologies, LLC) and we have successfully developed and fielded a multiplexed PDV system (MPDV) that employs small tunable lasers and Dense Wavelength Division Multiplexing (DWDM) technologies to combine 8 separate measurement points on a single fiber/detector/recording channel. We are planning to employ this technology on an upcoming very high-pressure equation of state experiment (ALT-3) that is being designed by VNIIEF and LANL [6].

References

[1] Oliver T. Strand, et al, "Velocimetry using heterodyne techniques," 26th Int. Conf. on High-Speed Photography and Photonics, Proc. of SPIE **5580** (2004) 593; O. T. Strand, et al, "Compact system for high-speed velocimetry using heterodyne techniques," Rev. Sci. Instr. **77** (2006) 083108-1.

[2] D. B. Holtkamp, "Survey of Optical Velocimetry Experiments – Applications of PDV, a Heterodyne Velocimeter," Proc. of 2006 Conf. on Megagauss Magnetic Field Generation, Santa Fe, New Mexico (2006)

[3] B. J. Jensen, et al, "Accuracy limits and window corrections for photon Doppler Velocimetry," J. Appl. Phys. 101 (2007) 013523; D. H. Dolan, "Accuracy and precision in photonic Doppler velocimetry," Rev. Sci. Instr. **81** (2010) 053905.

[4] Olga Tyupanova, "Study of Aluminum ALCAN Spall Fracture and Recollection Using an Explosive Pulsed Power Source on the Basis of a Helical EMG. Results of R-Damage 0-7 Experiments," Proc. of the 13th Int. Conf. on Megagauss Magnetic Field Generation and Related Topics, Suzhou, China, July 6-10, 2010.

[5] Robert G. Watt, et al, "Preshot report, MS-2: Development of a magnetically driven target for thermo-nuclear burn studies," Los Alamos National Laboratory Report LA-UR-10-01305 (2010); Robert G. Watt, et al, "MS-2 post-shot report," Los Alamos National Laboratory Report LA-UR-10-01981 (2010).

[6] C. Rousculp, et al, this meeting (2011).

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