Discovery at the Interface of Science and Engineering: Science Matters!

Engineering Sciences
Radiation Effects

Photonic Displacement Interferometer for Material Measurements in Extreme Environments

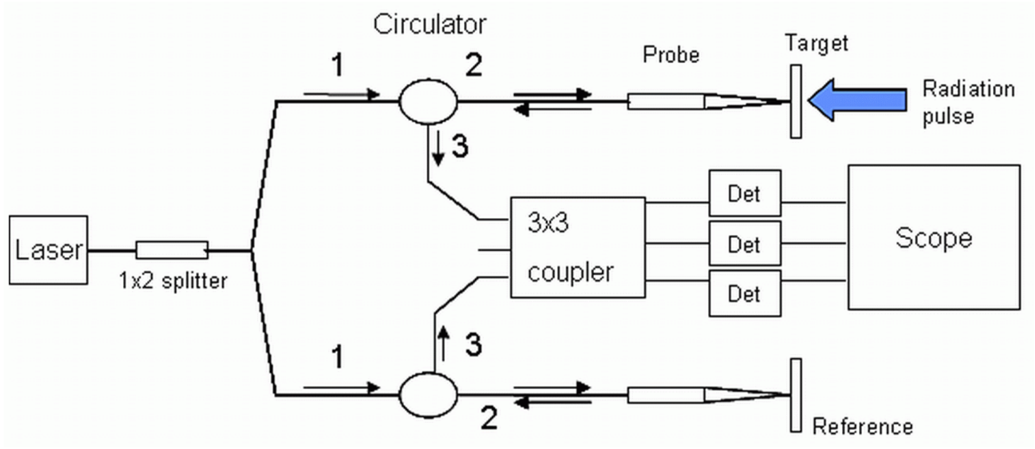

Figure 1: Basic elements of the PDI system. The circulator is a three port miniature photonic device that performs the function of a laser beam splitter. The focusing lens probe interrogates the specimen surface, and the circulator directs the retroreflected light to the 3x3 coupler. The reference leg provides the unshifted laser light that interferes with that returned from the probe leg as the two signals are mixed in the 3x3 coupler. The output of the 3x3 coupler consists of three optical signals which are 120 degrees out of phase with each other. The relative phases of these three signals give the direction of the surface motion. (see Fig. 2).

Laser interferometry is a natural choice for dynamic material response measurements, especially in environments high in EM (electro-magnetic) noise, such as Sandia's pulsed power accelerators. In the 1960s and 1970s, the bandwidths of electro-optic transducers and oscilloscopes limited the usefulness of displacement interferometry to material velocities less than 100 m/s. The development of the VISAR (Velocity Interferometer System for Any Reflector) at Sandia in 1972 [1] provided a solution to these limitations, and has been a work horse for material response measurements ever since. VISAR, however, has its own set of constraints on interpreting material response data, especially for what may now be termed 'low speed' measurements, and when measuring complex material or structural responses to flyer impacts or radiation pulses. The evolution of technology is such that instrument bandwidths have improved about 100-fold since then, and a concurrent development of photonic technology has led to a re-examination of displacement interferometry for basic measurements of material response in extreme environments.

Lawrence Livermore National Lab [2] developed the first Photonic Doppler Velocimeter system based on a fiber laser, a fiber optic circulator, a simple lensed probe, a fast detector and an oscilloscope, resulting in a velocimetry system that has essentially one single adjustment. However, the data can be difficult to interpret in terms of surface displacement where complex motions are involved, and are generally reduced using Fourier techniques to extract surface velocity. Sandia has solved these problems by incorporating an easy-to-use, all fiber-optic displacement interferometry system with a directionally-sensitive data reduction routine [3], tailored to the needs of measuring material and structural response to intense radiation pulses (Fig. 1). Since data is analyzed in terms of displacement, the system is called the Photonic Displacement Interferometer (PDI).

As shown in Fig.1, the reference leg of the PDI provides the unshifted laser light that interferes with that returned from the probe leg as the two signals are mixed in the 3x3 coupler. The output of the coupler consists of three optical signals which are 120 degrees out of phase with each other. The relative phases of these signals are what allow automated data reduction to occur – whether the phase of one signal 'leads' or 'lags' the others depends on the direction of the surface motion (Fig. 2).

Versatile instrument provides direction-sensitive information for fast material response studies

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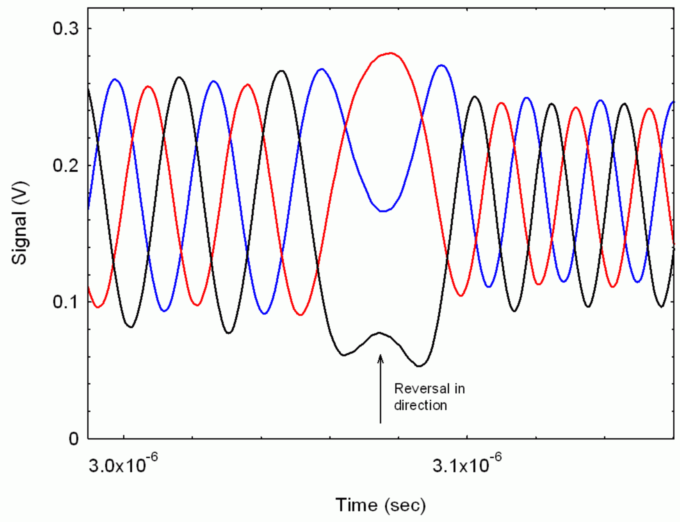

Figure 2: The three interference 'fringe' signals obtained from PDI system. Note the fringe order for times before the reversal – red, black, blue – changes after the reversal. This allows automated data analysis. If only the red signal were recorded, the reversal would be difficult to identify.

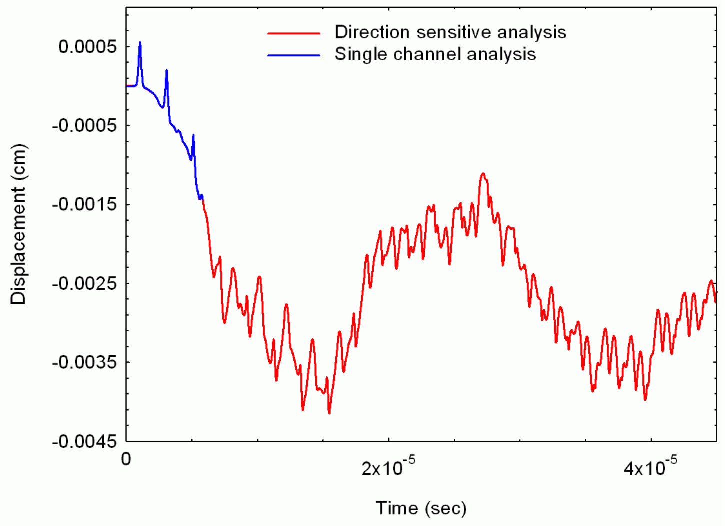

Figure 3: Time resolved displacement of simple aluminum disk irradiated by an high intensity electron beam pulse.

Two of the greatest advantages of this system are the noncontact nature of the measurement (the measurement does not perturb the response), and the immunity to EM interference. Thus material response measurements in the extreme EM environments of Sandia's Saturn and Z pulsed power facilities have been obtained without measurable disturbance of the optical signals.

As an example, Figure 3 shows the response of a simple aluminum disk to an high intensity, 10 nsec pulse of electrons. The detailed motion is complex, showing response to thermomechanical shock superposed with the structural response of the disk. The details have subnanosecond time resolution. Without the direction sensitive analysis capability, the motion cannot be reliably interpreted beyond about 5 microseconds.

A recent collaboration with the Atomic Weapons Establishment in England focused on time-resolved measurement of the impulse resulting from x-ray induced material blow off. In these experiments, a thin film of low vaporization enthalpy metal (Au/Bi) is applied to a substrate. The momentum imparted to the sample is determined by the average velocity, and details of the process are given by the subnanosecond resolved detail (Fig. 4).

The present system can measure three points on a sample. A 2 Watt laser provides enough light to interrogate up to 20 sample points. A number of these systems are currently being assembled at Sandia for applications beyond radiation response testing, including gas gun and isentropic compression testing, and various diagnostic applications at the Z accelerator. Demonstration as an impulse diagnostic for Sandia's Light Initiated High-Explosive Impulse Facility is planned for the fall.

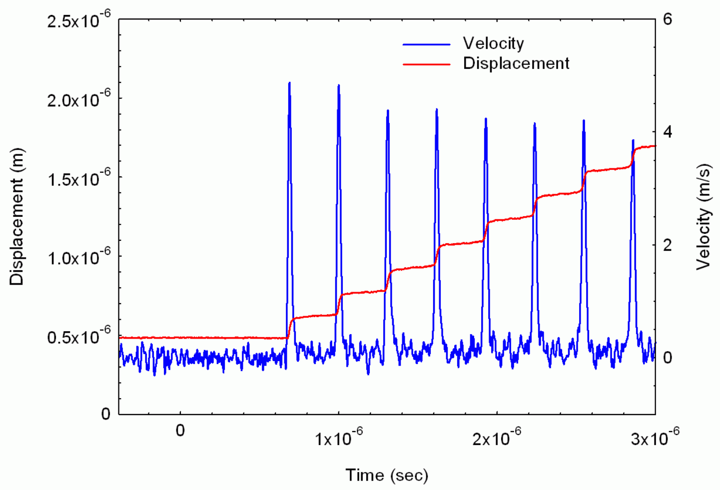

Figure 4: Response of a thin gold foil to an x-ray pulse from an Argon gas puff Z pinch in SNL's Saturn accelerator. The gross impulse imparted to the sample via blow off can be determined by the average slope of the displacement data. The spikes in the velocity curve represent the thermomechanical shock response of the foil.

References:

1. L.M. Barker and R.E. Hollenbeck, J. Appl. Phys. **43**, 4669 (1972).

2. O.T. Strand, D.R. Goosman, C. Martinez, T.L. Whitworth and W.W. Kuhlow, Rev. Sci. Instrum. **77**, 083108 (2006).

3. D.H. Dolan and Scott C. Jones, Sandia Report SAND2008-3871 (2008).

Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2008-5080P

National Nuclear Security Administration

08/2008