COMPARISON OF TRIATURE DOPPLER VELOCIMETRY AND VISAR

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Abstract. Triature Photon Doppler Velocimetry (TDV) is an adaptation of Photonic Doppler Velocimetry (PDV) that rejects common-mode data noise after splitting PDV three ways, with each signal 120° out of phase from each other. Testing has demonstrated that the TDV also improves temporal resolution from the typical five-nanoseconds of PDV to a subnanosecond range. This paper compares the temporal response of TDV with that of PDV and VISAR [velocity interferometer system for any reflector] in an experiment with a subnanosecond (~120-picosecond rise time) shock source.

Laboratory tests were performed using a high-power laser on targets of copper and aluminum. A fast VISAR with a single-point PDV and a prototype TDV were used. A special probe that combined PDV, TDV, and fast VISAR made simultaneous velocity measurements. Breakout velocities of 1.3 km/second on copper and 2.5 km/second on aluminum were observed, where TDV resolved rise times of ~200 ps. This resolution was better than that of a fast VISAR, which can achieve ~500 ps temporal resolution. Test methods and results are presented.

1. Introduction

Photonic Doppler velocimetry (PDV) was introduced by Ted Strand of Lawrence Livermore National Laboratory. Data are taken by mixing the Doppler-shifted light from a dynamic target (shifted light) with the base laser light (unshifted light), producing a heterodyned frequency in GHz range. This frequency is directly proportional to the velocity of the target that can be extracted with a fast Fourier transform analysis (FFT). Because of FFT’s inherent properties, the temporal resolution is 5 nanoseconds at best (requires a full cycle to extract a frequency).

Triature Doppler velocimetry (TDV) uses a quadrature analysis concept, using a portion of a cycle of three 120° out-of-phase, identical signals to extract a frequency. This improves the temporal resolution to better than 1 nanosecond.

The tests discussed here were performed with the Sandia National Laboratories fast VISAR system. Many experiments we conduct are light-starved; this condition limits the type of detectors available to experimenters that will achieve the maximum temporal resolution of VISAR systems. These comparison tests utilized avalanche photodiode (APD) detectors with a bandwidth from DC to 450 MHz and a sensitivity of 15kV/W; their temporal resolution is ~800 picoseconds.

A PDV/VISAR probe was constructed, by NSTec, to focus a 1550 nm (PDV) single-mode fiber and a 532 nm (VISAR) 100-micron core fiber on the same plane with a magnification of 0.5. The focal points were ~0.25mm apart, as shown in Figure 1.
Laser-induced shock was accomplished with a Continuum laser with a 120 mJ pulse at a 145 ps rise and 300 ps FWHM. The targets were 10-micron copper on glass or 10-micron aluminum on glass; the targets produced velocities of \( \approx 1 \) km/sec and \( \approx 2.5 \) km/sec, respectively. A two-lens imaging system was placed at the output of the laser to convert the Gaussian shape of the laser pulse to a flat-top pulse at the target, so that velocity was evenly distributed over a 1-mm-diameter area. This assured that velocities were identical for the PDV and VISAR, which enabled comparison. Figure 2 is a map of a series of experiments with the velocities measured using a PDV system shown in Table 1.

Initial calibrations of the PDV and VISAR were performed using a high-current calibration source that consisted of a 5 \( \mu \)F capacitor charged to 4.6 kV, generating approximately 14.5 kA. The current was focused onto a 0.25-inch copper strip, producing a shock of \( \approx 3.5 \) km/sec with a slow rise time of about 0.5 \( \mu \)sec as seen in Figure 3.
## Table 1. Velocity at each position of Figure 2 (each position is a separate shot).

| Shot /Position | Velocity | Shot /Position | Velocity | Shot /Position | Velocity | Shot /Position | Velocity |
|---------------|----------|---------------|----------|---------------|----------|---------------|----------|
| 1             | 379 m/sec| 6             | 303 m/sec| 1             | 1.1 km/sec| 6             | 1.2 km/sec|
| 2             | 378 m/sec| 7             | 341 m/sec| 2             | 1.3 km/sec| 7             | 1.3 km/sec|
| 3             | 303 m/sec| 8             | 341 m/sec| 3             | 1.5 km/sec| 8             | 1.3 km/sec|
| 4             | 379 m/sec| 9             | 870 m/sec| 4             | 1.4 km/sec| 9             | 0.95 km/sec|
| 5             | 455 m/sec| Average       | 416 m/sec| 5             | 1.7 km/sec| Average       | 1.31 km/sec|

*Figure 3. High-current calibration source PDV and VISAR data.*

2. **Results from TDV/VISAR comparison**

The TDV system use MITEQ detectors that operate from 100 kHz to 20 GHz. We discovered data loss at the initial breakout at lower frequencies. This made it extremely difficult to determine the precise time of breakout and obtain a precise rise time for the data.

Optical up-conversion moves the data base line into the operating range of the detectors. This is accomplished by using a tunable laser and mixing it with the base laser, so producing a heterodyned signal that can be adjusted to the desired frequency. The mixed signal can be additive or subtractive; data are distributed above or below the base line, as shown in Figure 4.

Figure 5 is a comparison of the TDV (red) and the VISAR data (blue) at long and short time scales for an aluminum target. In the long time scale graph the data compare quite well. For the short time scale, the TDV data rise time was near 200 ps and the VISAR data at ~20 ps (one resolution element of the digitizer). The VISAR appears to have a fast rise time because the lower bandwidths miss fringes. In order to obtain the correct velocity, fringes are added by the analysis software. However, since it is impossible to know exactly where the fringes should be added in time, fringes are added in the same time period, and a false rise time results, but the correct end velocity is achieved.
3. Conclusion
The Positive Light laser is a repeatable flat-top, high-power light source that produces fast velocities for testing velocimeter systems. Optical up-conversion works well with PDV and TDV to eliminate base line noise to determine accurate data breakout. VISAR resolution is limited by detector and recording bandwidth. TDV provides better than 0.5 nanosecond resolution.

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