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PORTABLE FIBER OPTIC COUPLED DOPPLER INTERFEROMETER SYSTEM FOR DETONATION AND SHOCK WAVE DIAGNOSTICS

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ABSTRACT

Testing and analysis of shock wave characteristics such as produced by detonators and ground shock propagation frequently require a method of measuring velocity and displacement of the surface of interest. One method of measurement is doppler interferometry. The VISAR (Velocity Interferometer System for Any Reflector) uses doppler interferometry and has gained wide acceptance as the preferred tool for shock measurement. An important asset of VISAR is that it measures velocity and displacement non intrusively. The conventional VISAR is not well suited for portability because of its sensitive components, large power and cooling requirements, and hazardous laser beam. A new VISAR using the latest technology in solid state lasers and detectors has been developed and tested. To further enhance this system's versatility, the unit is fiber optic coupled which allows remote testing, permitting the VISAR to be placed over a kilometer away from the target being measured. Because the laser light is contained in the fiber optic, operation of the system around personnel is far less hazardous. A software package for data reduction has also been developed for use with a personal computer. These new advances have produced a very versatile system with full portability which can be totally powered by batteries or a small generator. This paper describes the solid state VISAR and its peripheral components, fiber optic coupling methods and the fiber optic coupled sensors used for sending and receiving laser radiation.

1. VISAR OPERATION AND DESCRIPTION

The conventional VISAR consists of a single mode, single frequency laser (typically argon ion), interferometer cavity, peripheral optics, modulator, photomultiplier tubes (PMT's), amplifiers, digitizer(s) and computer (Fig. 1). In a typical VISAR setup of the "push-pull"configuration , the laser beam is routed through a focusing lens placed in front of the surface that is to be measured (the surface is diffusely reflective). The lens focuses the light on the surface and the scattered return light is routed back to the interferometer cavity (Fig. 2). The interferometer is a modified Michaelson cavity. The beam is split and routed through the cavity in which one beam travels through glass (delay leg) and an eighth wave retarder with a mirrored coating on the rear surface while the other beam goes through air (reference leg). The two beams are recombined so that the delayed portion is shifted in time with respect to the undelayed component. The two combined beams are each split and sent to polarizing beamsplitting cubes (PBC). The beams interfere with each other producing either a bright or dark spot (constructive or destructive interference) that is converted to electrical signals by the PMT. The polarizing beamsplitting

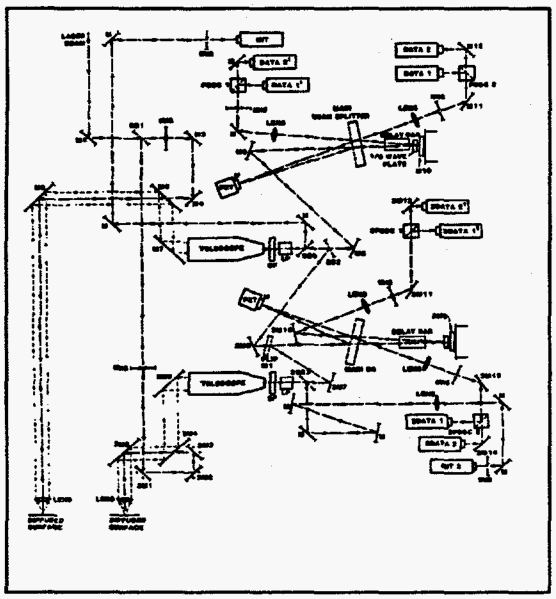


Fig. 1 Conventional VISAR Setup

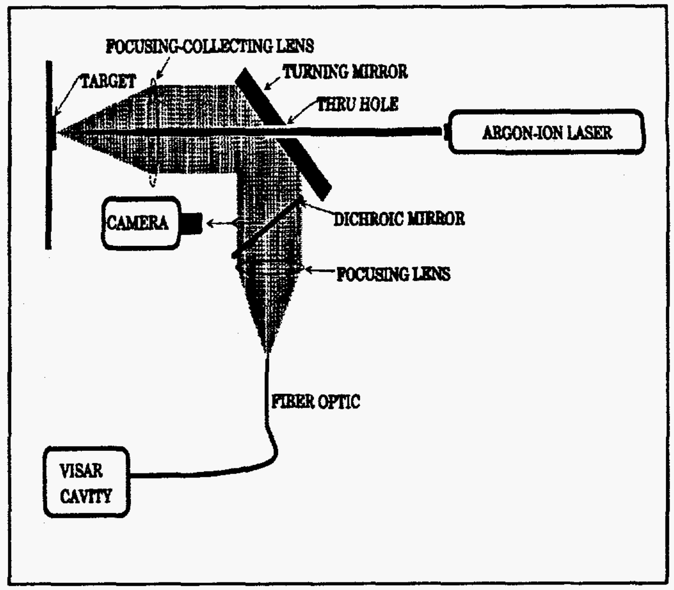


Fig. 2 External Light Paths

cubes separate and linearly polarize the light containing the doppler information into their "S" and "P" components (Fig. 3). The S and P light possess the same doppler information, but because the light passes through the 1/8 wave retarder twice, the phase is retarded by 90 degrees. The light that passes through the PBC (P component) is called DATA 2 and DATA 2' and light that is reflected (S component) is DATA 1 and DATA 1'. The two pairs of interfered light have identical phase-time information except that they are out of phase with each other by 180 degrees. DATA 1 is electronically inverted and added to DATA 1', likewise, DATA 2 is inverted and added to DATA 2'. The advantage of this method of inverting and adding the signals is that it cancels out self light and the signal amplitude is doubled. The stored data are collected and stored by high-speed digitizers and then manipulated and converted to displacement and velocity records using custom software (Fig. 4).

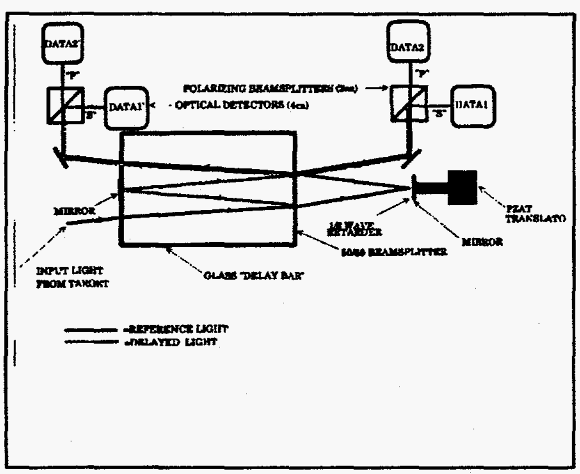


Fig. 3 Recombination of Light Paths

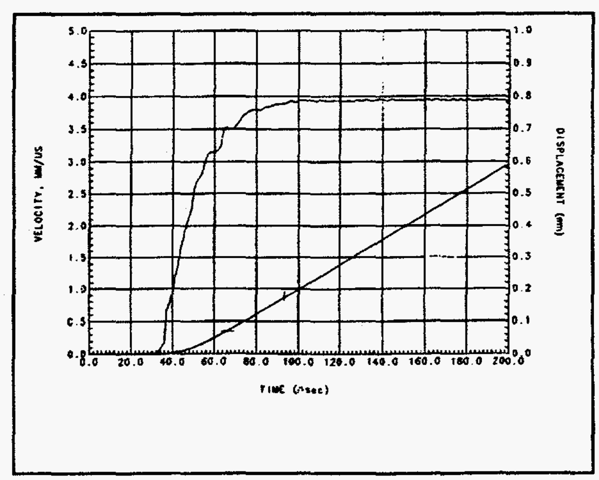


Fig. 4 Velocity and Displacement Records

When the target is at rest, the frequency of light in both legs of the interferometer cavity is equal and no change in the interference fringes pattern is observed (Fig. 5). The instant the target starts moving, a doppler shift of the light occurs (the optical equivalent of the changing pitch of a car engine as it passes by). Because the light in the glass portion of the interferometer cavity is delayed before it is recombined with the reference light, the interference fringe pattern moves. The velocity of the target is proportional to the number of fringes recorded and the amount of delay the interferometer induces to the light.

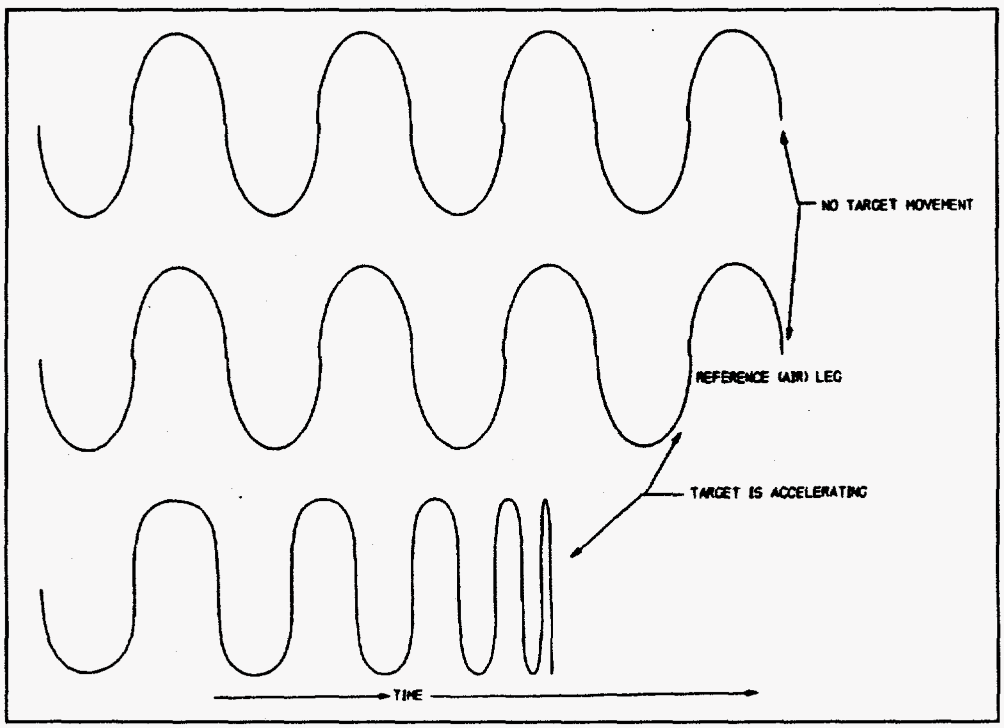


Fig. 5 Simulated Fringe Patterns

The velocity per fringe (VPF) constant relates several system parameters such as the wavelength of light (λ), the delay time (τ), the stress-dependent correction for a window ($\Delta v/v$), and the wavelength dependence for the refractive index of the window (δ). The instantaneous velocity [u(t)] is proportional to the VPF and the time-dependent phase angle between the two inverted and added signals by the equation:

$$u(t) = \lambda \frac{\phi(t)}{2\tau(1 + \Delta v / v)} \frac{1}{1 + \delta} = VPF \quad \phi(t)$$

The VISAR cavity can be configured with varying amounts of delay for the anticipated velocity range or multiple systems may be used to cover a wider range of velocities. The normal range of velocities covered by the VISAR is 100-8000 m/s.

2. SOLID STATE VISAR

VISAR has been limited to the laboratory because of its large size, sensitivity to transportation, large electrical & heating requirements and setup complexity. Recently, a new VISAR (Fixed Cavity VISAR) has been developed which uses an interferometer cavity that is permanently cemented together (Fig. 3). Although this improvement reduces the size and complexity of the system and simplifies operation, the large size, power and cooling requirements continue to restrict portability of the system. Also, fiber optic coupling is limited to short runs because of the high attenuation and low bandwidth for short (514 nm) wavelengths that the argon-ion laser produces.

Two types of solid state VISARs have been successfully designed, built and tested. The design differences revolve around the laser and detectors. These systems use low power consumption and the components are rugged enough to be used in the field. The attenuation and bandwidth are substantially lower than visible lasers allowing long fiber optic runs with minimal losses.

2.1. DIODE LASER VISAR

Single mode-single frequency diode lasers with a power output of 120 mW operating at 830 nm wavelength are used for this system. The output beam is collimated using either GRIN (GRadient INdex) lenses or aspherical lenses. To prevent mode hopping and damage to the laser, an optical isolator is installed. The Faraday effect is used to rotate the polarization of the laser light 45 degrees. Two polarizers are installed on either side of the Faraday rotator which cancels out any reflected light trying to re-enter the laser cavity. The transmitted light is then focused into a fiber optic and the light is routed to the experiment via an optical probe (Fig. 6). The light is focused on the target and the reflected light is picked up by a second fiber and transmitted to the interferometer cavity.

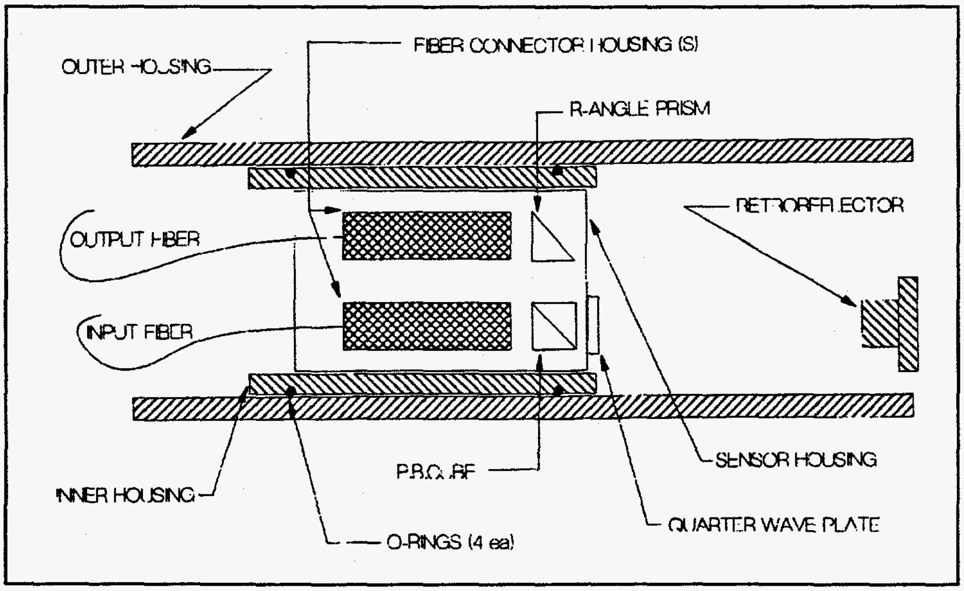


Fig. 6 Fiber Optic Probe for Diode Laser VISAR

The detectors used to convert optical power to electrical power are solid state Schottky silicon photodetectors. Silicon-based detectors are preferred because their sensitivity is peaked for the wavelength of this laser. Alignment and beam manipulation is difficult with an invisible beam. A simple solution uses a fiber optic splitter in reverse with a visible diode laser (680 nm wavelength) injected into the fiber optic and routed through the optics to the target area. Because the visible laser is routed through the same fiber optic as the invisible VISAR laser and the wavelength is not appreciably different, the insertion loss is only .5 dB per laser. This system enables the user to do the alignment without the use of infra-red imaging devices.

2.2 DIODE PUMPED Nd:YLF LASER VISAR

Although diode laser light has a fairly low loss in fiber optics, there are situations where minimal attenuation and maximum bandwidth are critical. Dispersion is a major concern in maximizing bandwidth. There is a point where dispersion approaches zero at a particular wavelength when light is propagating in a typical silica fiber optic (Fig. 7). A diode pumped Nd:YAG laser with an output wavelength of 1319 nm and output power of 160 mW is used in conjunction with InGaAs-based detectors. This VISAR is capable of operation with kilometer-length fiber optics.

3. DESIGN CONSIDERATIONS

Although these two types of lasers mentioned above are quite different in their lasing mechanisms, they share many of the same traits that must be considered when designing a solid state VISAR.

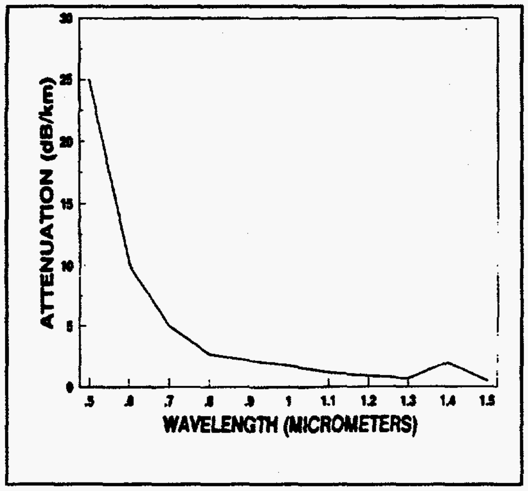
3.1 OPTICAL FEEDBACK

Optical isolation of the laser from any backreflected light is essential for proper mode structure and longevity of the laser. A diode laser operating in the single frequency-single longitudinal mode is especially sensitive to optical feedback and will hop modes or operate in a multimode structure with as little as .05% backreflected light returning to the cavity (Fig. 8). Isolation of greater than 38 dB using a TIGG crystal Faraday rotator is usually enough for most applications. Minimization of fiber optic connectors will also reduce the feedback due to Fresnel reflections at each connector surface. Wherever possible, connectors that use index matching fluid should be employed to virtually eliminate Fresnel backreflections.

The Nd:YLF lasers are 30-100 times less sensitive to optical feedback than diode lasers. Also, the longer operating wavelength allows the use of BIG (bismuth iron garnet) deposited film isolators. Termed "aspirin tablet" isolators, they are well suited for compact design when size is important.

3.2 LIGHT INJECTION INTO FIBER OPTIC CABLES

Injecting light from a laser diode into fiber optics is more difficult than with most lasers emitting a collimated beam because of the large non-uniform beam divergence. To reduce optical feedback, care must be taken to not design with planar surfaces that are normal to the laser. Because the beam's divergence is too large for direct transmission through the optical isolator, it must be collimated first, meaning that there is no isolator protecting the laser from the fresnel reflections off the lens. Two types of collimating lenses have been used successfully with the diode laser. A GRIN lens with a convex front surface and an angle polished rear surface both with anti-reflective coatings is an economical, compact method of collimating the light through the isolator. Recently, Corning Glass has been able to manufacture diffraction limited aspheric lenses that are also suitable for optimum collimation while minimizing aberrations.



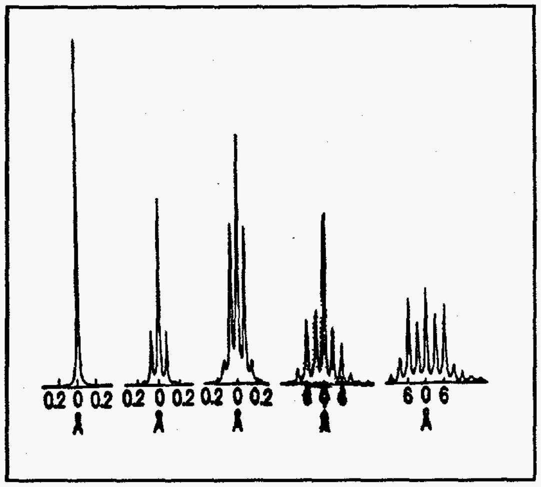


Fig. 7 Attenuation in Fiber Optics

Fig. 8 Spatial Mode Structure

These methods of collimation are not necessary for the Nd:YLF laser because the light is collimated well enough for transmission through the isolator. Selecting optics for injection of light into fiber optics is dependent on the diameter of the fiber optic core and its Numerical Aperture (NA). The NA is the sine of the half angle of the cone of light exiting a lens. The NA of a fiber optic is the sine of the maximum half angle that light is coupled and guided in a fiber and also the half angle of the exiting light. The ideal optical design for light injection is a diffraction limited lens with a focal length as short as possible with the working NA of the lens less than the NA of the fiber.

3.3 FIBER OPTIC SELECTION

Careful selection of fiber optics is essential for proper bandwidth and efficiency of the system. Multimode fiber optics are preferred because single mode fiber optics are difficult to inject light into, are sensitive to bending and exhibit nonlinear effects such as Stimulated Brillouin Scattering and wavelength broadening. Normally, light is sent to the target in a 50 μm fiber optic and collected with the largest fiber that still has adequate bandwidth for the test. The small diameter of the sending fiber has a smaller exit aperture and is easier to image a small spot on the target. Conversely, the smaller spot is more efficiently imaged into the return fiber and thus signal strength is larger. Visible wavelength laser beams not only exhibit large attenuation in fibers but the bandwidth is also lower due to more coupled modes and higher dispersion. Although the diode laser has low attenuation and dispersion in fiber optics compared to the argon-ion laser, the Nd:YLF laser operating at 1319 nm wavelength has much lower attenuation than the diode laser and has the lowest dispersion of any laser operating outside the 1300 nm wavelength. This is due to several modes of dispersion canceling out each other.

3.4 DETECTORS

For most uses, PIN, Schottky and APD are the three most common types of high speed solid state photodetectors. An avalanche photodiode (APD) has an internal gain when biased near its threshold. Its disadvantages are that it must have a very well regulated high voltage power supply and they also have fairly long transit times for the hole carriers. The PIN diodes have fairly high parasitic resistance which reduces the operating bandwidth. Schottky diodes are the preferred choice because they have low parasitic resistance allowing a high bandwidth while retaining a larger active area than APD or PIN photodiodes. Large active areas are essential for ease of alignment because the light must be focused completely into the active area of the detector (some high speed detectors have active areas of only 100 μm diameter).

4. SUMMARY

The visible laser/photomultiplier tube VISAR with the open beam to the target is the simplest, most light efficient system and is preferred for laboratory conditions where short, if any, distances of fiber optic transmission is required. If the user needs remote testing capabilities, low power requirements, portability, or foresees any condition where long lengths (>200 m) of fiber optic cable is needed, the solid state fiber coupled VISAR may be the system of choice.