RESEARCH PROFILE

The University of Wisconsin–Milwaukee
The Graduate School

John Gilbert demonstrates that continuous wave laser light can be launched and transmitted through a flexible fiber optic.

Gilbert hopes to develop techniques that "will ultimately give Milwaukee-based industries a technological edge over their competition."

Laser-Based Stress Analysis and Fiber Optics

For more than a century, most of the world's long-distance communication has been transmitted through copper wires using electric pulses. In recent years, those traditional methods have been complemented by a new technology stimulated by the availability of the laser–one that transmits messages by sending light pulses through thin glass fibers called fiber optics. These optical wave guides transmit light throughout their length by total internal reflection.

In addition to applications in telephone conversations, fiber optics are helping to provide solutions to problems in such diverse areas as engineering and medicine. Medical practitioners use the new technology with instruments such as endoscopes and cystoscopes that allow them to view illuminated interior structures in the human body. There are also a number of practical applications of fiber optics technology. Perhaps one of the most familiar is the supermarket scanner, in which a laser light beam reads the universal product code on consumer products and transmits pricing and inventory information through a computer network to a display terminal at the check out counter.

One of the scientists seeking to refine various fiber optic techniques relative to a number of different applications is John Gilbert, associate professor of engineering mechanics. Among several research goals, one of his primary aims is the development of laser-based stress analysis techniques which he hopes "will ultimately give Milwaukee-based industries a technological edge over their competition."

Gilbert is working, "trying to access remote areas of structures through fiber optics," he says, "to use them as environmentally insensitive light guides to channel laser light from the source, which is our laser, to a test object. Since fiber optics are small and flexible, one can use them to gain access to remote areas of structures, or to illuminate objects which are underground or submerged. We then attempt to transmit the signal back through a bundle of these fibers from the test surface to the recording site where we can track amplitude and/or phase changes caused by loads applied to the test object. Essentially what we're looking for is surface movement," he adds, "which gives us displacement information. We take the derivative of this data to determine strain and then incorporate material properties to obtain stress." This is called experimental stress analysis.

In testing actual engineering structures, experimental stress analysis has traditionally depended on techniques such as brittle coatings or strain gages. Gilbert's research in laser technology will provide alternate methods for conducting tests through fiber optics.

Thermal deformations of a leadless ceramic chip carrier.

He points out that a part of his research deals with holography, which is a method of reproducing three-dimensional images without cameras or lenses, using photographic film and laser light. In holography, a beam of coherent light from a laser is split in two by a semitransparent mirror, so that one beam–the signal beam–can illuminate and be diffracted by the object to be reproduced onto a photographic film or plate. The other beam–the reference beam–falls directly on the photographic film or plate. The superposition of the two beams causes interference patterns to be recorded as a hologram. An exact duplicate of the original object can be viewed through the developed plate when it is illuminated with the reference beam. In engineering applications, holograms are superimposed to reveal shape changes which are caused by applied forces. This process is called holographic interferometry.

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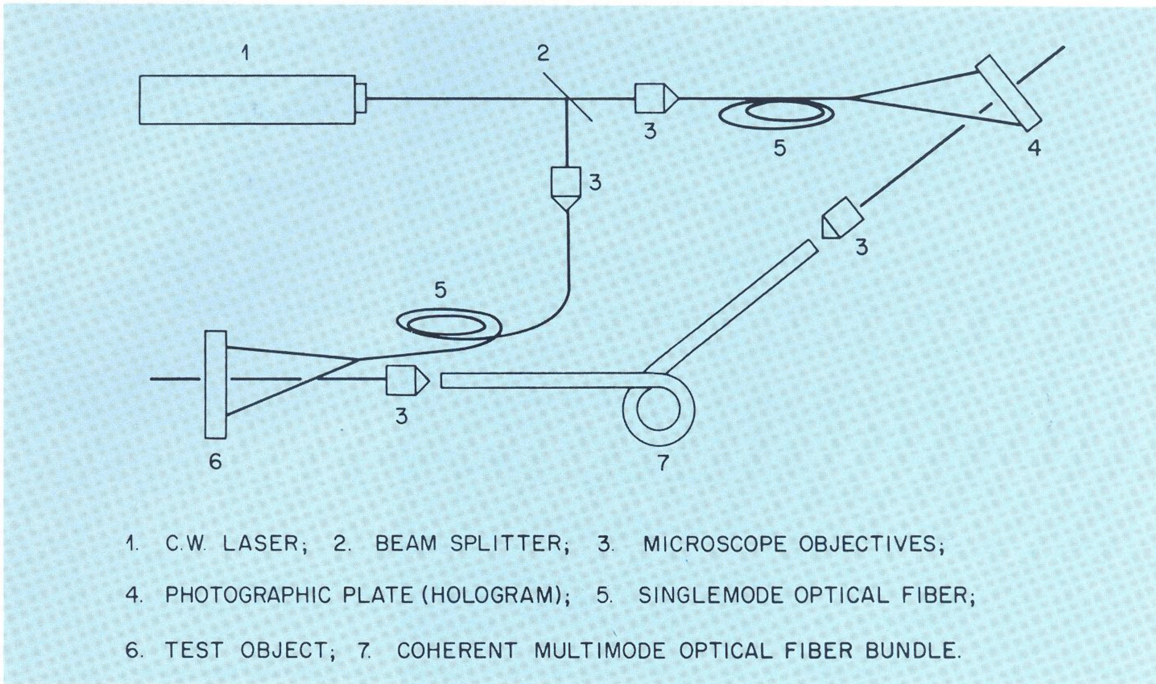

Experimental setup for holographic displacement analysis through fiber optics.

". . . laser based/fiber optic techniques . . . are non-contact, non-destructive, and extremely sensitive."

In pioneer studies, Gilbert has shown that it is possible to make holographic interferometric measurements through fiber optics on remote surfaces subjected to constant loading. He is now using a fiber optic system to record dynamic events in which the test object is subjected to continuously changing forces. In these tests, the photographic plate is replaced with a photopolymeric system which automatically records and stores holographic information on site and eliminates the need for processing film in a darkroom. The reconstructed image is captured using a vidicon camera, digitized with a microprocessor and then analyzed using a main-frame computer.

He explains that "one of the major advantages of using laser based/fiber optic techniques over more conventional experimental methods is that they are non-contact, non-destructive, and extremely sensitive. They can be applied to problems which up to now have been difficult or impossible to attack."

These might include detection of defects or crack initiation and growth in composite materials and measurement of deformation on external or internal surfaces of objects where direct access is difficult if not impossible. Such areas would be found, for example, inside an airplane wing or on the walls of an underground pipeline.

Gilbert notes that "we may ultimately be able to apply our approach to make strain measurements on organs in the human body." Fiber optics can also be used, he says, not only to gain access to remote areas of a structure, but "to reduce the number of optical components required for testing and to increase the flexibility of the experimental set-up.

"These newly developed holographic/fiber optic techniques can be used in many research-oriented efforts," he adds, "and in certain industrial applications. Unfortunately, however, adequate stability for production-related or in-situ testing cannot be completely assured with present generation fiber optics."

Until the needed components become available, Gilbert is searching for alternate means for transmitting holographic data in more practical applications. He explains that "the object wave reflected from the test surface can be combined with a reference beam at a remote location to produce a low frequency hologram. Instead of immediately recording the hologram at the test site, it can be transmitted through a fiber bundle to an alternate site for subsequent recording, playback, and analysis." Gilbert calls this new technique ultra low frequency (ULF) holography.

On the production line in a factory, for example, ULF holograms could be transmitted from work stations, through fiber optics, to another site such as a laboratory for observation and analysis. By measuring the differences shown in a number of holograms, scientists could determine whether the part, or product, is within quality specifications.

"Lasers allow us to test prototypes or even finished products without the threat of impairing their structural characteristics or their performance," Gilbert says. He adds, however, that "most current industrial applications of fiber optics are confined to short distance data links and commercially available fiber bundles are relatively short. Eventually, though, longer bundles will be produced, making remote sensing a real possibility in production line settings or wherever there is a need to test on one site and record and interpret the results at another site."

An alternate approach for measuring surface deformation relies on the specular nature of laser light scattered from an illuminated test object. Light from different points on the surface combines to produce interference which is observed as spots or speckles. These move when forces are applied to the object. Gilbert transmits a speckle pattern of the illuminated surface through fiber optics to his vidicon camera where it is digitized with a microprocessor. Loads are applied to the structure and a second displaced speckle pattern is recorded. The two patterns are numerically correlated in a main-frame computer to measure dis-

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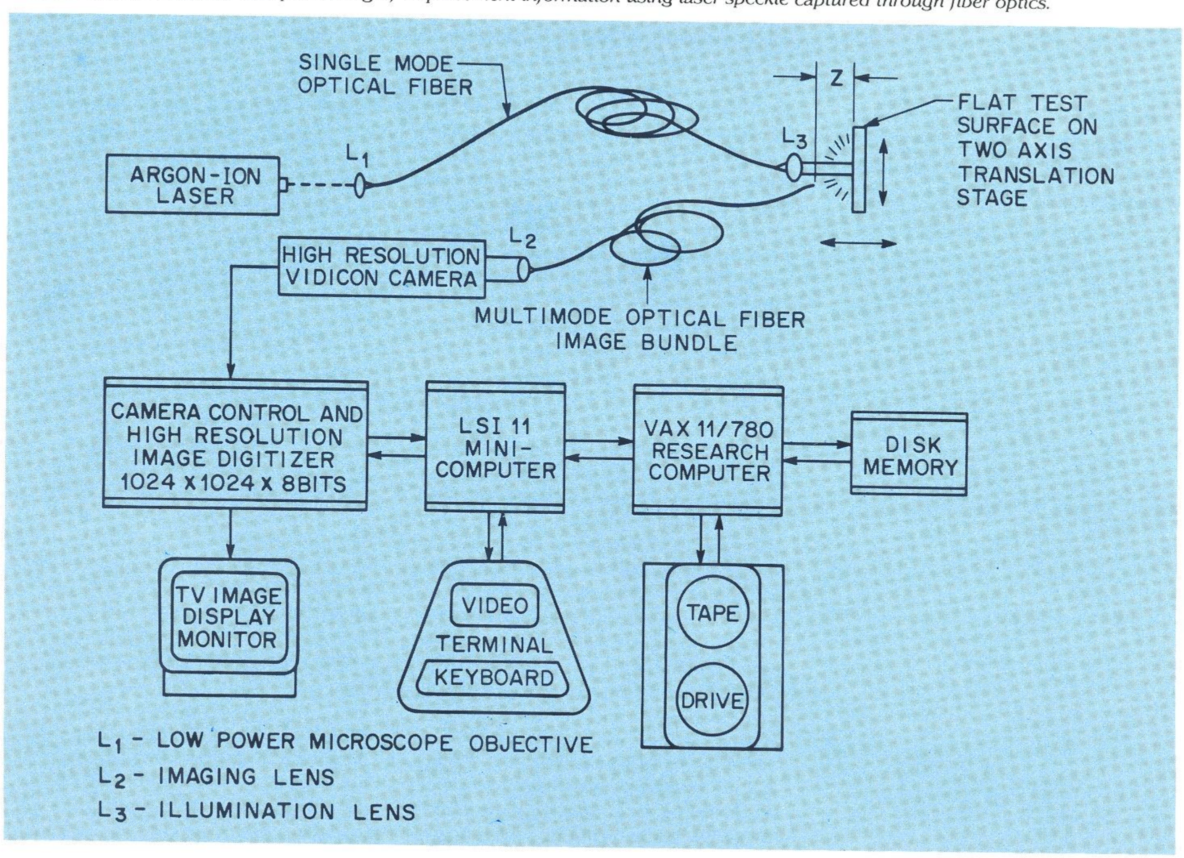
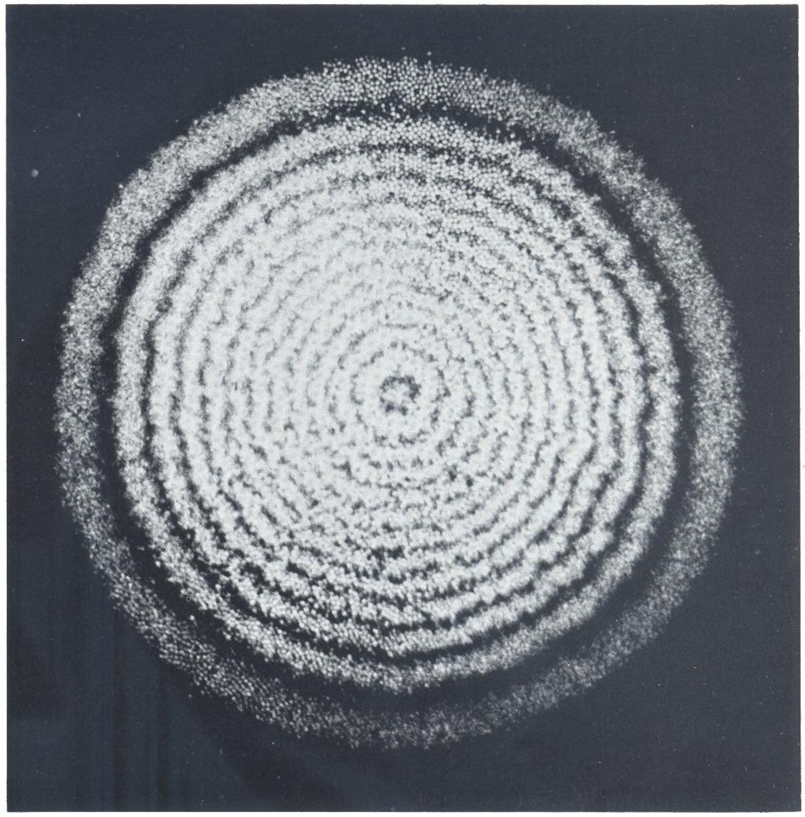
Photoelectronic-numerical data processing of displacement information using laser speckle captured through fiber optics.





Holographic displacement pattern of a circularly clamped disc loaded at its center.

"This technique combines the best of two approaches to stress analysis."

placement. This technique has recently been incorporated into a new hybrid testing method for stress analysis which combines experimental and finite element methods.

Gilbert explains that "the conventional finite element approach to stress analysis involves numerical modeling of a structure under applied loads. A grid network is established throughout the entire part and conditions are specified on each boundary in terms of displacement and/or traction. Stresses are computed based on an iterative numerical solution which is only as accurate as the mathematical description of the loading and geometry of the problem at hand. When these become complicated, the model may neglect important factors which could significantly influence the stress distribution in an actual prototype."

In Gilbert's new hybrid technique, a critical subsection of the part is isolated. Displacement is specified on the boundary of the subsection from experimental tests conducted on an actual prototype. Stresses are then numerically evaluated throughout the subsection using the finite element method. He asserts that "this technique combines the best of two approaches to stress analysis," and hopes to bring this method to the attention of Milwaukee-based industry in order "to give them a technological edge over their competition."

Gilbert's research in recording and analyzing surface deformation patterns is funded by the Army Research Office and the National Science Foundation. He also works with Bell Telephone Laboratories in Murray Hill, New Jersey, on data reduction techniques and is exploring possible medical applications with American Cystoscope Makers, Inc., of Stanford, Connecticut. Local industry, in particular the Allen Bradley Company, supports his research on the hybrid stress analysis method. RP