Optical Sensing with Coherent Imaging Fibre bundles

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Abstract

The use of coherent imaging fibre bundles for optical sensing is discussed. A description of the characteristics of the bundles is followed by examples of their use in laser velocimetry, shearography and optical coherence tomography.

Introduction

The use of coherent optical fibre bundles, in which the individual fibres are arranged such that the relative position of each individual fibre is exactly the same at the proximal and distal ends of the bundle, provide added functionality and flexibility for optical instrumentation. This paper briefly introduces the characteristics of the imaging fibre bundles followed by illustrations of their use in three different instruments; full-field planar Doppler velocimetry; speckle shearing intereferometry for quantitative full surface strain measurment; optical coherence tomography for biomedical and engineering applications.

Coherent Imaging Optical Fibre Bundles

Two types of commercially available bundle have been investigated for the instrumentation systems described later; wound and leached [1]. A wound bundle is comprised of many hundred "multifibres" wound on a mandrel. The multifibres are groups of 5x5 individual fibres assembled on a 10 µm centre spacing in a square-packed arrangement, as shown in figs 1 & 2. The individual fibres have a core diamter of 8um. The ends of the bundle are fused to produce a rigid section enclosed in a ferrule, while the centre portion remains flexible. Interstitial absorbers are used to reduce coupling between the fibres. Leached bundles are formed by drawing a rigid rod composed of stacked fibres, and then etching away the cladding from all except the end sections. Fibre bundles are purchased as a component of selected length, typically 0.5 to 4m, with both ends polished to a high-quality optical finish.

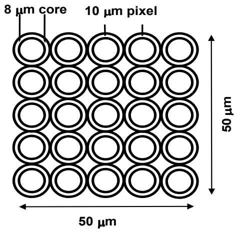

Fig.1. Wound fibre bundle "multifibre".

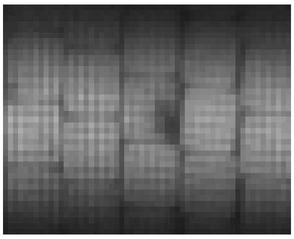

Fig.2. Photograph of 5x5 multifibres.

Losses are higher than for single fibres but typically 10-50% is transmitted dependent on length and wavelength.

Planar Doppler Velocimetry (PDV)

The non-intrusive measurement of flow using laser methods has proven to be invaluable as a diagnostic tool for many years both for the designer and also for those interested in fundamental investigations of fluid mechanics. In planar flow measurement a region of the flow is illuminated with a laser beam conditioned to form a light sheet in the region of interest. The light scattered from particles entrained in the flow is imaged onto two-dimensional detector arrays, usually CCDs .

Three components of velocity can be measured instantaneously or time-averaged depending on the laser source and image processing methods used. PDV was originally implemented using conventional optical components, but more recently the addition of optical fibres to the instrumentation has added considerable flexibility and functionality to the technique [2,3].

PDV relies upon measuring the Doppler frequency shift of light scattered from particles entrained in the flow. The technique allows the measurement of the three-dimensional flow velocities over many points in the plane, quickly and non-intrusively. Multiple viewing, or illumination, directions are required for multiple velocity component measurements. This would usually require multiple imaging systems, however the use of imaging fibre bundles allows several observation directions, and thus velocity components, to be measured simultaneously by spatially multiplexing on to a single CCD camera (fig 3.).

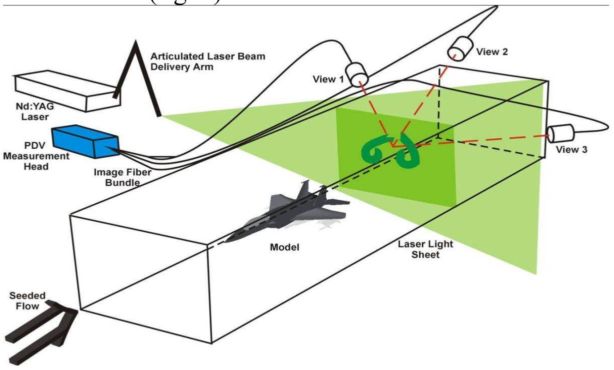

Fig 3. PDV using multiple imaging fibre bundles to view light scattered from a laser light sheet.

Wound fibre bundles (fig 4), each 4m long, are used with imaging optics attached to the individual ends. Each bundle conatins 600x500 individual fibres. The Doppler shifted scattered light is transduced to intensity using either an iodine absorption filter or an interferometeric filter. An exampe of a 3-component flow measured using this method is shown in Fig 5.

Figure 4 - (a) Entry faces of the four-channel bundle without imaging optics. (b) Combined exit face of the four bundles.

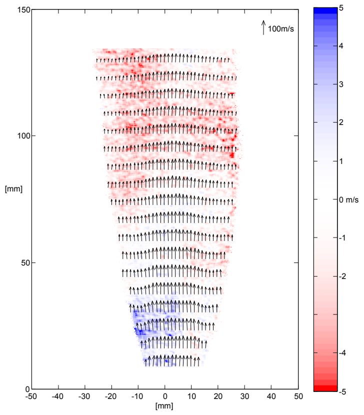

Fig 5. Jet flow measured with fibre bundle based PDV. The vectors show the in-plane direction and the magnitude of the flow and the colour coding indicates the out-of-plane velocity.Maximum velocity is ~100m/s

Speckle Shearing Interferometry

Measurement of surface strain in safety critical industrial components and structures is vital in reliability assessment, quality assurance and product optimization. Optical measurement techniques are advantageous because they can provide a non-contact, full-field measurement of the surface under investigation. Speckle shearing interferometry, often termed shearography, is a full-field optical technique that is sensitive to the derivative of displacement of the surface under investigation. Its resilience to environmental disturbances has made it a successful measurement technique for use in industrial settings where it is often used for the qualitative detection of mechanical defects in components. By illuminating, or viewing, from multiple directions it is possible to obtain quantitative surface strain information. The fibre imaging bundles described in the previous section have been combined with shearography to obtain quantitative measurements from static and rotating test objects [4]. The experimental arrangement is shown in fig 6 and example results in fig 7 for an illuminated area of ~4x3 cm^2.

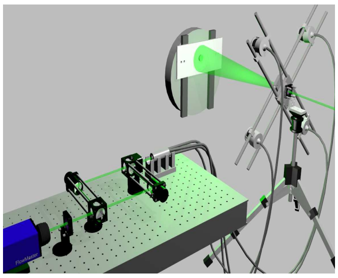

Fig 6. Light scattered from a static or rotating test object is collected by lens/imaging fibre bundles and ported to a CCD via a shearing interferometer.

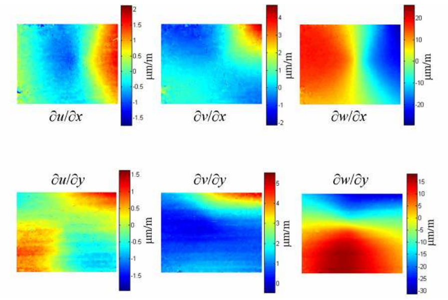

Fig 7. Orthogonal displacement derivative components from a flat plate clamped around the edge and deformed in the centre.

Optical Coherence Tomography (OCT)

OCT is an application of low-coherence interferometry used primarily for biological imaging, and seen as a potential aid in the identification and treatment of epithelial cancers. We are investigating coherent optical fibre bundles to develop small-diameter, passive OCT probes that offer 2-D or 3-D imaging of tissue and non-biological materials such as engineering composites, with no mechanical scanning required within the probe section. An example of an experimental OCT configuration is shown in fig 8 that operates at 1300nm and uses a leached fibre bundle [5].

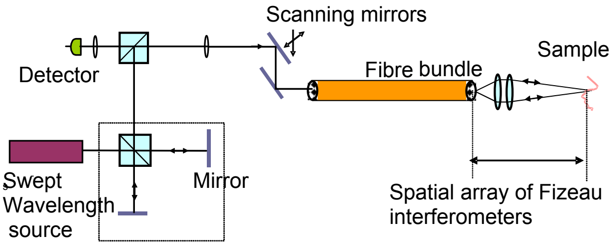

Fig 8. OCT with swept laser source. The beam is scanned across the input face of the fibre bundle and a Fizeau interferometer is formed between the distal fibre ends and the sample, sequentially, for every fibre in the bundle.

Summary

Coherent optical fibre imaging bundles offer a versatile and flexible contribution to a range of optical instrumentation systems. Development of fibre bundles that operate more effectively at longer wavelengths will result in this technology finding increasing use.

References

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