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COHERENT LIGHT METHODS FOR THE STUDY OF MECHANICAL VIBRATIONS

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SPECKLE REFERENCE BEAM (BY RETRO REFLECTION) HOLOGRAPHY FOR THE REAL TIME VISUALISATION OF VIBRATION PATTERNS.

BY P. Waddell - Mechanical Engineering Group, University of Strathclyde.
W. Fagan - Centre for Industrial Innovation, 100 Montrose St. Glasgow.

Introduction:

The authors have evolved a new form of hologram interferometer for the viewing of objects which have retro-reflective surface coatings. The system is capable of comfortably examining objects to around 5 feet in diameter, the objects being illuminated by a Spectra-Physics 1 milli-watt laser. The cost of the optics is minimal, several pounds. The interferometer could possibly be used in an industrial environment due to the lessening of vibration isolation requirements, by retro-reflecting a reference beam from the object under investigation.

Continuous wave laser holography (1, 2) has been limited to a laboratory environment, mainly due to the stringent vibration isolation requirements, essential for taking high quality holograms. Large surface area object illumination also presents the problem of acquiring very expensive, high powered, C.W. lasers to clearly illuminate the object allowing for large diffuse reflection light losses of the light back to the hologram. Pulsed holography (3, 4) has overcome the first limitation, and in private correspondence with Dr. R. Wuerker, T.R.W. Inc., Los Angeles, the authors have seen hologram photographs of the contours of a nine foot diameter paraboloid atenna using ruby laser illumination. In general however, additional technology is required and the associated increased expense has prevented a widespread acceptance of this technique. A further drawback is that one cannot monitor the surface distortion in real time with a pulsed laser illumination, usually essential for vibrational analysis to obtain perfectly formed patterns or to exactly determine the natural frequencies.

The technique described in this paper has been aimed at lessening the rigorous vibration isolation requirements and to use very low powered, inexpensive lasers for illuminating large surface areas.

The vibration isolation technique does not require; the attachment of mirrors to the object (5), the optical processing of the reference beam before striking the hologram (6), a scanning reference beam (7), or an electronic feedback servo-system (8, 9). All the advantages of C.W. holography are retained i.e., double exposure, time averaged and real time visualisation of the surface distortion. The authors have been investigating the use of retro-reflective materials for several years, the work having been published in papers (10, 11) and articles (12, 13). Using the 3 M Company "CODIT" paint, the largest object/ previously tackled by the authors was a 36 inch long steam turbine blade, illuminated by a 20 milli-watt Scientifica-Cook He-Ne laser (10).

A new material has been supplied to the authors by the 3 M Company, Minneapolis, U.S.A., which is around 40 times more reflective than "CODIT". The new material was obtained in paint and thin adhesive backed tape versions. It can be easily applied and removed from the object under investigation. The photographs of this paper illustrate the virtual images of the 36 inch long turbine blade, being illuminated by a 1 milli-watt laser. The blade is covered with the new retro-reflective material. A 1 milli-watt laser with polarised light output can be purchased from Spectra-Physics for just under £100.

The optical interferometer described above (10-13), is illustrated in Fig. No.1. Assuming the large, costly, beam splitter to be a perfect 50% reflective, 50% transmissive type, no absorption losses and the object to 100% retro-reflect all the incident light, only 25% of the laser intensity will fall on the hologram, i.e., 50% of 50%. However due to scattered reflection from the object and splitter absorption losses in passing through the splitter one will obtain at the hologram around 15%. The problem was how to eliminate the large beam splitter, incidentally cutting down on the cost of the optics, and still retain the retro-reflective action of the reflected light from the object to the viewers eye. Figure No.2A illustrates one arrangement of how this can be achieved. The laser light is opened out by a microscopic objective onto a very small mirror (¼ inch diameter laser mirror). From the mirror the light continues to open out onto the object. The retro-reflected light has a small cone angle of scattered light, which focusses behind the mirror, at a distance equal to that of the microscopic objective from the mirror. The cone diameter can be of the order of 1 inch diameter or larger for large objects, however one can obtain equally good holograms by placing the photographic plate beyond the focussed area in a larger cone diameter of light. The hologram still sees the entire object. Such a system gives a light gain over the splitter method, of approximately 5 times. 10% of the light intensity is taken off for a reference beam and 90% of the light intensity is used to illuminate the object. Allowing for small scattered light losses on the object, approximately 80% returns to the hologram, which compares with 15% by the splitter method. Employing such a system along with the new materials for coating the objects has resulted in an approximate gain of 200 (i.e., 5 x 40) over "CODIT" paint and the splitter arrangement. It is usual in such a system as that described above, to use reference/object beam intensity ratios (measured at hologram) of 1/10th to 1/5th as opposed to ratios of 3 - 5 for diffuse reflection holography. The new materials have absolutely no depolarisation and create little optical 'noise' in the reflected beam. To the hologram, the two beams (object and reference) are light intensities of equal polarisation and compatible noise content. In diffuse reflection /

holography the reflected beam is highly depolarised and has a large 'noise' content and has to be mixed with a much more intense non-depolarised, low noise content, reference beam. In Fig. No.2. the reference beam is directed by the splitter (glass sheet) to the objects surface, usually at an area where there is no forced vibration amplitude or strain, i.e., a node or a clamping position. From the surface it retro-reflects to the hologram. In reflection the speckles are found to be very widely separated, giving rise to a high quality reference beam. A speckle reference beam system for object motion compensation has been described in an excellent paper by an American researcher (14). Diffusely reflecting surfaces were used, the beam having to be focussed to a fine spot on the object before scattering to the hologram. Once again the reflected speckles are widely spaced giving a good reference beam for the hologram. However focussing of the reference beam can cause thermal expansion of the objects surface, giving rise to very poor hologram images, unless a temperature stabilisation period is allowed. Should a double pulse ruby laser be used, the speckle reference beam allowing a compensation for unwanted whole.body object movement between exposures, then the focussed beam could cause material damage to the object's surface. The authors' technique of using a very low powered laser and with no focussing of the beam means that objects made of any type of material may be investigated immediately and without surface damage.

To test the effectiveness of the retro-reflected speckle reference beam, to compensate for unwanted object displacement, the following experimental arrangement was used. The laser was placed on a wooden bench, the optics on a small thin steel table and the object on a wooden stool, no anti-vibration mounts were used.

Using the optical configuration illustrated by Fig. No.2., the authors investigated the vibration patterns, in real time, of a 36 inch long blade using a 1 milli-watt laser for illumination. A non contacting air horn vibrator was used to excite the model. It should be noted here that satisfactory illumination has also been achieved over a 60 inch diameter circle of light on a section of retro-reflective screen using a 1 milli-watt laser. Real Time/Time Averaged (10, 11, 12) and time averaged (15) virtual image photographs in this paper illustrate some of the modes of vibration.

Photograph No.1.	One torsional mode of vibration Real Time/Time Averaged
Photograph No.2.	One torsional, 2 transverse modes of vibration Real Time/Time Averaged
Photograph No.3.	One torsional, 4 transverse modes of vibration Time Averaged

Real Time/Time Averaged interferometry enables the viewer to quickly visualise the complete vibration patterns in real time, without the use of a stroboscope (10, 11, 12). A 35 mm camera and f stops of 2.5 to 4.0 will enable all the patterns to be photographed through the one hologram.

As mentioned in (10, 11, 12), an inexpensive exact location hologram plate holder, devised by the authors, enables the zero fringe (all dark) or all bright fields on the static and non vibrating object to be readily achieved. It is essential to have these conditions in the static object image hologram, to ensure the investigation of accurate vibration amplitude information. A modified version of the plate holder (10, 11, 12) is illustrated in Fig. No.3., and consists of a small laser mirror suspended over the hologram holding frame. Such an arrangement allows the retro-reflected cone of light, much larger than the mirror, to pass by the mirror and focus on the hologram and the viewers eye. A phase map of the vibrational pattern may be obtained by directing the reference beam to different parts of the object (16).

The photographs illustrate some interesting points. Waters (14) states that theoretically, highly curved objects can not be compensated for, with a focussed speckle reference beam. Since the surface normals vary rapidly over the surface they would not produce equal phase changes (from unwanted whole body movement) between the object and focussed reference beams. Waters however discovered in practice that considerable surface angular variations were compensated for in diffuse reflection and the holograms still produced good images. The photographs 1 - 3 above all show good reproduction quality and reasonable contrast in the fringes, the motion of the highly curved surface apparently being compensated for. Work is being undertaken at the moment by the authors to investigate the different types of whole body motion which can be compensated for by retro-reflected speckle reference beams. Motions to be considered are (1) transverse, i.e., normal to the surface, this is taken care of by a normal reference beam to the surface as used in this paper. (2) lateral motion i.e., along the object surface direction is taken care of by having the object illumination almost normal to the surface, and the angle between the incident illumination direction and the hologram to be as small as possible. This is achieved in the retro-reflective system described. The object is placed at a reasonable distance from the hologram to reduce the cone angle of object illumination to the object surface. The object being placed at a distance from the hologram presents no reflected light intensity problems at the hologram, the retro-reflected light still focussing at the hologram. The angle between the illumination at any object surface point and the hologram is nil, since the incident and reflected light is almost in line at all points of the objects surface. Diffuse reflecting surfaces of large objects would lose a great deal of the incident light in reflecting to the hologram, especially when the object is placed at a considerable distance. (3) Rotational motion of an object about a plane on the objects surface cannot be compensated for with either a retro-reflected, unopened, reference beam or a focussed, diffuse reflected, reference beam. Different points on the surface have different degrees of motion i.e., zero at the rotation axis and increasing with increased radius from that axis. In such a case a strip or strips of reference beam could illuminate along a radius of the rotating object to be retro-reflected to the hologram. The reference beam strips will have phase variations, proportional to distance from the rotational axis, impressed upon them. The strips will mix with the focussed object beam reflected light at the hologram thus producing strips of compensated holograms, each one compensating for a particular radius. The authors are investigating this and other novel techniques for a complete object motion compensating reference beam system, enabling C.W. holography to be applied to large industrial objects in situ. It is hoped in the near future to use photo-plastic holograms, where no chemical processing of the hologram will be required. One technique is to apply a voltage over a plastic film, which is coated with a thin metallic layer. Light from the object landing on the film, alters the electric charge locally, melts the plastic and forms a series of ridges. High resolution images are presently being advertised by several manufacturers. Additional information can be added a number of times without erasing the original image. The strain pattern or a difference in shape pattern could still be compared hours or days later by comparing the new and old images. The system promises to be very cheap and of course easily transportable. The plates are insensitive to light until the electric charge is applied; thus they can be loaded into a holding frame in an industrial environment without fear of 'fogging'. Retro-reflected light intensities normally are very high, thus even with the overhead lights on, if the charge is applied during the exposure time for the hologram, the retro-reflected light pattern only will be recorded. The 3 M and General Electric Companies, U.S.A., amongst others, are already at an advanced stage of progress with such photoplastics and similar techniques. It is hoped that such a recording system coupled to a viewing system such as described in this paper will provide a complete system for strain and vibration pattern analysis for a few hundred pounds, including the laser cost. Patents have been applied for.

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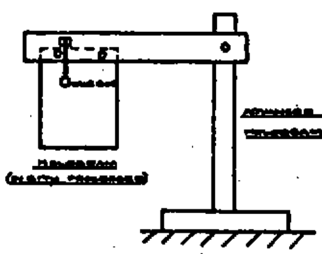

Fig. 3

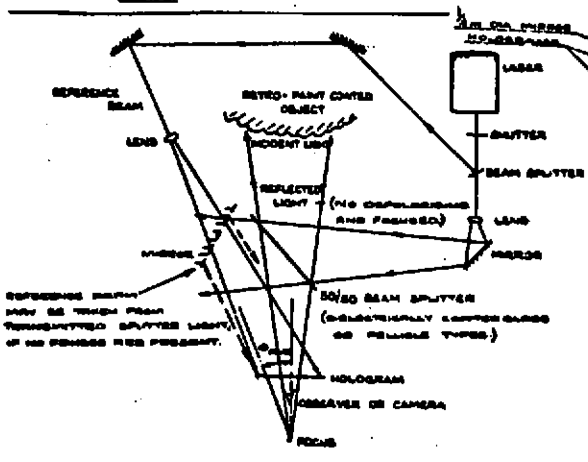

FIG. 1. RETRO-PAINTED MODEL SYSTEM.

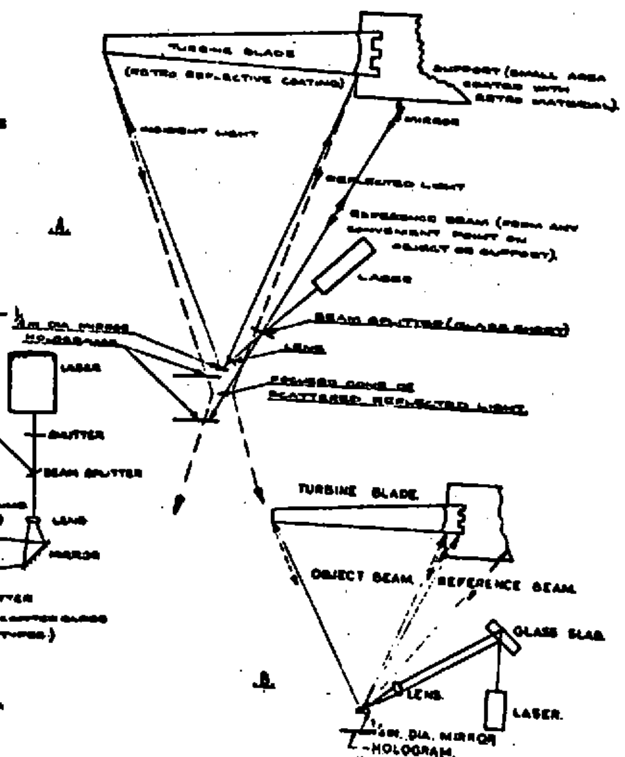

Fig 2.