REPETITIVELY PULSED LASERS FOR HOLOGRAPHIC RECORDING

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The recording and measurement of mechanical vibrations has provided some of the first evidence for the power and usefulness of holographic and speckle-correlation methods. Most of the work which has proved itself so far has been restricted to the measurement of amplitude distributions on the external surfaces of solid bodies, usually in respect of displacement in one resolved direction. Even in this limited field of study, coherent methods have greatly surpassed the convenience and usefulness of established techniques, and often have provided almost an embarrassing redundancy of information. Perhaps it may not be too early now to take a general view of the extent of the problem presented in recording and measuring vibration by optical methods. It will then be possible to relate present achievements to possible extensions, to pick out promising developments, and to see what laser sources will be needed.

The study of vibration divides itself in three ways. Firstly, the nature of the vibration itself has over-riding influence on the recording and measurement. Apart from the question of whether the vibration is steady or changing, a forced vibration or a resonant vibration, damped or undamped, and other similar questions, it is necessary to ask how many independent modes of oscillation exist and how these inter-relate, to optimize the recording and measurement. Cases may be characterized, in the second place, by the number of spatial dimensions of the vibrating object over which observations are to be made from the holographic record, and thirdly, by distinguishing the range of observations as functions of the time variable.

1. Degrees of freedom for oscillatory behaviour ("F" in Table.)

Mechanical vibration may involve the simultaneous action or interaction of oscillations in many physical characteristics. For example at any point in a vibrating structure or elastic medium, there may be oscillations in

Spatial displacement or rotation (1,2, or more orthogonal vectors), Fluid velocity, Temperature, Magnetic or Electric Potential, Density, Pressure, or Refractive Index.

The interactions between these oscillations may be regarded as separate entities, and the number of such distinguishable entities, or degrees of freedom, is an indication of the magnitude of the recording and measuring problem. As an example, we could confine our attention to a simple case, where the vibration at a point in an isotropic solid has three components in the x, y, z directions which we have to regard as independent.

2. Extent of coverage of the vibrating body ("M" in Table.)

Often it is known, or may be assumed, that the vibration is a simple one of known form, and measurement at a single point (M=0) is sufficient. More generally, and especially with complex structures and real components, measurements at an array of positions spaced in a line (M=1), over a surface (M=2) or through a three dimensional space (M=3) are needed.

3. Vibration as a function of time ("T" in Table.)

The time variable may be essentially eliminated when only the amplitude distribution is required. An instantaneous record or time-section is then sufficient. Alternatively, when the vibration is unchanging, time-average recording yields a record of amplitude distribution. Vibration-phase information can be obtained by stroboscopic methods, although this technique is usually limited to the study of forced vibrations. In cases where the vibration is changing frequency, is damped, or other unrelated vibration modes exist, time-resolved methods may be essential. Further, two successive time-resolved holograms can then combine, providing a time-differentiation effect.

4. Table of variables

Experimental uses of coherent methods in vibration measurement may be related in terms of the two variables "F" and "M" above. Some recently published accounts are tabulated below where the numbers refer to the references listed at the end of this note.

The numbers in brackets refer to published papers containing the possibility of application in the area indicated.

TABLE

Measuring dimensions	Degrees of freedom F=1, eg Vx	F=2, eg Vxy	F=3, eg Vxyz
M=0 (at a point)	10 T_R		
M=1 (linear)	11 T_R 12 T_R	(13)	
M=2 (surface)	1,2,3 T_A 4,5,6,7 T_S 7,8,9 T_R 13 T_D	(13) (16)	(13)
M=3 (space)	13 T_D 13 T_S	(13) (16)	(13)

Time variable: T_S = "Section" (Instantaneous, Stroboscopic)
T_A = "Time average" (Integrated in time)
T_R = "Time resolved" (Sequential, Real-time)
T_D = "Time differentiated" (Double-pulse)

The first uses of holography in vibration are usually traced to Powell and Stetson[1], and to Burch and Ennos in this country. The "time average" (=T_A) method is still in use and is mainly applied to record amplitude perpendicular to a surface, as a two dimensional pattern[2]. Other, more complicated, vibrations lead to difficulties[3].

A possibility of greater scope is the method of "time section" (=T_S), or its equivalent for repetitive forced vibration, stroboscopic holography[4,5,6,7]. Observation of vibration by speckle correlation[8] is often a real-time method (=T_R). Video-recording extensions of the method[9] may also come in the same class. All of these produce two dimensional patterns of the variation in a single parameter, but two parameters should be accessible when M is 2 or greater. Although this has been demonstrated for displacement[19], little has been done with vibration. Measurement at a point (M=0) is sufficient for uniform vibration or, of course, for point-sampling as with Doppler probes[10]. In the study of propagating waves, measurements in only one dimension (M=1)[11,7,12] may suffice. The "time differential" technique also included in some of these papers[12,13] has been extended to cover several time differentials simultaneously[13].

5. Outline for discussion of lasers and holographic techniques

It is clear from the table that most work so far has been concerned with the measurement in only one vibrational degree of freedom and there has been little development of sequential holographic recording and differential techniques which are essential to extend studies outside the steady forced vibration case. Better use can undoubtedly be made of the holographic method to measure more dimensions[19] or to cope with more degrees of freedom[13], as indicated in the table. The common problem is to find suitable repetitive coherent sources. Some of the pulsed lasers developed at NPL[12,14] are shown in Figure 1. A 20 kHz neodymium-second harmonic laser was used for the sequential recording of the propagation of an elastic vibration in a solid bar[12,15]. Ruby lasers have been used for the recording of the progress of waves in gas with three-dimensional distributions and for various high-speed hologram time sequences[16]. One such laser is shown in Figure 2, with a scatter plate recording system useful in recording three dimensional structures and fields which may be transilluminated, as a time sequence[16].

Time differentiation has been the object in development of the laser shown in Fig. 3. The double-pulse coherent output has been used to produce a frozen-fringe record of a progressing surface wave, as shown in Fig. 4, and in other ways.

Simplified, small, portable pulsed laser units have also been developed and are likely to be useful in vibration recording[12,14,17]. After recording with some of these systems the measurement will be made by interfering reconstructions from separated elementary holograms in the time sequence[13,18].

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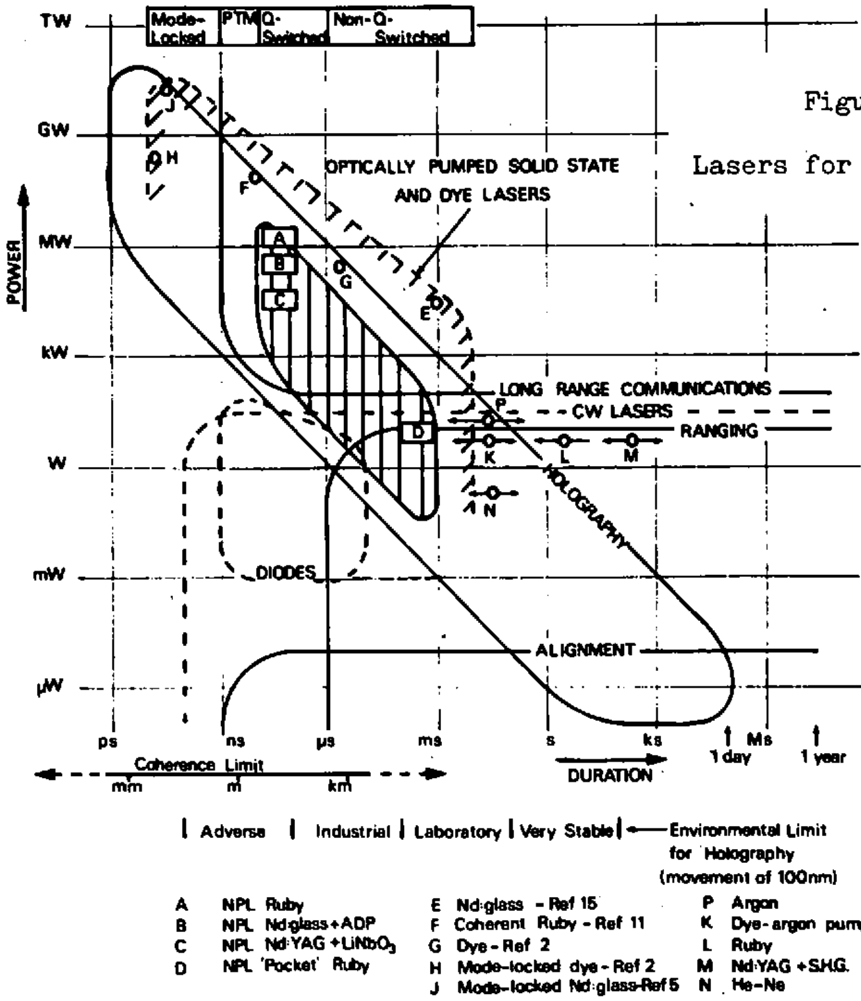


Figure 1

Lasers for Holography

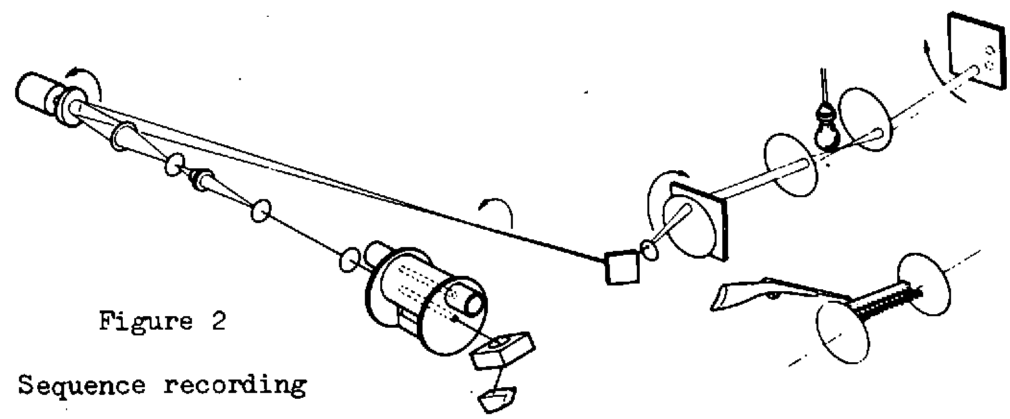
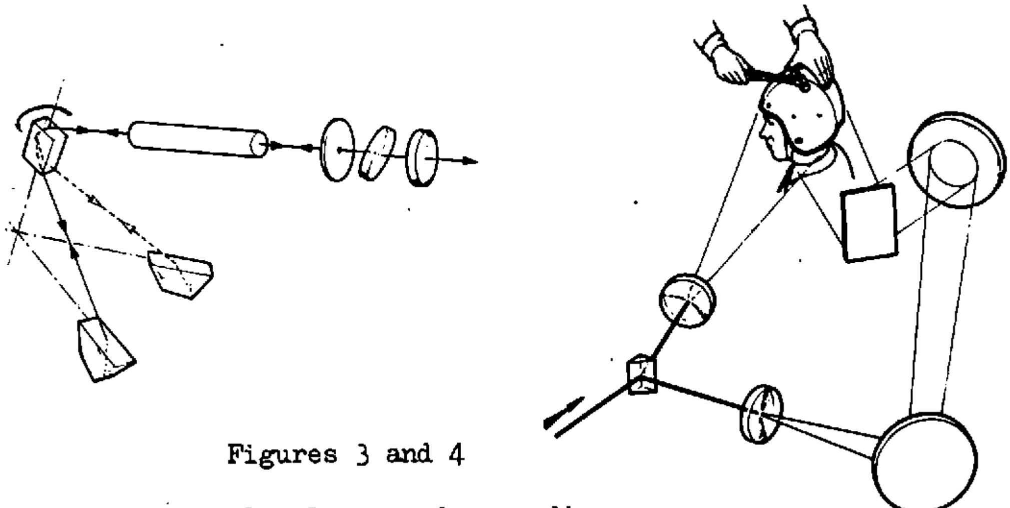


Figure 2

Sequence recording



Figures 3 and 4

Double pulse laser and recording