Jesus Blanco-Garcia, Angel F. Doval, Antonio Fernandez, Benito V. Dorrio, Carlos Lopez, Ramon Soto, Jose M. Alen, José L. Fernandez and Mariano Perez-Amor, "Crack detection by TV holography: continuous and pulsed techniques," Proc. SPIE 2730, "Second Iberoamerican Meeting on Optics," 101-105 (5 February 1996)

http://dx.doi.org/10.1117/12.231047

Crack detection by TV-holography: continuous and pulsed techniques

J. Blanco-García, A.F. Doval, A. Fernández, B.V. Dorrío, C. López, R. Soto, J.M. Alén, J.L. Fernández, M. Pérez-Amor

Univ. de Vigo. Dpto. de Física Aplicada. Lagoas-Marcosende, 9. Vigo 36200 (Spain)

ABSTRACT

Two TV-Holographic techniques to detect cracks in mechanical elements are demonstrated. One of them employs continuous illumination and is based in the modal analysis of the part. The other one consists in the study by pulsed TV-Holography of transient waves induced in the part.

Keywords: Crack detection, TV-Holography, Vibration modes, Transient waves.

1. INTRODUCTION.

The non-destructive detection and measurement of cracks in mechanical elements is one of the most interesting subjects within the field of the industrial inspection. The reason for this is that cracks, generally due to material fatigue, are the main cause of faults and breaks in pieces under cyclical stress.

TV-Holography (TV-H) is an interferometric technique that presents, besides the characteristic performances of this kind of techniques, such as its high sensitivity and its non-contacting nature, the advantages of yielding information simultaneously of all the object surface points (whole-field) and its high speed of data acquisition. These properties make this technique to be regarded as one of the most potentiality for being applied in crack detection, potentiality not completely explored up to now.

In this work two different TV-H techniques for crack detection, one with a He-Ne continuous laser as light source and another with a Nd-YAG pulsed laser, are demonstrated.

The most extended continuous illumination TV-H technique for crack detection is the study of the object under static deformation[1]. However, this technique is rather sensitive to environmental disturbances and object instabilities. It is for this reason that we have tried a dynamic technique. The object under study is excited at the frequency of one of its vibration modes. The presence of a crack is pointed out by irregularities, such as discontinuities or asymmetries, in the resulting time-average fringe pattern.

Pulsed TV-H has been proved as an useful tool for transient wave analysis. Different systems and operation modes were demonstrated[2,3,4]. It presents, among others, the advantage of its high temporal resolution which make it specially suitable for hostile environment applications. Here, an electronic speckle pattern interferometer with out-of-plane sensitivity is operated in single-pulse mode. The object is stricken, this gives raise to waves propagating through its surface. Cracks make this waves diffract or attenuate, being these effects clearly identifiable in a correlogram corresponding to a deformation state during the wave propagation.

2. TIME-AVERAGE TV-H FOR CRACK DETECTION.

The time-average TV-H for vibration analysis presents the attractiveness of its experimental simplicity. Here, we will describe our system of continuous illumination TV-H for vibration modal analysis and the obtained results when we applied it to crack detection.

2.1. Description of the system.

It is represented in the Fig. 1. Essentially, it consists in an out-of-plane speckle pattern interferometer with both beams, illumination and reference, guided by monomode fiber. The light source is a 5 mW He-Ne laser. A directional coupler (DC) splits the laser beam into the illumination and the reference ones. In the reference beam, a phase modulator (PM), a polarization controller (PC) and a variable attenuation device (VAD) allow the control of the beam parameters.

The object was a circular aluminum plate clamped at its center in which a crack was made. The excitation was applied by means of a piezo electric (PZ) attached to its back side.

The main computer controls the optical phase modulator for the contrast enhancement of the time-average fringes and, also the image acquisition and processing system (image PC).

2.2. Results.

Fig. 2 shows some of the obtained fringe patterns, each one belonging to a different resonance mode of the object. The crack (30×0,5 mm) is clearly identifiable for the fringe discontinuities. As it can be seen, the identification of the crack is independent from the excited mode, however it is required to excite one whose wavelength is comparable to the crack length and with an enough amplitude to be detected.

The dynamic nature of the time-average technique (whose reference image is refreshed at 25 Hz) allows to say that the technique we are describing here is adequate for crack detection even in industrial environments since relatively slow disturbances (such as density air changes or object dislocations) result canceled.

3. TV-H ANALYSIS OF TRANSIENT WAVES FOR CRACK DETECTION.

In this section we will describe our system of pulsed TV-H for crack detection and show the first results we obtained with this technique.

3.1. Description of the system.

Fig. 3 shows the block diagram of our experimental set-up. Basically, it can be divided into five systems:

a) The light source: a frequency-doubled Nd:YAG pulsed laser.

b) Out-of-plane speckle pattern interferometer with a CCD camera as image sensor and the reference beam guided by monomode fiber.

c) Acquisition and process image system: a personal computer (IMAGE PC) equipped with digitizer and array processor boards.

d) Object excitation chain: an electromagnetic hammer and its electronic driver.

e) Computerized laser control and synchronisms. The PRINCIPAL PC controls simultaneously the laser, the IMAGE PC and the synchronism system. This allows the synchronization among the light pulses from the laser, the CCD camera scanning, the object excitation and the image acquisition.

The synchronism system is composed by an external delay generator (EDG) and a synchronism unit that generates pulse trains for the laser triggering, the CCD camera and the driver of the electromagnetic hammer.

3.2. Operation mode.

In this earlier phase of our study of transient techniques for crack detection we have begun by a single pulse technique because it implies a less complexity in the synchronization of the different elements of the system.

The operation procedure was as follows:

1) In a first stage the object, at rest, is illuminated by the laser pulses synchronized with the CCD camera (25 Hz).
2) Next, by means of the principal computer we give the order for starting the sequence of acquisition.
3) The first step of this sequence is the acquisition of a specklegram with the object at rest, just with the light pulse immediately before it is stricken.
4) The object is stricken.
5) A second specklegram is acquired with the object illuminated by the laser pulse immediately after the impact.
6) Both specklegrams are subtracted yielding a correlation fringe pattern of the object deformation.

The delay between the impact and this laser pulse can be adjusted. This allows to carry out a set of experiments to obtain a correlogram sequence monitoring the evolution of the induced wave.

3.3. Results.

One of the above mentioned correlogram series is shown in Fig. 3. The object is a cantilever aluminum beam (dimensions: 200×55×1 mm) with an artificial crack (2×10 mm).

Images from **A** to **E** show the wave propagation before it reaches the crack. In the image **F** the wave is attenuated by the presence of the crack as it can be seen from the slight wavefront flatness. Images from **G** to **I** show the wave diffraction, it can be observed the formation of secondary wavelets at the extremes of the crack. Finally, images from **J** to **L** display the propagation of the wave after the crack, including the wave reflected by the extreme of the beam, shown in the last one.

We found that this technique is not affected by the environmental disturbances at least in laboratory conditions. This is because, in spite of employing a single-pulse method, the time interval bethween reference and measure pulses is short enough (80 ms).

4. CONCLUSIONS AND FURTHER IMPROVEMENTS.

Two TV-H techniques for crack detection being developed by our group have been described. From the first results we conclude that both techniques can be applied successfully to the crack detection problem even in industrial environments.

The stationary technique presents the advantage of its experimental simplicity which allows the design and implementation of compact systems (specially because the utilization of optical fiber in both arms of the interferometer).

Nevertheless its reliability depends on the possibility to excite and detect low spatial wavelength resonance modes of the object.

The transient technique, in spite of the complexity of the required system, seems more suitable to analyze any kind of object, since superficial waves can be induced with an enough energetic excitation.

One of the most interesting improvements of the stationary technique is the implementation of phase evaluation. For this, the stroboscopic technique seems more adequate as long as it render sinusoidal fringe patterns, easier to phase-evaluate by the most common techniques[5]. Moreover, they allow the study of the mechanical phase distribution, as some of the authors have demonstated in a former work[6]. This is of great interest provided that cracks not only affect the vibration amplitude but also its phase.

With respect to the transient technique, the first improvement to carry out is the utilization of double pulse illumination. This will increase the temporal resolution in the study of the transient wave, besides to allow the measurement of greater amplitudes. Furthermore double pulse will increase the insensitive of the technique to hostile environment disturbances. Another important progress will be the application of a phase evaluation method to obtain quantitative measurements.

5. ACKNOWLEDGMENTS.

The authors acknowledge the financial sponsorship given to this work by Xunta de Galicia (XUGA 32105B92), CICYT (TAP-263/93), University of Vigo and Iberdrola.

6. REFERENCES.

1. R. S. Sirohi, "Speckle Methods in Experimental Mechanics", Speckle Metrology (Sirohi Ed.).pp. 99-156, Marcel Dekker. New York, 1993.
2. R. Spooren, "Double-pulse subtraction TV holography", Opt. Eng. 31 (5), pp. 1000-1007 1992.
3. G. Pedrini and H.J. Tiziani, "Double-pulse electronic speckle interferometry for vibration analysis", Appl. Opt. 33 (34), pp. 7857-7863, 1994.
4. V.P.W. Shim, S.L. Toh and S.E. Quah, "Impact-induced Flexural Waves in a Timoshenko Beam. Shearographic Detection and Analysis", Exp. Mech. 34 (4), pp. 340-348, 1994.
5. A.F. Doval, J.L. Fernández, M. Pérez-Amor, J.D. Valera and J.D.C. Jones, "Phase-stepped additive stroboscopic fibre optic TV holography for vibration analysis", Optical Measurements and Sensors for the Process Industries, (Gorecki and Preater Ed.). SPIE Vol. 2248, pp. 229-240, Frankfurt, 1994.
6. J.D. Valera, A.F. Doval and J.D.C. Jones, "Determination of vibration phase with electronic speckle pattern interferometry (ESPI)", Elect. Let. 28 (25), pp. 2292-2302, 1992.

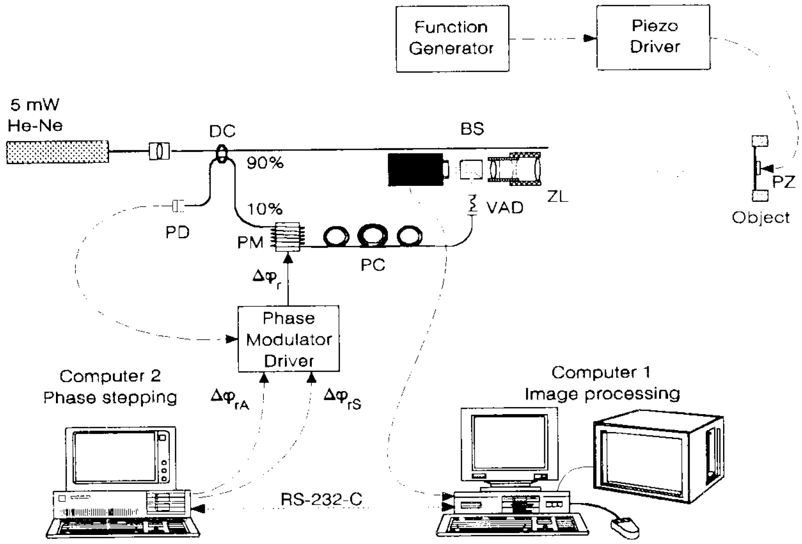

Fig. 1: Experimental set-up of the stationary TV-H technique for crack detection. Symbols are explained in the text.

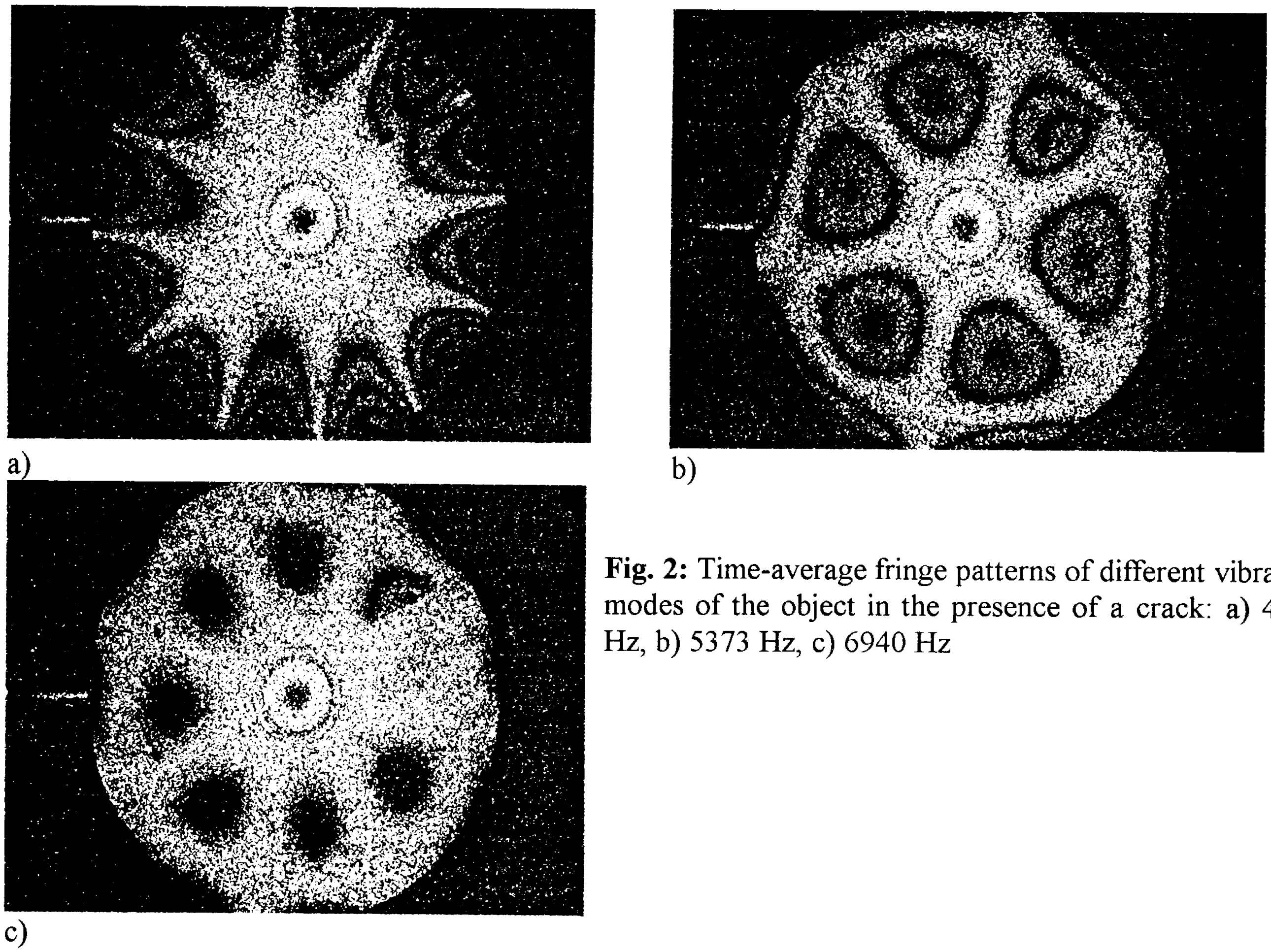

Fig. 2: Time-average fringe patterns of different vibration modes of the object in the presence of a crack: a) 4630 Hz, b) 5373 Hz, c) 6940 Hz

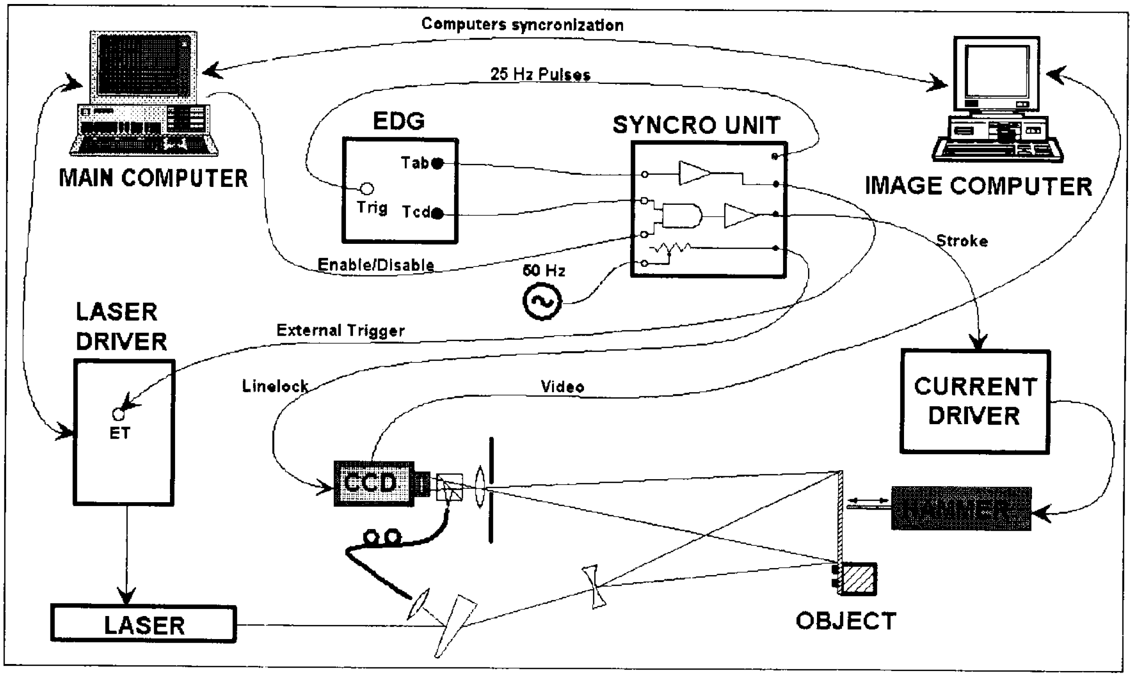

Fig. 3: Lay-out of the pulsed TV-H system for crack detection.

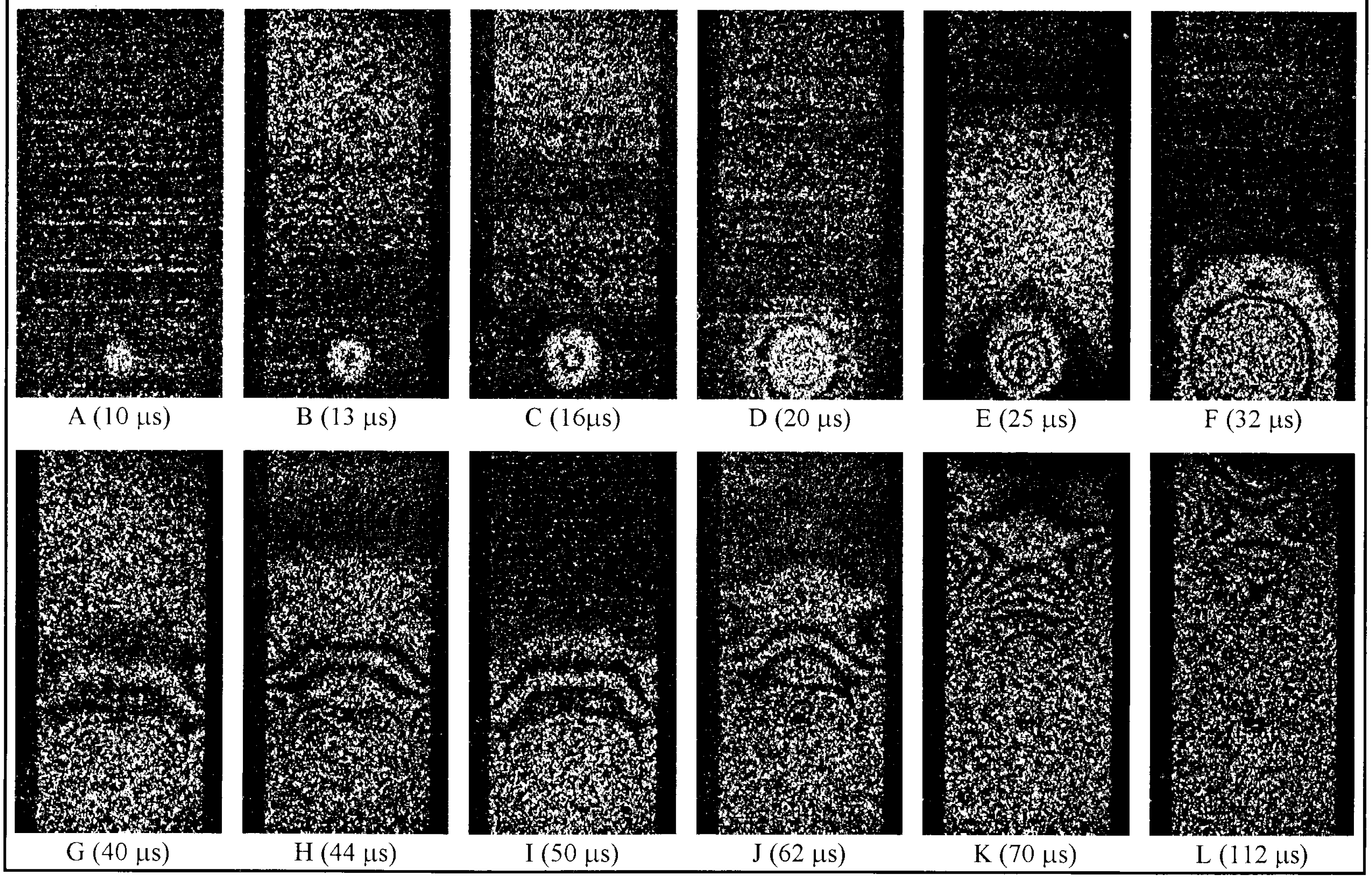

Fig. 4: Correlogram sequence showing the evolution of a transient wave along an aluminum beam with a crack. In parenthesis the time after the impact. Explanation in the text.