A&QT-R 2002 (THETA 13)
International Conference on Automation, Control and Testing, Robotics
May 23-25, 2002, Cluj-Napoca, Romania - -

DEVELOPMENTS IN ELECTRONIC COMPONENTS AND PCB TESTING BY DIGITAL SPECKLE PATTERN INTERFEROMETRY

Dan Borza

Laboratoire de Mécanique de Rouen
Institut National des Sciences Appliquées de Rouen
B. P. 8, Avenue de l'Université, 76800 Saint-Etienne du Rouvray, France
Tél./Fax: (+33) 232959742; Email:borza@insa-rouen.fr

ABSTRACT

Non-destructive testing of electronic components and PCB by non-contact electro-optical techniques is a valuable tool in quality control. Phase-stepped electronic speckle pattern interferometry and phase-stepped projection moiré are able to provide the real-time display of fringe patterns directly related to the displacement field or to the displacement derivatives field of a tested component under thermal and/or mechanical stressing. When using a CW laser, both fields may be obtained under either static or vibrational testing.

An important part of the heavy thermo-mechanical sollicitations occur during the PCB fabrication process. The sensitivities of the testing techniques must be adapted to the values of the displacements (usually high) and the real-time interferogram or moiré display has to be of good contrast, while keeping the laser power low.

The paper describes a few contributions of the the Photomechanics laboratory of the Laboratoire de Mécanique de Rouen, France to these stringent demands.

One of these contributions is a novel vibration measurement interferometric method, the quasi-binary electronic holography. With respect to the well-known time-averaged method, the measurement range is extended by a factor of two and the contrast of the fringe pattern is greately improved.

Other contributions concern the development of a user-friendly dedicated software.

KEY WORDS

Testing, electronic holography, interferometric methods

NOMENCLATURE

$J_0(\varphi_d)$.is the zero-order Bessel function of the first kind and argument φ_d

$I_O(x,y)$ is the irradiance of the object wave, strongly affected by laser speckle;

$I_r(x,y)$ is the irradiance of the uniform reference wave.

λ is the laser light wavelength;

$\varphi(x,y)$ is the relative local phase between object wave and reference wave.

d(x,y) is the displacement (either static or vibrational amplitude) of the object point imaged at (x,y)

1. INTRODUCTION

The testing of printed circuit boards during and after their fabrication is a necessary step in any factory. Besides detecting defective boards in view of their elimination (or, if possible, reparation), the testing allows detecting and correcting different weak points concerning some components or their positionning on the PCB, the parameters of the fabrication process and the thermo-mechanical stresses occured during fabrication.

One of the factors which favor the apparition of high stresses is the very large difference between the mechanical and thermal properties of different components and the PCB itself. Materials as different as ceramics and epoxy, metals and plastic coexist and interact while the assembly is submitted to high vibration levels, high thermal gradients and mechanical stresses. Shocs and vibrations occur during the positionning or implantation of the components and during the final PCB separation, thermal differences of over 300 K with non-negligible spatial and temporal gradients and accompanied by large deformations are inherent to the automated fabrication process.. Temporary or remanent stresses are often destructive

Among the experimental studies done on these subjects, some uses of electro-optical field techniques have been described, for example, in [1]. .

Some of the most representative electro-optical field techniques will be shortly described hereafter, whith emphasis on their respective metrological characteristics and illustrated by sample applications achieved in our laboratory.

2. PHASE-STEPPED INTERFEROMETRY

Several techniques belong to this group. Electronic holography, which is the successor of holographic interferometry, allows real-time measurement of quasi-static displacement fields at the surface of the tested object, as well as real-time measurement of steady-state vibration modes. Electronic shearography allows real-time visualization of the whole field of displacement derivative with respect to an arbitrary direction. Electronic speckle correlation allows real-time measurement of the in-plane displacement field. Projection moiré is used as a desensitized technique, allowing the measurement of large displacements.

With the (eventual) exception of the projection moiré, all these techniques use the image of the object obtained in coherent light, $I_O(x,y)$, eventually the irradiance of a uniform reference wave, $I_r(x,y)$.

Their common and most general characteristic is the extensive use of computers and CCD cameras, which finally lead to the complete elimination of tedious, time-consuming and often laboratory-confined procedures of interferogram recording on high-resolution media, such as holographic plates. The two-step process of interferogram recording and image reconstruction have been completely replaced by algorithms involving temporal or spatial phase shifting (or stepping) under coherent illumination of the object. Temporal phase stepping is most often achieved by using piezo-electric actuators, in a 3, 4 or 5-step (usually 4) sliding cycle. Dedicated pipelined processors are calculating and displaying in real-time, at the normal video frame rate, a continuous stream of interferometric patterns obtained by simple operations between the acquired images.

2.1 Electronic holography. for steady-state vibration measurements.

The most widely used method in vibration measurement is the time-average method. The image being displayed after the acquisition of each 4-frame bucket is given by:

$$I_{TAV}(x,y) = A\sqrt{I_O(x,y)I_r(x,y)}\left|J_0\left[\varphi_d(x,y)\right]\right| \quad (1)$$

In eq. (1), A is a constant and φ_d is the fringe locus, given by:

$$\varphi_d(x,y) = \frac{4\pi}{\lambda}d(x,y) \quad (2)$$

The typical aspect of such an image is shown in Fig. 1

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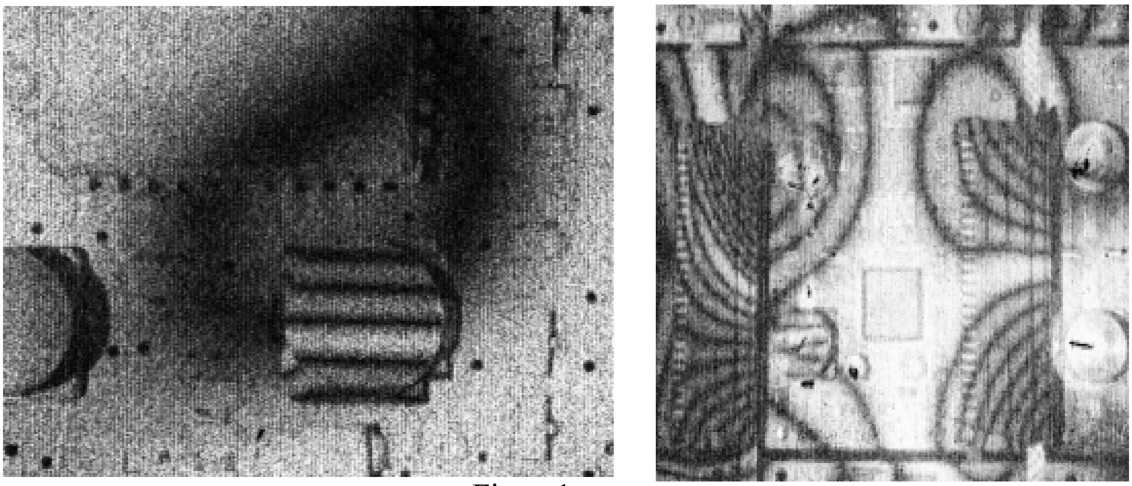

Figure1.

In Fig. 1, the image at left represents the iso-amplitude (straight) fringes of an inductor which has a local resonance; part of its energy is spread through the PCB and transmitted to the lower right part of an IC. The image at right presents the PC plate before being cut into nine identical boards; on the central board, as well as on the left one, the vibrations are produced by the resonances of a relatively heavy connector, and transmitted to some very sensitive components, including a tiny PZT transducer which may thus transmit an erroneous signal with dramatic consequences, since this product is part of the security system of a means of locomotion

Some other experimental results in the field of vibration-based NDT are shown in Fig. 2 and Fig. 3.

The image in Fig. 2 presents a defective section of a connector, while the image in Fig. 3 .shows a resonant vibration mode of an IC .

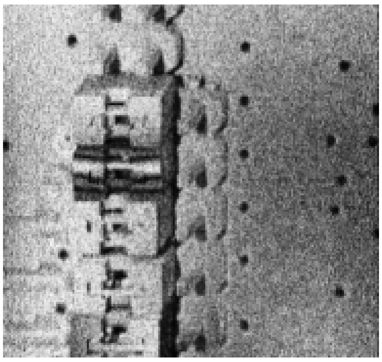

Figure 2

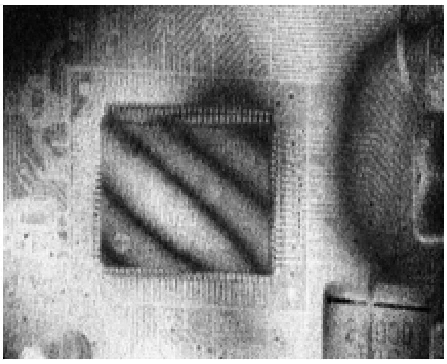

Figure 3

This particular vibration mode, presenting a nodal diagonal, is very dangereous because of the high values of stresses induced in the chip and in the pins.

From the metrological point of view, the iso-amplitude fringes given by (1) have two important characteristics: their successive maxima are decreasing fast with increasing fringe order, according to the values of succcessive minima and maxima of the Bessel function; secondly, the sensitivity is very high, which may produce a too high fringe density to allow spatial separation and counting. The quantitative interpretation may then become prohibited by the poor spatial resolution due to electronic and speckle noise, and by the low fringe contrast in the displayed image

2.2 Electronic holography. for measuring quasi-static deformation fields.

Several operating modes (and fringe pattern types) are available for measuring quasi-static, out-of-plane displacement fields. One of them produces fringe patterns of cosine type, given by:

$$I_{STAT}(x,y) = A\sqrt{I_O(x,y)I_r(x,y)} \times \cos^2(\Delta\varphi_{st}) \quad (3)$$

The second, more useful operating mode, is phase imaging. The fringes are representing the modulo 2π phase difference between the reference state and the deformed state of the object:

$$I_{STAT\_PH}(x,y) = A \times \Delta\varphi_{st}\big|_{mod\ 2\pi} \quad (4)$$

The term $\Delta\varphi_{st}$ is given by eq. (2).

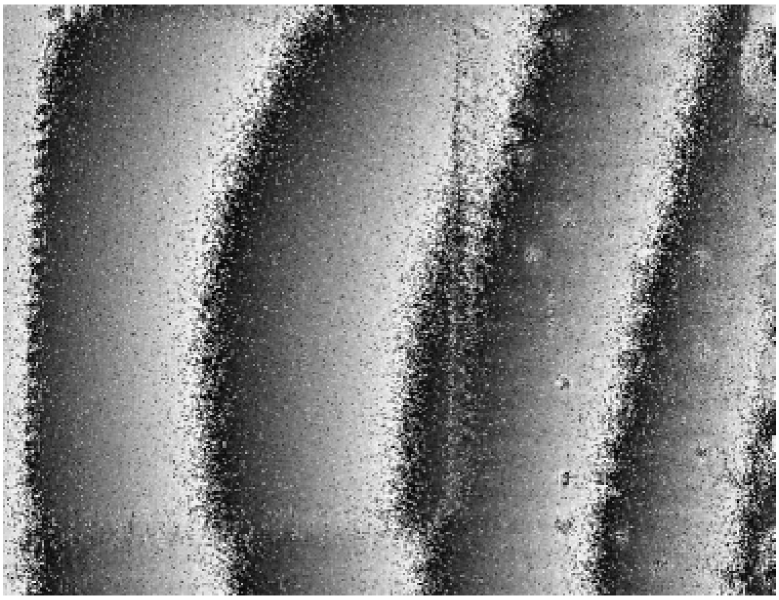

Figure 4

As an example, Fig. 4 presents the displacement field produced by a moderate heating of a PCB. The discontinuity of the displacement field indicates that the pins of the IC in the left half of the image left will are exposed to a stress state.

To be noticed also the regular "waves" of the deformed epoxy - glass fiber printed circuit, due to the glass fibers embedded in the epoxy matrix.

The modulo 2π fringe pattern may be unwrapped in order to quantitatively calculate the displacement field.

Phase unwrapping may be either spatial or temporal, and has to eliminate the 2π phase jumps in the wrapped phase. The task is rather difficult because of the random speckle noise and of (eventual) fringe discontinuities.

The phase hologram presented in Fig. 5 represents another situation similar to that presented in Fig. 4 (thermal effects). The image at left shows the wrapped phase, before any filtering. After an edge-preserving de-noise filtering and the phase unwrapping, and after the compensation of the deformation of the printed circuit, the displacement field at the upper surface of the chip may be isolated and presented, as in the image at right. A profile of the deformation along a horizontal line selection is shown in the central image .

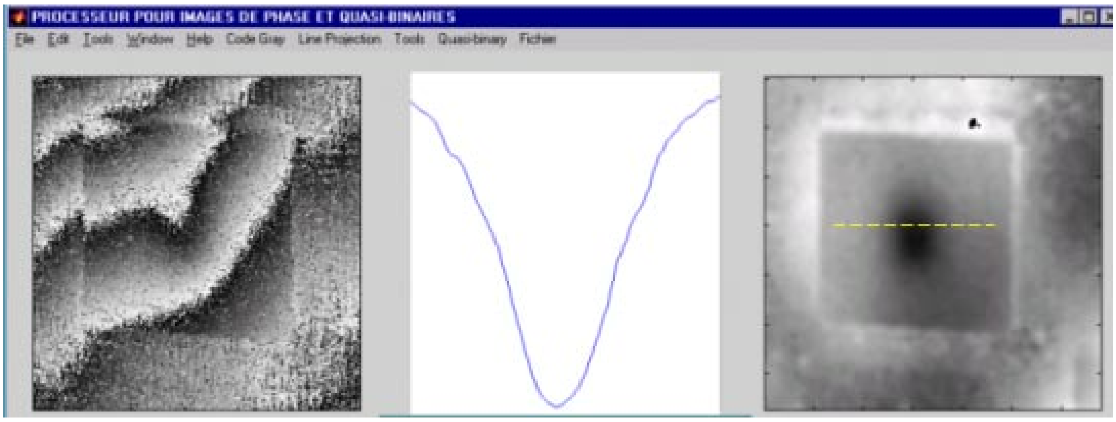

Figure 5

2.3 Electronic shearography. for measuring derivatives of deformation fields.

All the methods presented for electronic holography may be adapted for shearography. The interferograms are noisier, because there is no uniform reference wave. For quasi-static displacement fields, supposing the derivative is calculated with respect to the x direction, the brightness of the real-time phase image is given by (4), but the expression of the static phase is:

$$\varphi_{st}(x, y) = \frac{4\pi}{\lambda} K \frac{\partial d(x, y)}{\partial x}\bigg|_{\mathrm{mod}\ 2\pi} \tag{5}$$

K is an(adjustable) constant allowing to adapt the sensitivity.

A particularity of this technique is the very reduced degree of environmental influence on the measurement process.

In NDT, shearography is widely used, especially for composite materials, because of the high detection capability of small local gradients produced by a small defect.in a global deformation field.

Figure 6 presents the shearographic results of a test concerning the effects of heating on a Quad Flat Pack IC, surface mounted. The destruction of the chip, due to high thermal variations during board fabrication and during the cooling of the board at the end of the process, occurs because of high-valued shear stresses, along a diagonal.

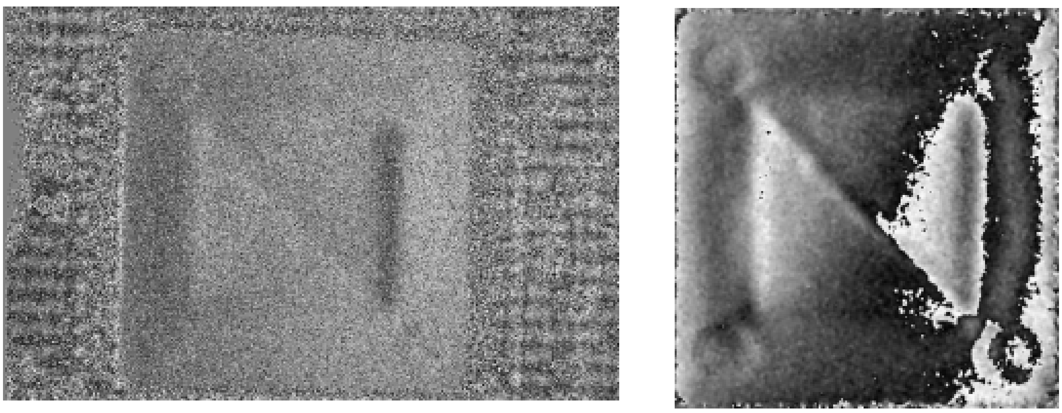

Figure 6

3. QUASI-BINARY ELECTRONIC HOLOGRAPHY / SHEAROGRAPHY

As shown at § 2.1, the major drawbacks of time-averaged holography are the contrast, strongly decreasing with increasing fringe order, and the too high sensitivity with respect to the vibration amplitudes.

At the Photomechanics Laboratory of the Laboratoire de Mécanique de Rouen, a novel interferometric method was developped. It was previously presented. in [1]. We call it "quasi-binary" because of the unusual fringe profile. In fact, instead of the Bessel-type fringes given by eq. (1), in the fringe patterns obtained through the new method the intensity I_{QB} is simply given by:

$$I_{QB} = \begin{cases} \alpha \text{ ,if } J_0(\Delta\varphi_d) \geq 0 \\ \beta \text{ ,if } J_0(\Delta\varphi_d) < 0 \end{cases} \tag{6}$$

In eq. (6), α and β are constants of values significantly different, and allow easy thresholding and obtention of binary holograms. Figure 7 presents (left) a "classical" time-averaged electronic hologram and (right) the equivalent quasi-binary one.

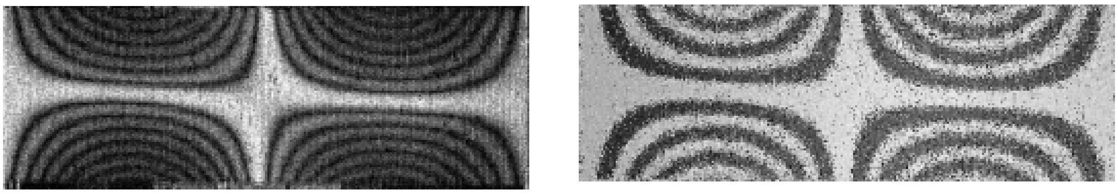

Figure 7

After filtering (Fig. 8, left) and thresholding (Fig. 8, right) the quantitative interpretation of may be done by morphological binary operations, much simpler than phase unwrapping or fringe indexing.

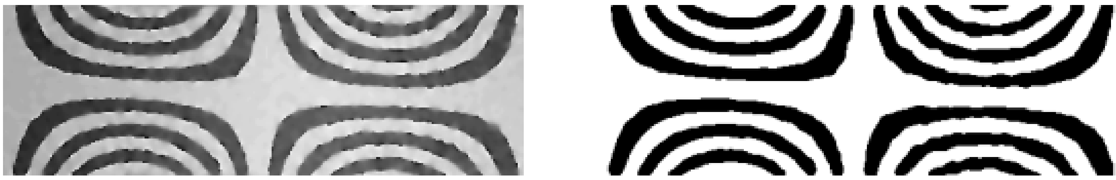

Figure 8

The measurement range characterizing the new technique is extended by a factor of two, and the contrast is high and has a constant value for all fringe orders.

4 CONCLUSIONS

Phase-stepped interferometry may bring valuable contributions in testing electronic components and assemblies. New interferometric methods extend the capabilities of these techniques.

5 REFERENCES

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