# NDT OF AERONAUTICAL MATERIALS BY DIGITAL SHEAROGRAPHY

Yubei Zhang, Zheng Wang and Guangping Guo
Beijing Institute of Aeronautical Materials, Beijing 100095, P.R.China.

Abstract: Digital shearography is a well-known interferometric technique that has established itself as a reliable alternative to conventional methods in NDT of varies aeronautical materials and parts., and is increasingly being used in the aviation industry. Unlike the photographic interferometry methods it can instantly and in real time produce interferometric images in digital form, with no film processing required. The purpose of this paper is to introduce the available technology of shearography during the last decade. NDT Inspections of some aircraft materials were performed with our shearographic systems in a Lab or workshop environment. The testing results and analyses are presented.

*Keywords: shearography; laser interferometry; phase shifting; NDT.*

## 1. INTRODUCTION

Digital shearography, a laser interferometric technique acquired great achievement in the past ten years, those efficiency, sensitivity and conveniency of shearography device have been improved significantly, reaching the practiced application and commercialization [1]. A considerable amount of research in the area of NDT using shearography has been done. Digital shearography has been successfully applied to industrial production rather than stayed on the laboratory. Especially for the aircraft manufacturing shearography is a suitable testing method with which large components can be tested in short time. The technology is not merely used as an experiment in lab. It is an effective tool for production quality inspection [2] [3].

The research on laser interferometry has been carried on since 1980s in Inspection Center, AVIC Beijing Institute of Aeronautical Materials. Experiencing the development early, such as dry plate, developing picture and fixation, glass photogram and TV holography shearography, from making shearographic device by ourself to purchasing commercialized interferometric system, our work is now towards non-destructive testing for aircraft productions under factory environment.

## 2. PRINCIPLE

Digital shearography is an interferometric measurement technique with which it is possible to detect component deformation by measuring the gradient of the deformation. Usually [4] [5], people detect surface deformation by measuring phase-difference change. By means of Michelson interferometer arrangement with a high performance piezo translator (PZT) to produce phase shifting, CCD camera records the intensity I(x,y) of the interferogram including background A(x,y), contrast B(x,y) and phase distribution Φ(x, y) which is relative to the optical path difference between the object beam and reference beam. By controlling piezo translator, phase shifting 90°, 180° and 270° can be obtained respectively. The phase distribution Φ(x,y) is then determined. The following equations describe the fundamental for calculating phase distribution Φ(x,y) by recording four phase-shifting intensity images:

$$I_1(x,y) = A(x,y) + B(x,y)\cos[\Phi(x,y)] \qquad (1)$$

$$I_2(x,y) = A(x,y) + B(x,y)\cos[\Phi(x,y) + 90°] \qquad (2)$$

$$I_3(x,y) = A(x,y) + B(x,y)\cos[\Phi(x,y) + 180°] \quad (3)$$

$$I_4(x,y) = A(x,y) + B(x,y)\cos[\Phi(x,y) + 270°] \quad (4)$$

$$\Phi(x,y) = \arctan\left[\frac{I_4(x,y) - I_2(x,y)}{I_1(x,y) - I_3(x,y)}\right] \quad (5)$$

The phase distribution Φ(x, y) or say wrapped phase is relative phase-difference change. Through further handling, called phase unwrapping, a continuous and smooth phase map was obained.

## 3. PROGRESS IN APPLICATION

In conventional shearography, the phase-difference change was determined by fringe orders. Digital shearography in conjunction with the phase-shifting technique permits the phase-difference change to be measured at each pixel point. Hence the sensitivity for detecting defects is greatly increased. As a useful tool for deformation measurements, with additional characteristics of full-field description, variable sensitivity, rapid inspection, etc., digital shearography has got more and more applications in aircraft industry. Meantime the imaging interferometer based on shearography has a considerable development which allows real-time measurement of changes to a target surface as small as only 3 nm [1].

Digital shearography is also profited from the developments of computer and optic-electronic industry recent years. Due to choices of CCD camera with a high resolution and improvement in software for display contrast, moreover, application of real-time phase measurement technique, the inspecting system has a higher sensitivity and accuracy. When a big field of view is selected, it is possible to detect all small defects over the components. Even if detected area is bigger than the field of view, by using image stitching function which allows individual images to be combined to form a composite image, the resolution could be kept in a high level so that the smaller and deeper defects in the whole objects can be found out. Detecting defects in honeycomb structure is a common work to shearography. With the development of technology, people no longer need worry about the detection on near surface, but want to find out middle septum and farside defects simultaneously.

Several years ago, light reflex was one of the major disadvantages of shearography. Detection was difficult when applied to polished, perfectly painted or metallic surfaces, due to the direct reflex of the illuminating laser and the high intensity of the light distribution. In practice, the components to be inspected often show very different reflection characteristics of the surface and painting is not allowable. The inspecting system has to allow measurements even with reflecting or colored surfaces. Some improvements has been made in measuring system to solve the problem, such as extending dynamic range and raising the SNR of measuring system, putting the laser source close to camera when setting up, and so on. As a result, the effect of light reflex is now very small. The measurement could be carried out on strongly reflecting and colored surfaces.

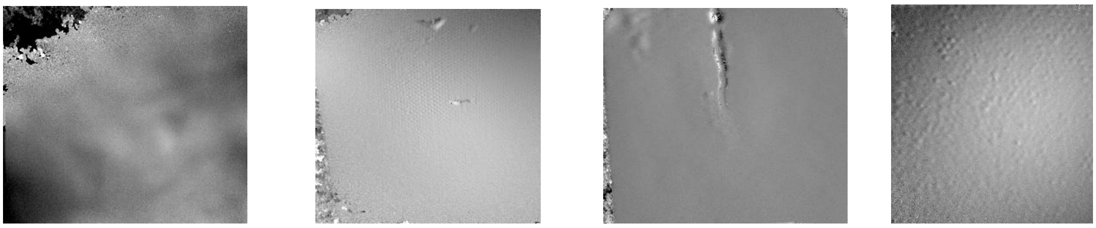
For an advanced shearographic NDT system, the improvement of each detail is important, whatever hardware or software, measurement or calibration. The camera chosen must be with high resolution and sensitivity. The amount of phase-shifting should be calibrated accurately. Capturing Multi-images is a valuable way to reduce the error of phase measurement and to raise detecting ability of inspecting system dynamically. The realized real-time phase subtracting is also a great advancement as compared with real-time subtracting in time domain.

4. NDT RESULTS BY SHEAROGRAPHY

Heat, vacuum, Pressure changing, as well as vibration excitation are the common methods of loading. Due to the high sensitivity of shearography, only small loads are required usually. When using a thermal loading an object is put under heat excitation with heating lamps. The damaged parts of a component which lead to an inhomogeneous mechanical stiffness can be seen in the deformation image. Faulty areas show a specific deformation pattern in contrast to areas without defects.

Followings are some testing results by using digital shearography.

(a) (b) (c) (d)



(e) (f) (g) (h)

Fig.1 Testing the glass-fibre reinforced plastic pieces of damaged radome, thermal loading. (a)(b)(c)(d) Glass-fibre reinforced plastic cut out of aircraft radome, skin thick: 2.5mm, 1.5mm, 1.5mm, 1.0mm. (e)(f)(g)(h) Corresponding inspecting results of components above, unwrapped phase images, showing disbonds, and defects caused by porosity, moisture, impact damage and so on.

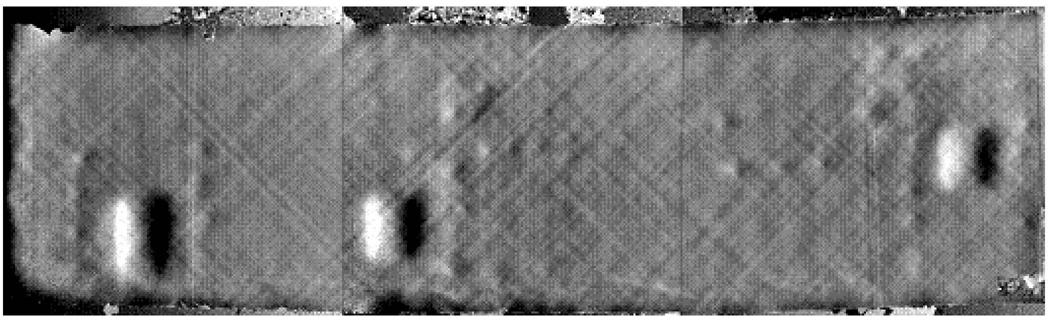
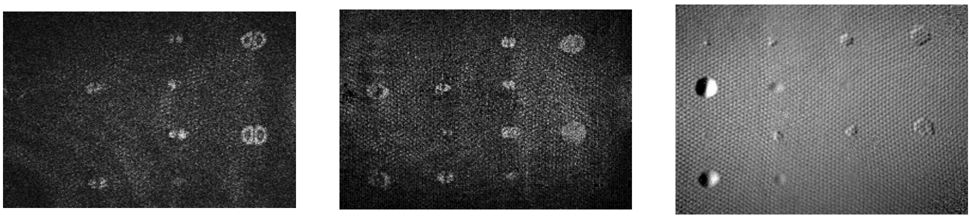
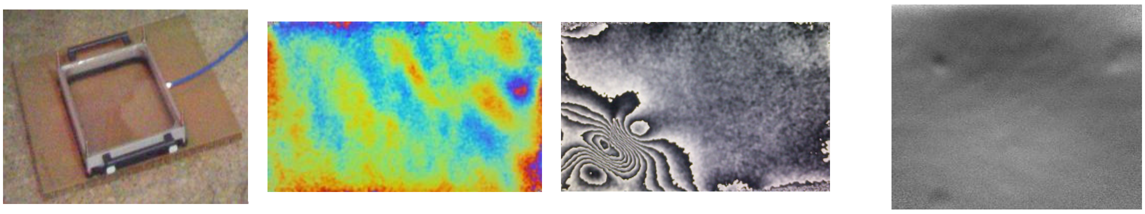


Fig.2 Unwrapped phase images of detecting carbon fibre compound component under thermal loading, showing the prepared delaminations (60×40,50×40,40×40), the Panel size: 700×200×4; stitched image is combined with three images. Unit: mm.



(a)Real-time subtraction with a low resolution camera
(b)Real-time subtraction with a high resolutioncamera
(c)Real-time phase subtraction

Fig.3 comparison of image quality on the same aluminium honeycomb panel (450×330×30), Thermal loading, showing the prepared disbonds with the sizes of Φ25, Φ20, Φ15, Φ10. (Unit: mm).



(a) (b) (c) (d)

Fig.4 Performed test on a glass-fibre honeycomb composite structure (500×500×35). Skin thick: 1.5, honeycomb thick: 32. Prepared disbonds with the sizes of Φ50, Φ25, Φ12, (unit: mm). (a)Vacuum loading only for (b) and (c); (b) Φ25disbond on farside; (c) Φ50disbond on farside; (d)Thermal loading, upper, from left to right: Φ12 and Φ25 disbond at near surface; lower: Φ12 disbond at far side.

## 5. CONCLUSIONS

Digital shearography has evolved into a very powerful NDT tool for the rapid inspection of composite materials. The Improvements in sensitivity and dynamic range of the measuring system makes it more effective to detect delamination, impact damage, skin-to-core disbond, etc. in aircraft structures. The defects about 10mm even at far side in a component panel of 35mm thickness can be found out easily.

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