TWENTYFIFTH EUROPEAN ROTORCRAFT FORUM

Paper n° N7

NON DESTRUCTIVE TESTING OF WIDE SCALE HELICOPTER STRUCTURES USING SHEAROGRAPHY

BY

R. KRUPKA(#), R. PEZZONI(*)
(#)STN ATLAS ELEKTRONIK, GERMANY; (*)AGUSTA, ITALY

SEPTEMBER 14-16, 1999
R O M E
ITALY

ASSOCIAZIONE INDUSTRIE PER L'AEROSPAZIO, I SISTEMI E LA DIFESA
ASSOCIAZIONE ITALIANA DI AERONAUTICA ED ASTRONAUTICA

NON DESTRUCTIVE TESTING OF WIDE SCALE HELICOPTER STRUCTURES USING SHEAROGRAPHY

René Krupka, *STN ATLAS Elektronik GmbH, Sebaldsbruecker Heerstrasse 235*
D- 28305 Bremen - Germany, E-mail: krupka@stn-atlas.de
Roberto Pezzoni, *AGUSTA LTS, Via Giovanni Agusta 520*
21017 Cascina Costa di Samarate – Italy, E-mail: r.pezzoni@agusta.it

Abstract

Experimental results of shearographic measurements for NDT are presented. The activities have been carried out on AGUSTA large area helicopter components and structures with a shearographic measurement system developed by STN ATLAS. Shearography can be used as NDT method that allows the non-contact large area defect detection and structural analysis of composites and other aerospace lightweight structures with respect to faulty materials and structural defects. Of main interest are defects which are situated below the surface and are not detectable using visual inspection. In contrast to conventional methods such as ultrasonic, X-ray or eddy current, the system presented allows a fast and large area survey inspection. This paper presents the most representative results of the AGUSTA/STN ATLAS recent nondestructive testing cooperation activities as well as a brief description of the laser-shearography technique and the main concepts of the system used. Comparisons and obtained improvements are presented with respect to previous measurement activities carried out in AGUSTA on the same kind of structures but with a different shearographic inspection system.

Key words: shearography, NDT, nondestructive testing, composites

INTRODUCTION

In the field of quality assurance and security testing of individual components up to complete systems, measurement techniques using nondestructive methods gain increasing significance. The overall goal is the determination of structural properties, detection of hidden defects as well as heavily stressed points. Well established methods as ultrasonic inspection, X-ray and eddy current techniques are very time consuming and restricted to relative small areas [1]. Furthermore most of these techniques are tactile. The major advantages are the high lateral resolution and the relative large penetration depth.

Optical methods (e.g. thermography, holography or shearography) are mostly non-contact. Due to the low penetration depth of the radiation they are indirect methods. This means in contrast to X-ray or ultrasonics the optical methods don't sense the hidden defects or structural properties directly. Instead they detect either the defect induced temperature change or the deformation of the surface respectively, while loading the sample. Thermography is restricted to small areas, whereas holography is extremely sensitive to environmental influences (vibration). These drawbacks were overcome by shearography, an optical method using laser, which combines non-contact measurement technique with the possibility of fast and nondestructive large area inspection. Inherently due to internal reference it is relatively insensitive to the environment and therefore applicable to sites outside the lab.

A typical area of application of optical methods is the field of aerospace with components of composite or other lightweight structures.

SHEAROGRAPHY

Shearography [2], an optical measuring technique using coherent light, is used for the interferometric inspection of optical as well as technical surfaces. The sample under test is illuminated using a laser and imaged on a CCD camera (TV-shearography) via a special optical shearing element (fig. 1). The shearing element allows a coherent superposition of two laterally displaced images of the surface of the sample in the image plane. The lateral displacement is called the shear of the images [3]. The superposition of the two images is called the shearogram, which is a interferogram of an object wave with the sheared object wave as a reference wave.

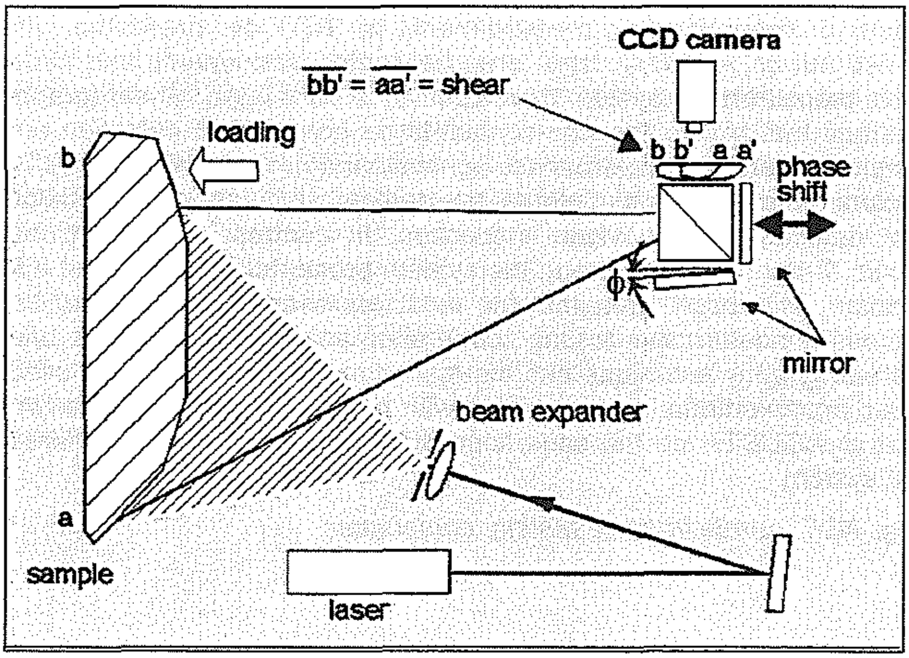

Figure 1: Principle of shearography.

Two of such images are recorded for different loading conditions of the sample. The loading should induce some deformation or alter the deformation state of the surface of the sample. Typical loadings are thermal, acoustical or mechanical and could be applied in a static or dynamic way.

The absolute difference of two shearograms recorded at different loading situations of the sample results in an interference fringe pattern which is directly correlated to the difference in deformation state. Later on this difference image is referred to as "D-image". In contrast to holographic interferometry the fringes indicate the slope of the deformation rather than the deformation itself. Defects inside the object may alternate the local surface deformation induced by the loading and result in a disturbance of the (more or less regular) loading fringes. This allows the detection and classification of defects using the shearographic fringe images.

IMAGE PROCESSING

The resulting D-images always exhibit a very noisy structure. This is due to the speckles. Speckles are statistical interference patterns which occur after reflection of a coherent wave on a rough surface giving the image a grainy structure [4,5]. Regarding shearography the speckles are the carrier of information, coding the wave field and surface state information respectively and giving rise to the interference fringe patterns. However the grainy nature of the speckles is conserved and significantly decreases contrast and signal to noise ratio of the D-images.

The strong noise and low contrast of the D-images require an adapted image post processing. Possible procedures can be well separated into either image improvement or image evaluation. They aim at removing the speckle noise and increasing the fringe contrast in order to improve the visibility of the fringes as well as their local alteration [6], [7]. Adequate improvement operations use median, mean value and geometrical filtering, gray value spreading and contrast enhancement.

A further improvement in image quality can be obtained with quantitative evaluation methods using spatial carrier frequency or temporal phase shifting [8]. Compared to the D-images the phase shifting technique requires a higher experimental expenditure but significantly improves the defect visibility.

SYSTEM CONCEPT

Figure 2 shows the basic concept of the realized system [15]. The major parts are the illumination source and the image acquisition. The laser is a frequency doubled pulsed Nd:YAG laser emitting at 532 nm. The maximum pulse energy is 250 mJ at a repetition rate of 50 Hz. The pulse width is 5 ns. The shearographic head consists of a CCD camera and the shearing element.

The shearing element is a interferometer in Michelson arrangement. A beam splitter and two adjustable mirrors followed by an photo objective image the sample onto the CCD. For phase shifting measurements one mirror can be translated using a piezoelectric actuator. The camera, a digital camera with 1k x 1k pixels has a maximum repetition rate of 30 Hz and limits the maximum acquisition rate of the system. The synchronization of camera and laser is done using a pulse-/delay-generator. The laser is fired in the temporal center of the exposition which is typically chosen to be 127 µs. Due to this low exposure time environmental influences (light, vibration) could be well suppressed. For vibrational studies the control of the laser and the camera can be well adapted to the excitation of the sample under test.

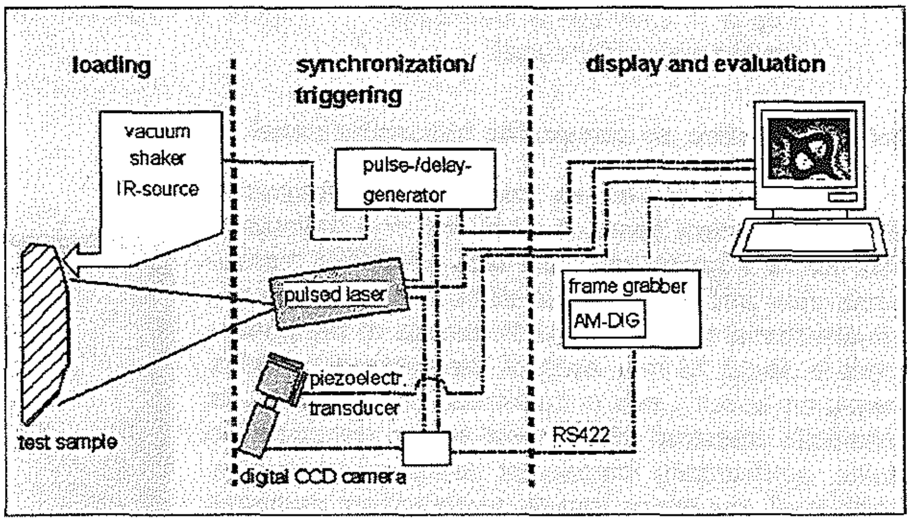

Figure 2: Setup of the Shearographic Measurement System ILIAS [15].

RESULTS

The system was applied for

- defect detection,
- structural analysis as well as
- fatigue testing inspection

of composite parts used in the field of aerospace.

The most useful results have been realised in defect detection and structural analysis of wide scale helicopter panels and structures using thermal loading and the phase shifting technique.

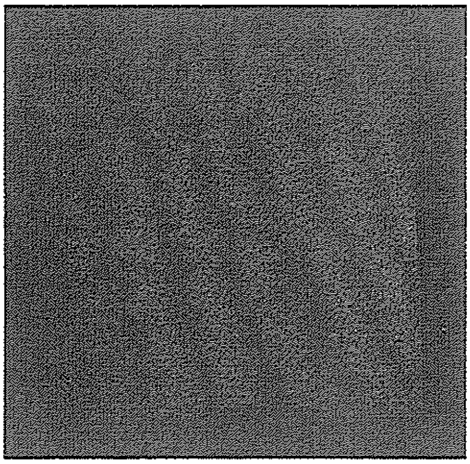

Figure 4: D-image of thermally loaded helicopter panel.

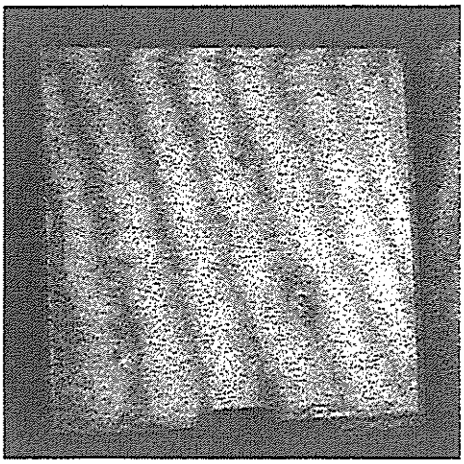

Figure 5: Improved D-image.

Defect detection on composite helicopter panel

Figure 3 shows an image of an composite structural element panel of a tail unit of a helicopter. This part is a typical structure with a NOMEX honeycomb core and two external skins in graphite/epoxy uni-directional cross-ply. The thickness of the honeycomb is about 13 mm, each of the external surfaces measures about 1 mm in thickness. This sample was especially prepared with several typical delamination faults, synthetically introduced using teflon inserts. Additionally the image reveals some impact damages which can easily be seen on the outer surface. The total size of this part is 80 x 80 cm². For inspection this panel was thermally loaded with a set of up to four IR lamps. The D-image of an unloaded and thermally induced deformed panel is shown in figure 4. The original image exhibits very low contrast and strong noise. After image improvement operation using an appropriate combination of filtering and contrast operations the fringe visibility is significantly improved (cfr. figure 5) although the defect visibility is relative poor.

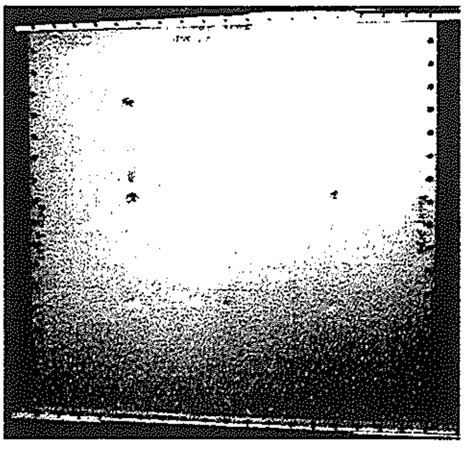

Figure 3: Composite helicopter-panel.

The application of the phase shifting technique significantly improves the image quality as well as the defect visibility. The phase shifting technique calculates the phase of the corresponding surface state using at least three images acquired for the same loading state but with an individual phase shift of 90 degree. This phase shift could easily be introduced by moving one of the two mirrors of the shearing element. The acquisition of the images must be sufficiently fast particularly for (transient) thermal loading. The realized system allows the acquisition of successive images of 1k x 1k pixels within 33 ms. This is sufficiently fast not to alter the loading state of the surface during three or four acquisitions. Figure 6 shows the calculated phase map. This image is still very noisy, but can be significantly improved (cf. fig. 7) using some special filtering which removes the statistical noise but maintains the 2π-discontinuities of the image. Figure 8 finally shows the unwrapped phase map obtained after removing the 2π-discontinuities adding a function of 2π-steps [9].

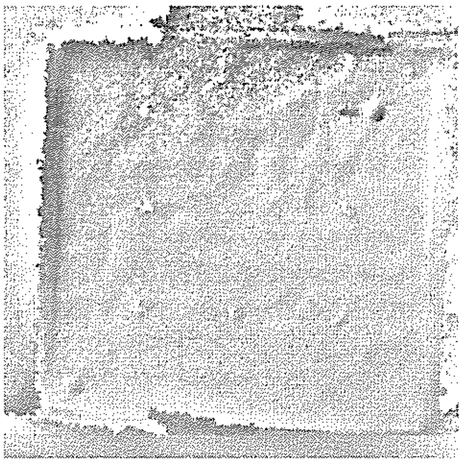

Figure 8: Unwrapped phase image

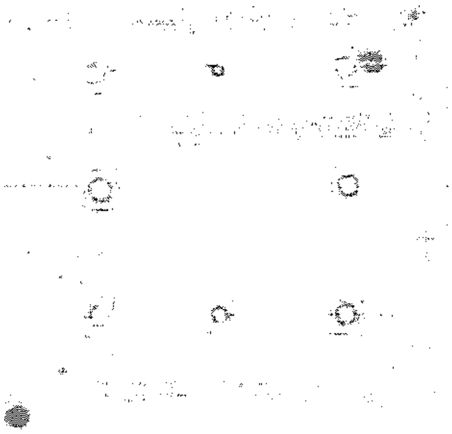

Figure 9: Result of mechanical impedance analyzer measurement

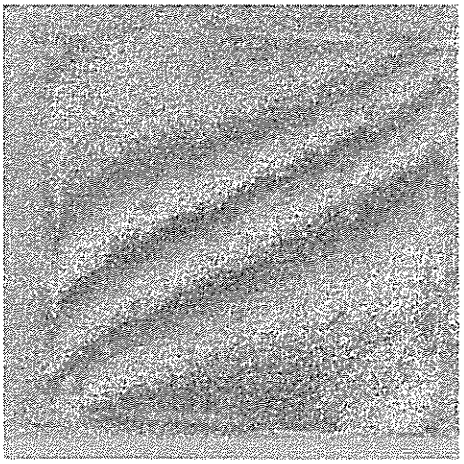

Figure 6: Phase image.

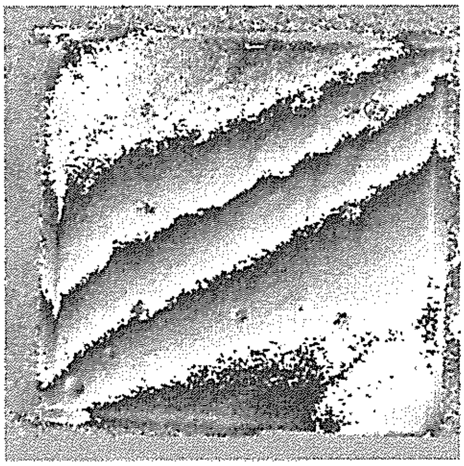

Figure 7: Filtered phase image.

This result can be compared with a measurement using a mechanical impedance analyzer (MIA) (fig. 9). This device mechanically senses the response of the sample for local mechanical periodical excitation [10]. A quite good agreement between both measurements is achieved. All delamination defects can be sensed with the shearographic inspection in a non-contact and nondestructive way. In contrast to conventional techniques the shearographic inspection is considerably faster.

The complete testing of the panel inclusive image evaluation takes not more than one minute

Full tail unit inspection

The size of the sample to be tested was significantly increased by taking an original full tail unit of a helicopter. This unit measures about 3.5 m in height and 3.5 m in width. On the lower right part a disbond defect has been synthetically introduced between the honeycomb core and the outer skin. The defect is round shaped and measures about 70 mm in size. Besides the defect detection we were aiming for structural features of the sample. Figure 10 shows an image of the tail unit. The corresponding phase map is shown in figure 11. The sample again was loaded thermally using IR lamps.

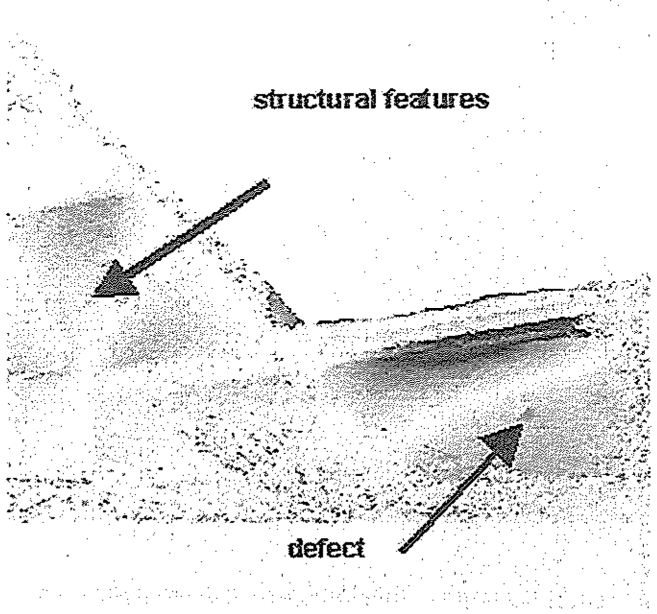

Figure 11: Wrapped phase map of 3m x 3m area of the tail unit (thermal loading)

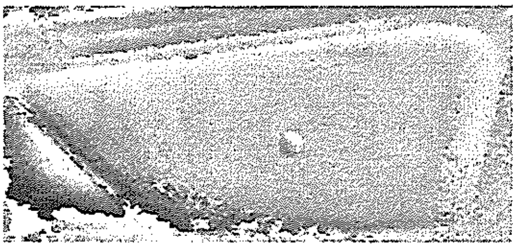

Figure 12: phase map of "defect area" of fig. 10 and 11.

The visibility of the disbond is quite good (fig. 11). Besides this one no other defect was detected, which is in agreement with conventional measurements. The structural properties of the sample can also be resolved. The individual composite parts can be well recognized.

The size of the defect is about 1/50 of the tail dimension. This can be estimated to be the lateral resolution for the specific defect and loading condition. Previous recent activities on the same kind of structure but with a different inspection system and significant reduced inspection area gave a maximum lateral resolution of about 1/13 of the lateral dimension of the sample [11].

Figure 10: Full helicopter tail unit.

Therefore the results presented here demonstrates the use of this shearographic system for a fast and large area survey inspection. Once a defect has been found or a given region is supposed to be faulty, the region of interest can be examined with higher lateral resolution by solely decreasing the field of view.

Fig. 12 shows the result of a thermally loaded shearographic measurement of the lower right part of the tail unit where the disbond defect has been found.

Due to the limited lateral size of the inspection area the absolute resolution is significantly enhanced, allowing a more detailed study of the defect.

Again the defect is recognized very well with no other fault in this area. If further information is needed this area can now also be examined using other NDT methods.

Fatigue Testing Inspection

Fatigue testing often requires the periodical loading of a given sample for millions of cycles. After a certain number of cycles the sample has to be examined for defects or structural alteration. Conventional NDT methods as ultrasonic or X-ray testing requires the dismantling of the sample from the testing bench, a time consuming and therefore expensive procedure. The use of this shearographic system allows the non-contact study of the sample without dismantling or even without pausing the fatigue testing. This is called "in-situ" study. An example is shown for the fatigue testing of a helicopter blade structural element .

The sample is fixed at the bottom and periodically bended moving the top about 5 cm orthogonal to the surface (fig. 13).

The cycle frequency is 2 Hz.

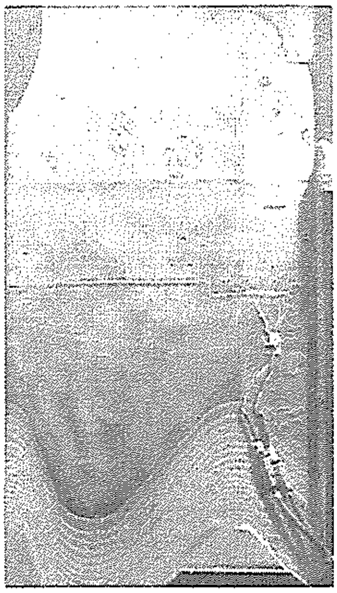

Figure 13: Structural element for a helicopter main rotor blade mounted for fatigue testing.

Figure 14: Phase map corresponding to fig. 13.

Figure 14 shows the corresponding shearographically acquired phase map using thermal loading while the sample is at rest, but still mounted in the testing bench.

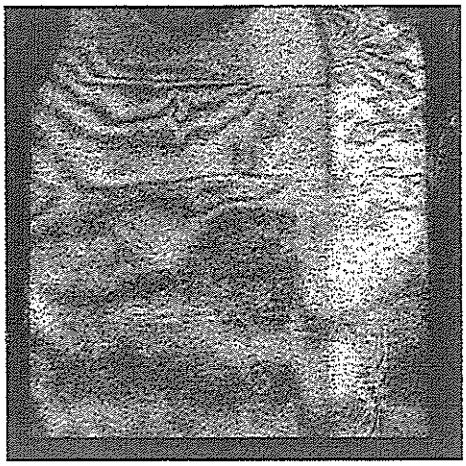

Figure 15: "In-situ" D-image of fatigue tested blade.

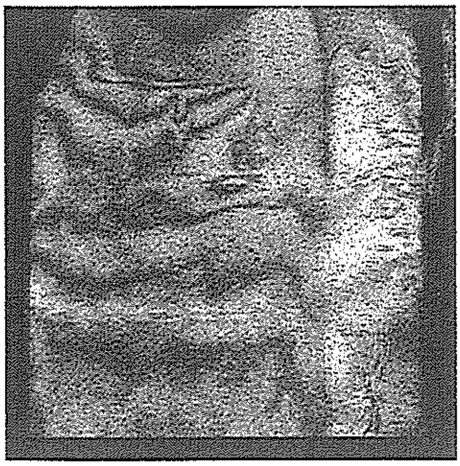

Figure 16: "In-situ" D-image of fatigue tested blade.

The phase map reveals some delamination defects as well as the region of different materials inside the sample. A diagonal delamination which could result from the fatigue testing is evident. Using this technique it is very convenient to test the sample in regular intervals to study the evolution of the defects and to estimate the failure of the sample.

While testing the sample the inspection is also possible. However due to the repositioning error of the cycling device phase shifting measurements are not very meaningful. Therefore we restricted the acquisition to D-images. Figures 15 and 16 show the difference of two images which were acquired for the sample in the same position. Due to the repositioning error we find a large number of more or less regular interference fringes which are disturbed in the regions of heavily stressed points. These must be attributed to the defects.

CONCLUSIONS

Experimental results of shearographic measurements on wide scale helicopter structures were presented. The system used allows the real-time non-contact and nondestructive detection of defects and structural properties of composites and other lightweight structures. The use of a pulsed laser for illumination shows significant benefits due to a large inspection area (up to 10 m^2) and suppression of environmental influences, which makes the system also useful for "in-situ" applications outside a laboratory. Examples of inspection of composites used for helicopters were shown and demonstrate the capability of the system to detect defects in wide scale structures, strongly reducing the inspection time and validating this kind of technique as very promising in the field of aerospace (composites, lightweight structures) particularly for the production-NDT, fatigue testing monitoring and maintenance inspections.

A good defect visibility was achieved using certain images processing and evaluation methods. The application of the phase shifting technique is the adequate means to significantly reduce the speckle noise and enhance the image contrast also for pulsed illumination. Due to the short illumination time the system also allows the analysis of vibrating objects which in contrast to conventional systems the shearographic system performs faster and for larger areas.

REFERENCES

1. G. Zenzinger: Zerstörungsfreie Materialprüfung mit Wärmebildgeräten, MTU München.
2. Y.Y. Hung, Shearography: a new optical method for strain measurement and nondestructive testing, Optical Engineering Vol.21, No.3., p. 391, 1982.
3. Y.Y. Hung, C.Y. Liang: Image shearing camera for direct measurements of surface strains. Applied Optics Vol. 18, No.7, p. 1046, 1979.
4. R.K.Erf, Speckle Metrology, Academic Press, New York, 1978.
5. R.S. Sirohi, Speckle Metrology, Marcel Dekker, New York, 1993.
6. Th. R. Crimmins: Geometric filter for speckle reduction, Applied Optics, 24(10), 1985.
7. T. Kreis: Holographic Interferometry: Principles and Methods, Akademie Verlag, 1996.
8. W. Osten: Digitale Verarbeitung und Auswertung von Interferenzbildern. Akademie Verlag, Berlin, 1991.
9. M. Takeda, T. Abe: Phase unwrapping by a maximum cross-amplitude spanning tree algorithm: a comparative study, Opt. Eng. Vol. 35, No. 8, p.2345, 1996.

10. P.Cawley: The Sensitivity of the mechanical impedance method of nondestructive testing, NDT International Vol. 20, No. 4, p. 209, Aug. 1987.
11. L.G. Merletti, M. Fusari: Shearography: A fast NDI method for composite structures, Proceedings of the 23rd European Rotorcraft Forum, Sept. 1997.
12. R.K.Erf: Holographic Nondestructive Testing, Academic Press, London, 1974.
13. ILIAS – Interferometric Laser Inspection of Large Area Surfaces, STN ATLAS Elektronik GmbH, Bremen.