NDE of Aerospace CFRP Composites with Laser Shearography

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Abstract

Full-field optical techniques used for Non-Destructive Evaluation (NDE), such as Laser Shearography, Thermography or X-Ray, are gaining more and more importance in industry, as they allow the inspection of large component areas over a relatively short period of time. However, each of these techniques having varying sensitivity to different physical properties of the material. And so, for different materials to be inspected, different methods may be more suitable than others.
As an interferometric technique, Laser Shearography is sensitive to changes of out-of-plane stiffness in the material, which cause differences in the surface deformation under load in the range of µm. In general, critical flaws cause a reduction in the stiffness of materials, which can easily be detected using Shearography.
A description of the technique will be presented, focusing on the requirements for automated detection systems and show a measurement of a typical test sample. Using component samples with known defects, the detectability of the different types of flaws can be determined.

1. Introduction

Laser Shearography is an optical-based Non-Destructive Testing (NDT) technique that can identify internal material discontinuities or anomalies in homogenous and non-homogenous materials in an accelerated manner. The highly sensitive interferometric sensor can measure and detect microscopic surface out-of-plan deformations caused by internal flaws when a small stress is applied to an object. This can be done using thermal, pressure, vibration or mechanical excitation. The results are displayed on-line (live) as the material responds to the excitation and can be easily interpreted by the operator.
Laser Shearography can be used not only as an NDE technique, but also as a developmental quality assurance process for composite structures design. It quickly detects and locates discontinuities in composites materials. The system systematically finds flaws such as: Wrinkles, Disbonds, Delaminations, Cracks, Crushed Core, Kissing bonds, Fluid Ingresses, Cracked Cores, Repair Defects, Voids, Foreign Objects, Impact damage (BVID's), etc. Compared to other NDE techniques, Laser Shearography exhibits excellent Probability of Detection (PoD) levels
(From: „An inspector calls", Aerospace Testing International magazine, Feb. 2004, http://www.aerospacetestinginternational.com/):

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Table 1: Flaw sizing and false call summary table for 3-ply carbon

	Flaw Coverage						
Inspection Device	**100%**	**99%-75%**	**74%-50%**	**49%-25%**	**<25%**	**90%PoD Level**	**False Calls**
Airbus Tap Hammer	28%	30%	27%	13%	2%	2.44	2.9
Boeing Tap Hammer	21%	34%	25%	16%	4%	2.33	4.7
LFBT	28%	29%	20%	18%	5%	2.55	3.3
MIA	26%	26%	26%	18%	4%	1.49	1.9
Wichitech DTH	32%	39%	19%	8%	2%	1.71	1.6
Woodpecker	31%	28%	20%	14%	7%	2.05	0.1
CATT	28%	38%	19%	13%	2%	1.10	1.0
MAUS	47%	31%	4%	4%	14%	0.55	9.0
S.A.M.	11%	40%	32%	9%	8%	0.84	8.0
Shearography	49%	27%	15%	9%	0%	<.50	0.0

Table 1. Flaw sizing and false call summary table for 3-ply-carbon

Shearography can be used not only as an experimental technique under controlled laboratory conditions, but also as a tool for quality control in production and service, where accurate and reproducible test results must be guaranteed.

The different parameters that control the indication, have to be optimized for the flaw to be detected. Here the type, duration and amplitude of load are parameters which are outside the optical shearography sensor itself. They must be selected in order to achieve the best influence of the surface's out-of-plane deformation above the flaw. As the indication will have time dependency, the relative timing of the image acquisition to the loading is important as well. The shear vector of the sensor directly sets the sensitivity of the detectable out-of-plane anomalies and therefore builds an important setting as well.

As a consequence all these parameter must be optimized in the setup phase and controlled and documented during the test itself.

2. Testing of a CFRP sample

Any internal structural anomaly which is creating a local weakness or reinforcement of the measured object will generate an additional phase difference under the application of a loading i.e. heating, vibrations, vacuum, pressurization, bending, etc. The resulting phase map is then a compound of both the natural deformation of the sample under the applied load and of the local defect. One can filter the natural deformation of the sample if needed.

As a Shearography system the commercially available FlawExplorer is used. The sensor head includes the optical system, the laser illumination and the complete control electronics. The sensor is connected to a laptop via GigE cable only. This concept allows a very compact system, which can easily be integrated in an automatization process, like robotic systems.

Figure 1. FlawExplorer Shearing System

The following results were measured on a 190mm x 190mm, 5mm thick CFRP sample. Multiple holes were drilled on the underside of the panel representing artificial defects. The diameter of the holes and depth varied from 5mm to 20mm and 0.5mm to 3.0mm, respectively. Heat was applied on the sample for 10 seconds, a reference image was captured 30 seconds later which was then compared to the deformation image after 60 seconds after heating. Figure 2 shows a picture of the sample with the holes and the wrapped phase map. The deviation from the homogeneous grey-value indicates a change in the stiffness of the material.

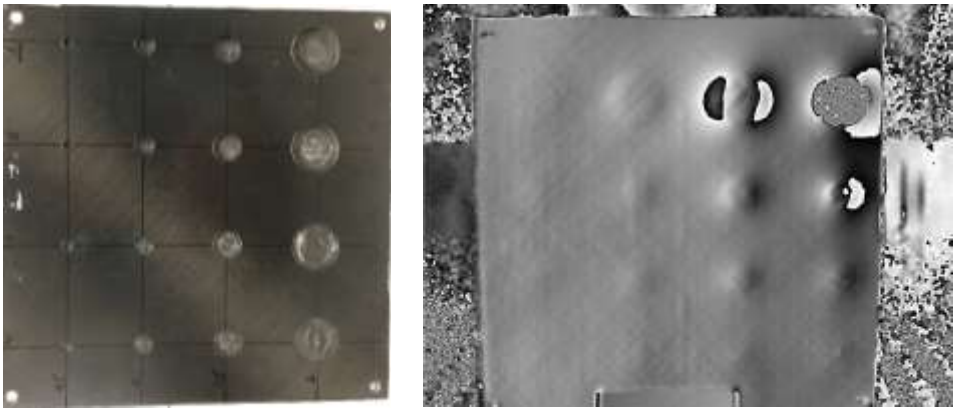

Figure 2. Sample with drilled bottom holes (left) and measured phase map (right)

The detectability of the defects is summarized in table 2.

Table 2. Detectability of artificial defects

[mm] depth diameter	0.5	1	2	3
5	[light orange]	[deep orange]	[deep orange]	[red]
10	[green]	[green]	[light orange]	[deep orange]
15	[green]	[green]	[light orange]	[deep orange]
20	[green]	[green]	[green]	[deep orange]

Green: Easily detected
Light Orange: Detected
Deep Orange: Barely Detected
Red: Not detected

Table 3 summarize the settings and parameters used for this measurement and visualization of the results. This data is given by the software, automatically as a reporting feature.

Table 3. Evaluation and visualization parameter

Measurement / Visualization program:	Istra 4D x64 Version: 4.4.6.303 / 4.4.7.347
Exposure time/ Camera gain:	0,050 s / 0
Shear angle/distance:	0 deg / 3,06 mm (20,0 px)
Reference/ Current step:	Step 06 | 29.18 s / Step 25 | 62.03 s
Low/high pass filter size:	4,0 px / 240px
Median filter size:	N/A
Wrap phases scaling value:	[-pi/1 ... pi/1)

3. Conclusion

Laser Shearography is an attractive NDE technique because it instantly identifies defects via active stressing of the structural surface. The main limitations of Shearography come from the prerequisite of the loading procedure for the creation of sufficient deformation to be detected. (Shearography has sub-μm sensitivity). This is either the consequence of the material being too stiff or because the defect is too deep to be excited. Defects with very little impact on the structure will also not be detected – these are usually not considered in NDT because most properly they might not harm the structure.