Development of measurement techniques by image processing for aerospace materials inspection

Doctoral school in: Space Sciences, Technologies and Measurements

Curriculum: Mechanical Measurements for Engineering and Space

Cycle: XXXII

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Admission to the final exam.

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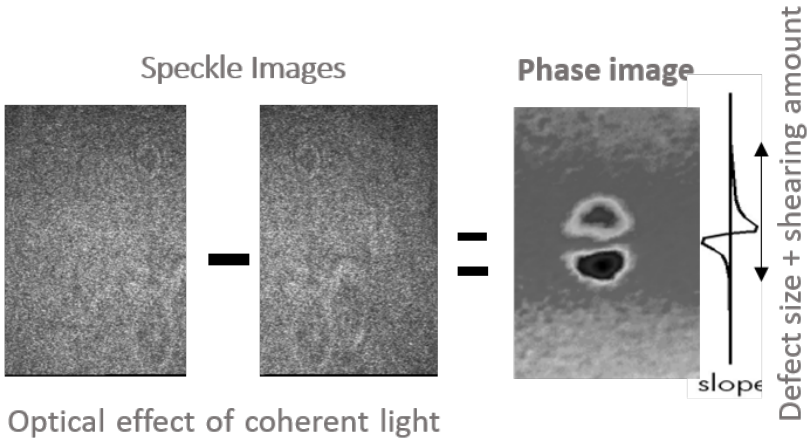
Aim of the work

Development of a standard, reliable and quantitative measurement procedure for Shearography inspections of composite materials in case of thermal load applications.

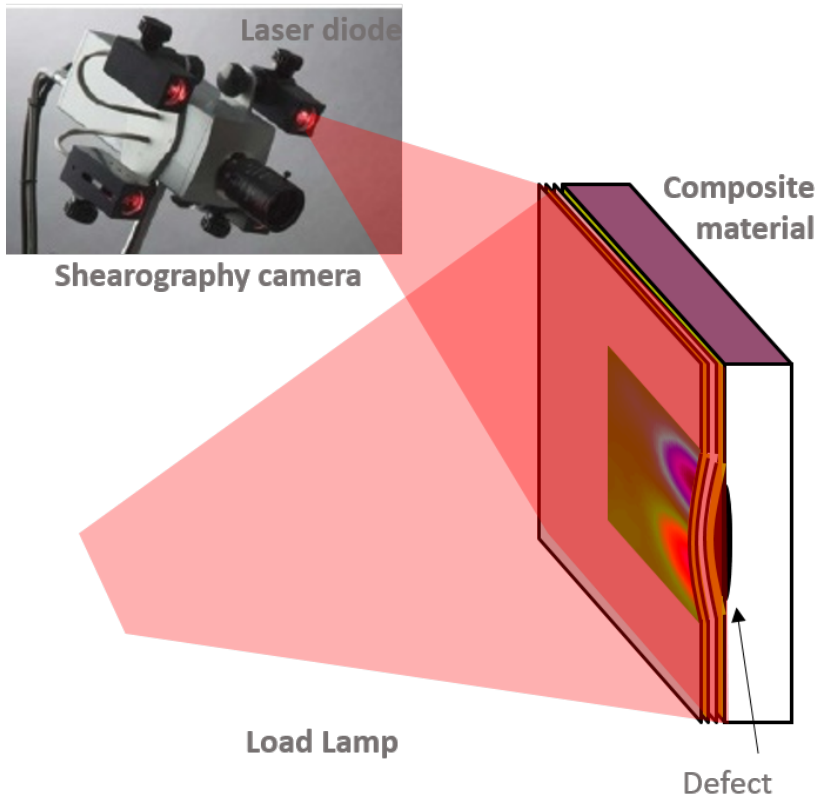
Shearography

Measurement principle

- Interferometric, full-field technique
- No need of reference beam
- Output: first derivative along a specific direction (shear) of the out-of-plane displacement of the observed surface.



Optical effect of coherent light interacting with rough surface



Detection of composite materials defects and damages, such as:

- Delaminations
- Debondings
- Impact damages

State of the art

- Current softwares
- Current procedures
- Current devices

Algorithms for defect characterisation

No robust algorithm for defect size and morphology carachterization.

Software support for indications about procedures

- Numerical models for fringe prediction for the determination of the effects of test conditions (shear, defect depth, defect size. . .):
  - knowledge of material properties is compulsory
  - prediction of noise and sensitivity effects is impossible.
- The more precise are the ones based on vacuum loading conditions, while for thermal load applications:
  - problems about considering the attenuation of thermal radiation;
  - confident with experimental results only for defects very close to the surface (up to 1 mm depth);
  - problems about definition of boundary conditions of the framed portion of the surface.

Heating time

General and qualitative indications provided by Shearography producers according to heating source and/or inspected material.

Uncertainty sources

In literature the problems of air turbulences and residual radiations even after lamps' switching-off are highlighted.

Acquisition sequence

No standard indication. The moment when to store reference image is an open issue too.

The evolution of Shearography systems and devices over time involved mostly software interfaces rather than new hardware solutions.

- Triggering the acquisition with the heating lamps and acquiring a video sequence with a given frame rate.
- Accessing raw data.

Unfortunately, software upgrades are very expensive.

Work packages

Limitations of Shearography technique described by state of the art, have been studied and overcome in this work according to the following work packages:

A new algorithm for defect size and morphological characterization

1. Data encoding, phase computation and optical corrections.
2. Local shear computation.
3. Phase-map Filtering and Unwrapping.
4. Wavelet Transform Scanning plus Structural Intensity Analysis.
5. Defect area evaluation.

A new algorithm for defect size and morphological characterization

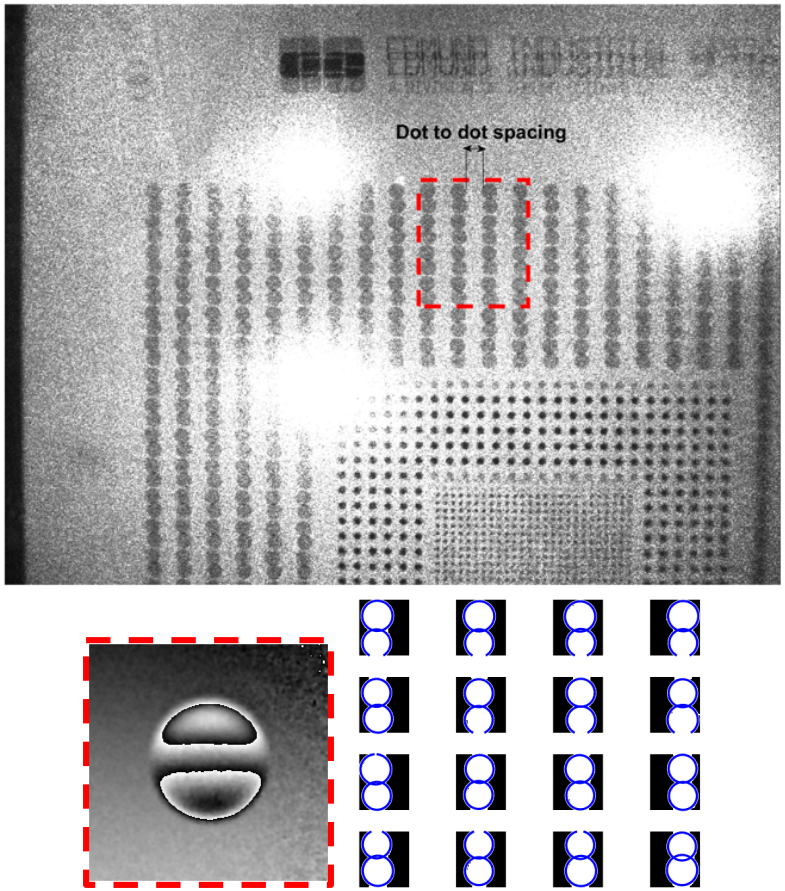
Data encoding, phase computation and optical corrections

A new algorithm for defect size and morphological characterization

Local shear computation

Computation of:

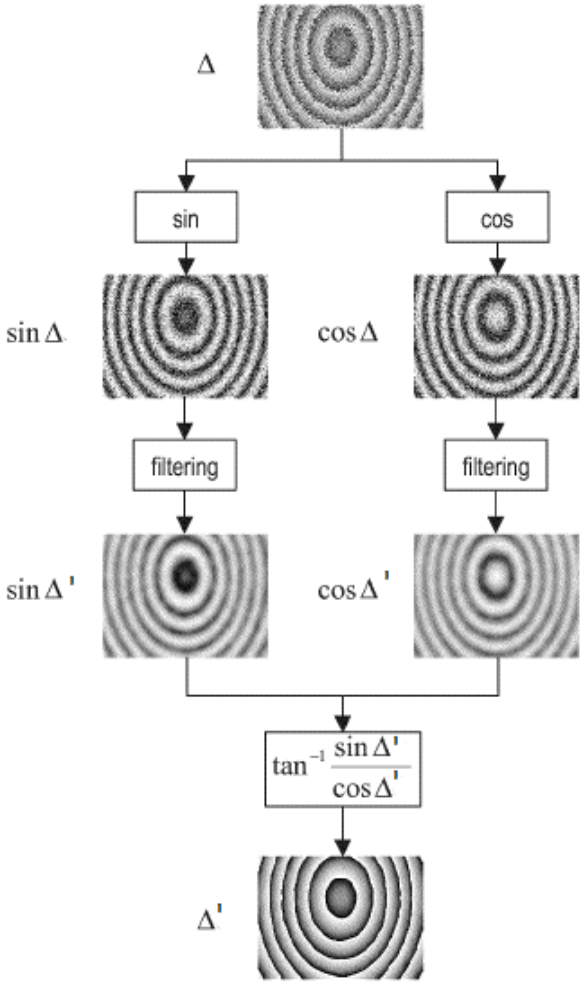
- *mm/pixel* ratio;
- shear components;



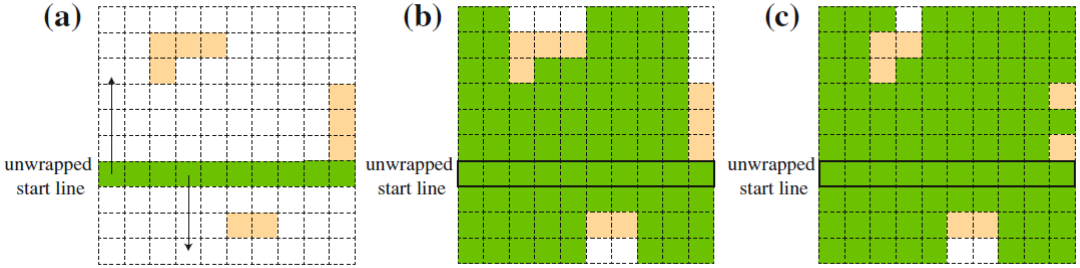
A new algorithm for defect size and morphological characterization

Phase-map Filtering and Unwrapping

Filtering



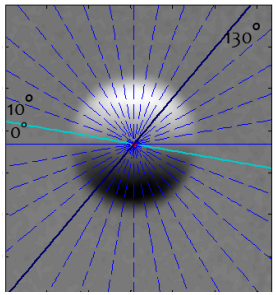
Unwrapping

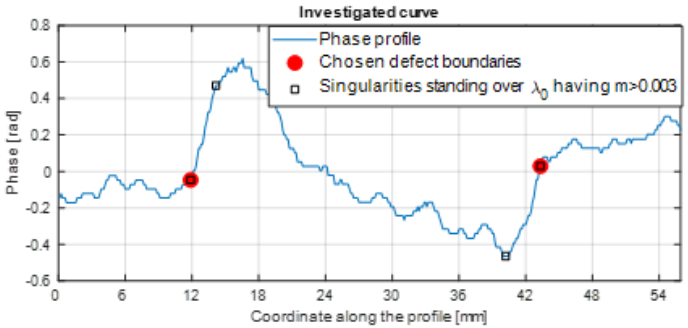


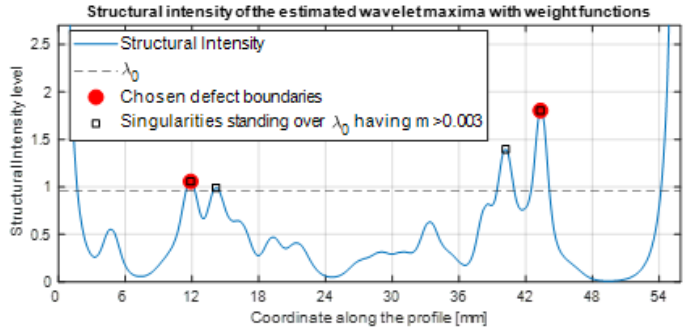
A new algorithm for defect size and morphological characterization

Wavelet Transform Scanning plus Structural Intensity Analysis

- Entropy-based threshold for centroid detection;
- definition of a set of line passing through the centroid (1° angular spacing);
- extrapolation of of the phase profiles along the scanning lines by a sub-pixel interpolation ;
- Wavelet Transform computation of each profile;
- selection of the dominant singularities thanks to Structural Intensity parameter associated to an automatic choice of related hyperparameters (excess mass, absolute threshold).





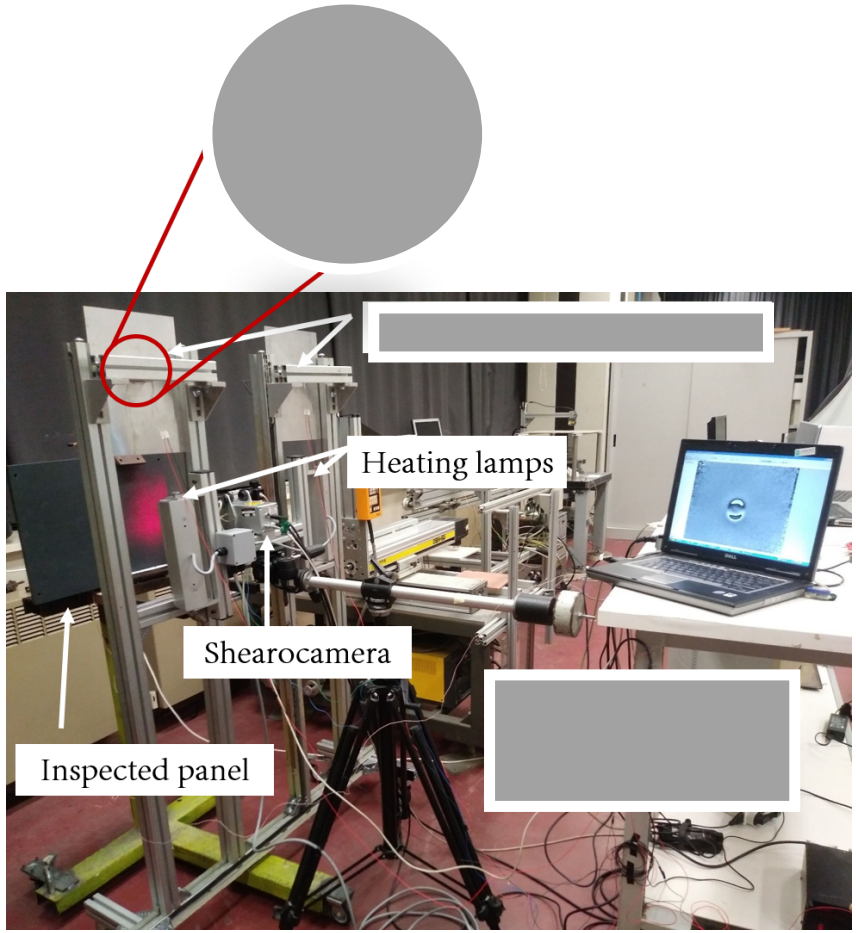


A new algorithm for defect size and morphological characterization

Defect area evaluation

Design and equipment of a computerised measurement setup

Setup elements



Design and equipment of a computerised measurement setup

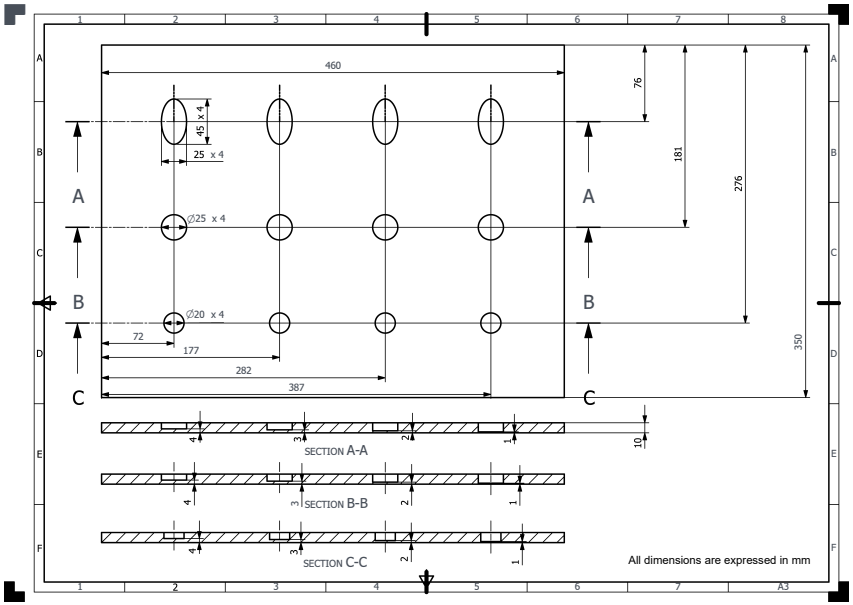
Acquisition sequence: design of a Virtual User in Labview environment

A new test procedure

The developed procedure exploits the new hardware and software discussed above, and can be divided in:

- preliminary operations;
- defect characterization.

At first a PVC test panel with artificial and accessible defects was used for implementation, then three real case studies validated the procedure.



A new test procedure

Preliminary operations: definition of measurement ranges

This phase is carried out before checking the presence of possible defects and involves the definition of measurement ranges for what concerns:

A new test procedure

Preliminary operations: definition of heating time range

A defect can be well represented by Shearography technique only if its deformation is sufficiently different from the deformation of the rest of the structure.

A new test procedure

Preliminary operations: definition of *heating time* range

A new test procedure

Preliminary operations: definition of *shear* range

A new test procedure

Preliminary operations: definition of *out-of-plane displacement* range for given heating time

A new test procedure

Defect characterization

Variables influencing defect size estimation

For the PVC specimen, the values chosen for developing the procedure are:

Shearing amount [mm]	Distance of observation [cm]	Heating time [s]	Defect size [mm]	Defect depth [mm]
3, 5, 10	24, 50, 70	1, 2, 3, 5, 10, 15	1, 2, 3, 4	10, 15, 25

A new test procedure

Defect characterization

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Defect characterization

Validation by means of three case studies

Sandwich panel 1: honeycomb core + carbon fiber skin affected by teflon inserts.

Sandwich panel 2: honeycomb core + fiberglass skin with a sub superficial delamination.

Carbon thin plate affected by teflon inserts.

Validation by means of three case studies

Sandwich panel 1: Shearography inspection

Validation by means of three case studies

Sandwich panel 1: comparison with Ultrasound results

Validation by means of three case studies

Sandwich panel 2: Shearography inspection

Validation by means of three case studies

Sandwich panel 2: comparison with Ultrasound results

Validation by means of three case studies

Carbon thin plate: Shearography inspection

Validation by means of three case studies

Carbon thin plate: comparison with Ultrasound results

Conclusions

- A deep study of Shearography technique was performed in order to define the limitations that still impede its quantitative use.
- A specific algorithm for defect size estimation and morphological reconstruction was developed.
- A programmable and robust measurement setup was designed and equipped.
- A repeatable measurement procedure for Shearography inspections involving thermal load applications was developed and validated on real case studies.

THANKS FOR YOUR ATTENTION