Deflectometry as a full-field NDT tool

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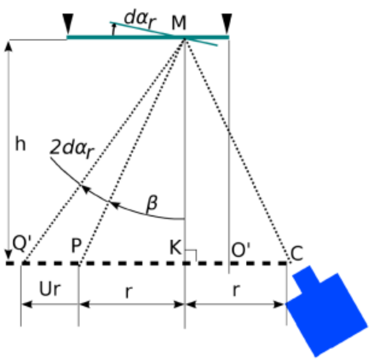
Abstract. Deflectometry is a technique for measuring full-field slopes at the surface of a specularly-reflective (mirror-like) deforming body. It is very sensitive and can measure surface slopes and curvatures of the order of 1 μrad and 1 km^{-1}, respectively. It is a perfect tool for high-resolution NDT and vibration-induced deformations. The present paper shows how deflectometry can be coupled to the Virtual Fields Method to 'read' deformation maps for defects and damage on thin plates.

Introduction

The principle of deflectometry is shown in Figure 1. The test specimen is flat and exhibits a mirror-like finish, in which case a pixel C of the camera will record the image of point P on the grid target via point M on the specimen. A local change of slope $d\alpha_r$ caused by bending deformation will shift the point imaged by pixel C to point Q' on the grid target. Therefore, by measuring this displacement U_r through simple standard spatial phase shifting algorithms, one can obtain the local change of slope at point M on the specimen by $d\alpha_r = 2\pi U_r/h$ where h is the specimen to target distance. This simple relationship is a very good approximation when h is large compared to the specimen size. Apart from being very simple and inexpensive, this technique enables one to tailor its resolution independently from its spatial resolution by adjusting h. Indeed, for a given resolution in U_r (which is mainly related to the grid sampling, the phase shifting algorithm and the camera noise level), increasing h will improve the resolution in local slope change nearly at will. A typical strain resolution of the order of a few microstrain has been reported in [1] on a thin beam where strains are proportional to curvatures.

The price to pay for such performance, however, is that since standard engineering material surfaces are not generally mirror-like, some surface preparation is required. For flat panels, a thin layer of resin gel coat is moulded against a flat and smooth glass panel [1,2] It was shown in [1] that this thin layer (~0.1 mm) does not significantly affect the strain measurement accuracy.



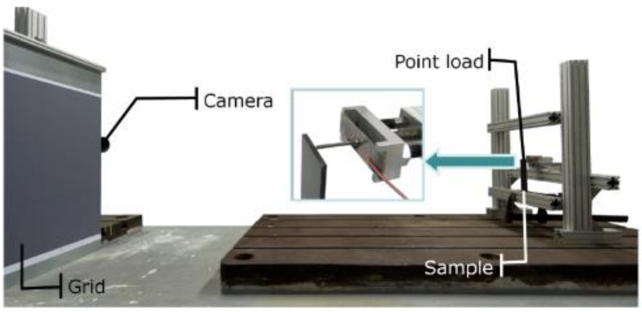


Figure 1– Principle of deflectometry (left) and typical experimental set-up [6] (right)

Application to damage detection

While deflectometry provides very detailed surface deformation information, detecting the presence of a damage is not a straightforward process. For instance, in Fig. 2, the surface strains obtained from curvature using thin plate theory are shown, for a composite plate loaded in bending and pinned at three corners [3]. The question is whether any damage is present in this plate and if so, how to extract it. In the literature, comparison with a virgin panel has been used but this requires a reference strain state for an undamaged panel, which is not always available.

This is why the Equilibrium Gap was developed. It is an application of the Virtual Fields Method where a small sub-window of data points is scanned across the specimen to check for local loss of mechanical equilibrium. If a damage is present, like a delamination, then the measured curvatures do not provide surface strains and the derived stresses are spurious [3]. In Figure 4, the Equilibrium Gap map clearly shows the location of the impact damage, confirmed by C-scan.

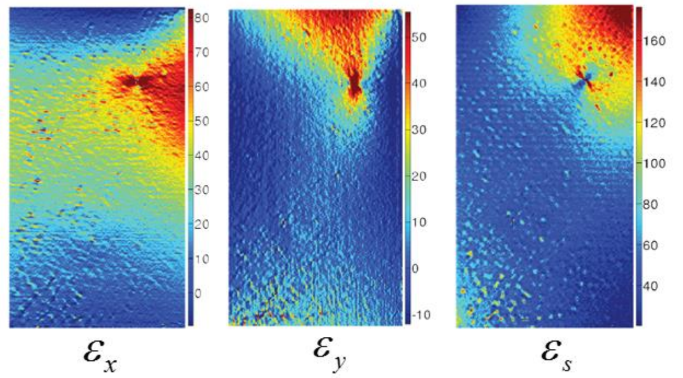


Figure 3 – Surface strains from curvatures, thin composite plate in bending, three corners pinned [3]

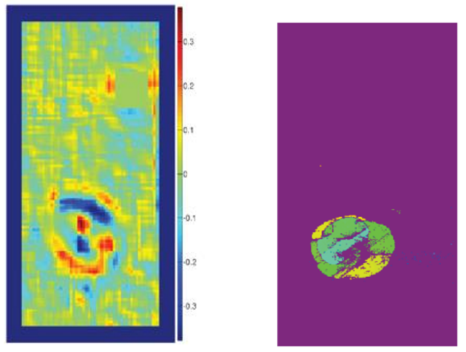


Figure 4 – Equilibrium Gap map (left) and C-scan (right)

Examples of application

The paper will provide examples on impacted composite plates [1,3] as well as Lamb wave imaging based detection [4]. For instance, Figure 5 shows the surface strain maps from a glass plate excited ultrasonically at 20 kHz. It is impossible to visually distinguish the presence of a possible defect. Something can be seen at the top-left corner but this is the location of the ultrasonic horn. However, the Equilibrium Gap map shows the location of the defect very clearly in Figure 6. It should noted here that time-resolved deformations are required, the images were captured using a ultra-high speed camera [4] and inertial forces are taken into account in the local equilibrium.

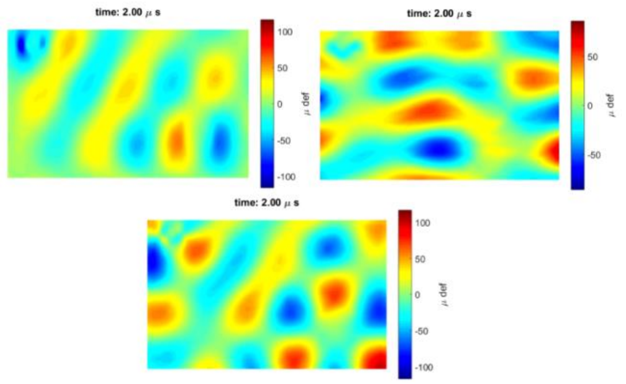


Figure 5 – Surface strains from curvatures on a glass plate with a thin patch at the back

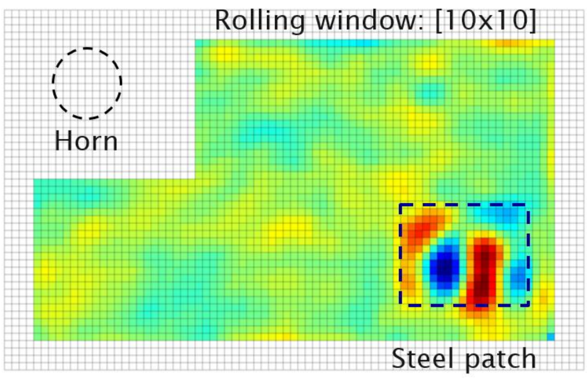


Figure 6 – Equilibrium Gap map (dotted contour shows actual patch position)

Conclusion

Deflectometry is an under-researched technique with great potential for vibration-based measurements and NDT. Its main present limitation is that only flat surfaces could be studied. Extension to moderately curved surfaces is currently underway.

References

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