Towards combining thermoelastic stress analysis and digital image correlation for strain-based NDE

R.C. Waugh[a], J.M. Dulieu-Barton and S. Quinn

Faculty of Engineering and the Environment, University of Southampton, Southampton. SO17 1BJ. UK

[a]rcw1n09@soton.ac.uk

Abstract Digital image correlation (DIC) and thermoelastic stress analysis (TSA) is applied to metallic and composite plates subject to excitation at their resonant frequency to develop sufficient strains to enable measurement. The portable loading device that provides the excitation is described. Mode shapes are identified with the TSA identifying the stress field induced by the modal excitation and the DIC identifying the displacement field. The data are compared to extract complimentary information from the two techniques. This work forms a step towards a combined non-destructive evaluation procedure which can identify and quantify the effect of defects more fully, particularly when examining component performance in service applications.

Introduction In recent years DIC [1] has become a very popular full field technique, however it is limited in spatial resolution thus areas with high displacement or strain gradients, such as around defects, are not well resolved without using high magnification optics and hence limiting the field of view. TSA [2] is an established active thermographic technique with high spatial resolution but can only provide the principal stress sum, which is not a failure criterion. The two techniques can more complete picture of the structural response by using TSA to identify local effects at damage sites and DIC to provide the component strains.

The practicalities of in-situ loading and robust inspection must be considered to enable the testing of in service structures. Natural frequency excitation has previously been successfully used to obtain the thermoelastic response [3]. The current work uses a vibration based remote loading system [4] to excite components at resonant frequencies to enable inspection based on both TSA and DIC.

As load rates increase in DIC the preference is to use camera systems with lower spatial resolution and increase frame rate of data collection [5] or to synchronise the load signal and data capture [6]. The current work uses the lock-in approach well established in TSA, based on a fast Fourier transform, to construct the DIC data relative to the loading frequency [7]. The behaviour of two plates made of an aluminium alloy and a carbon fibre reinforced plastic is investigated. First mode excitation frequencies are of the order of 100 Hz. The aim of the current work is to use lower cost cameras with frame rates of a few hertz to collect images for use in DIC using the lock-in approach.

Methodology A schematic of the experimental set up is provided in Fig. 1. The load was imparted into the plates using a permanent magnet shaker (LDS V201) positioned below the plate. The lock in signal was collected using an accelerometer attached to the stinger. TSA was undertaken using a Cedip 480M IR detector and 3D DIC was carried out using two LaVision E-lite 5 MP cameras. The DIC data was then exported to Matlab where the lock-in processing was performed.

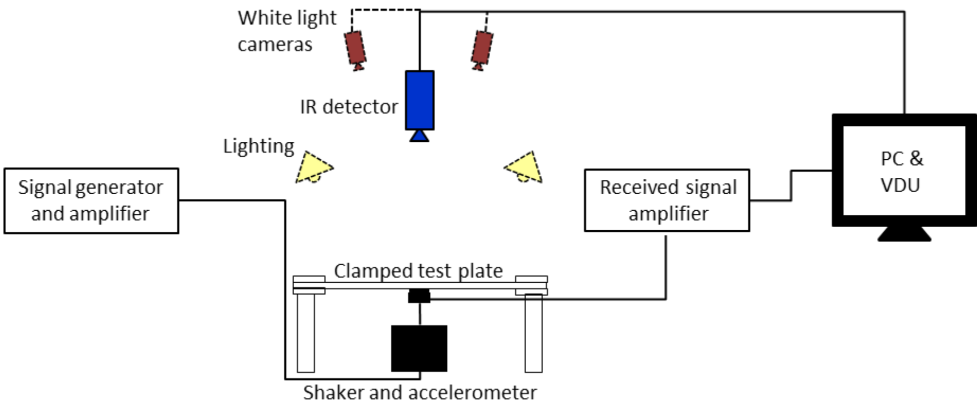

Figure 1 Schematic of experimental set-up.

Results The effect of the stinger is apparent in the thermoelastic data where large concentrations in the response are visible in the contour and the line plot, shown in Figs. 2a and b. This concentration around the stinger location causes a bias in the TSA data. In TSA the 'stress mode shape' is found which is affected by the presence of the stinger as local reinforcement is provided to that region of the plate. Aside from this concentration the TSA data appears to show the expected pattern for the excitation of the second mode in aluminium. The DIC displacement data captures the second mode shape, shown in Fig. 2d. The DIC line plot taken across the plate in Fig. 2e, provides a mode shape closer to that expected however the variation in magnitude of the two peaks demonstrates that there is some effect of stinger location present. The phase data shown in Fig. 2c and f reveals that the two halves of the plate are out of phase with each other as expected. The TSA phase data is highlighting one half of the top surface is in compression while the other half is in tension while the DIC phase data is illustrating where half the plate has a positive displacement while the other is negative. The clamped edges provide a zero displacement in the DIC data however stress concentrations are highlighted in the ΔT/T data. Some edge effects are apparent in the DIC phase data.

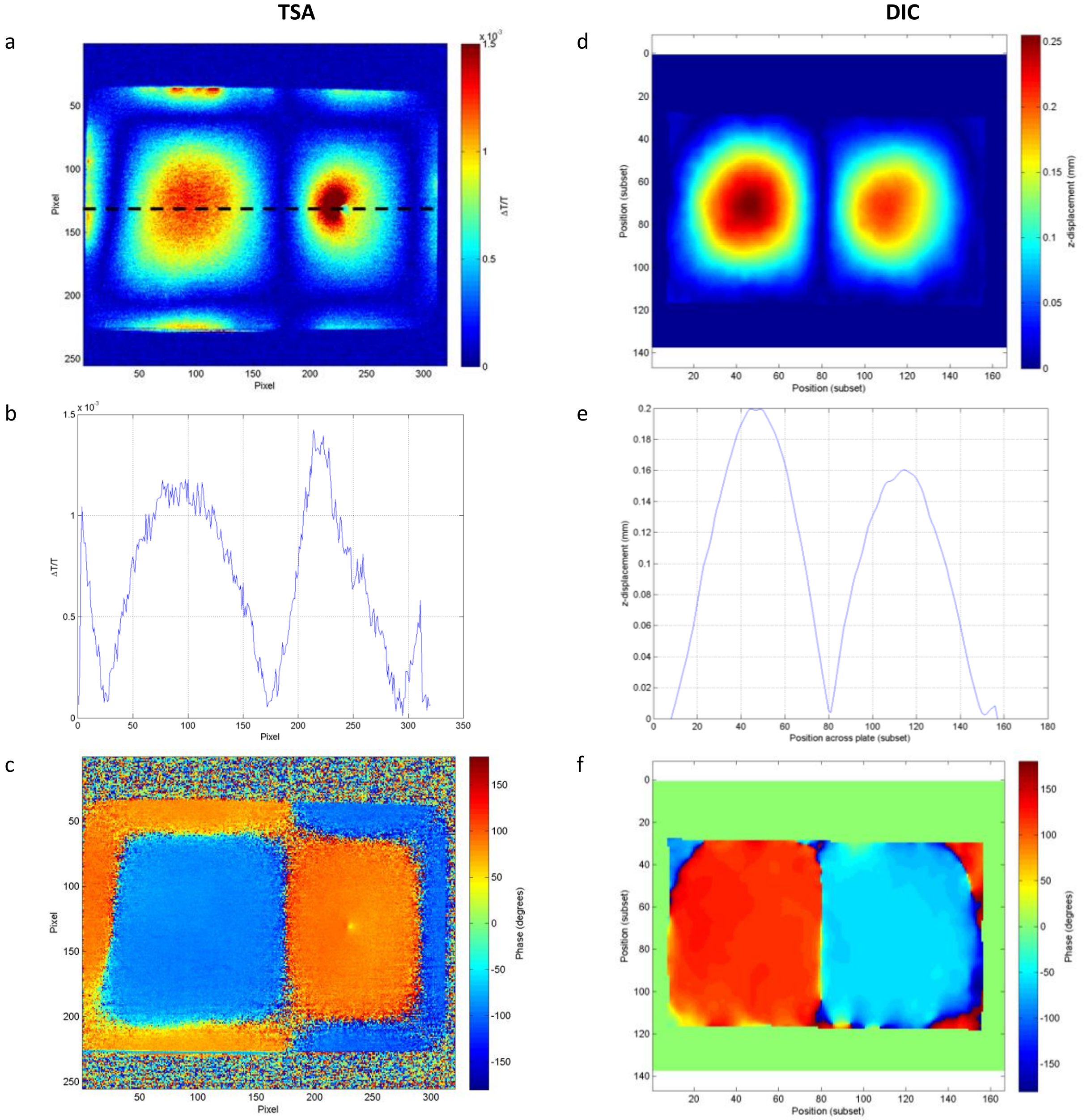

Figure 2 Aluminium plate second mode (221 Hz) – TSA data a) ΔT/T, b) ΔT/T horizontal profile at pixel 130 and c) phase data; DIC data d) z-displacement, e) z-displacement horizontal profile at subset 70 and f) phase data.

Conclusions A remote loading technique based on natural frequency excitation has been successfully trialled for both TSA and DIC. Through selection of the correct sampling parameters it is possible to apply a lock-in algorithm to reconstruct the data and produce lock-in DIC taken during a dynamic cyclically loaded test using greatly under sampled data. Further work is ongoing to improve loading technique via use of a suction cup [4] to reduce the stress concentrations imparted by using the rigid stinger. Future work will also focus on extracting strain data from the DIC and applying the technique to composite components.

References

[1] Sutton, M.A., Orteu, J-J. & Schreier, H.W., Springer (2009).
[2] Dulieu-Barton, J.M., Thermoelastic Stress Analysis, In *Optical Methods for Solid Mechanics*, P. Rastogi & E. Hack. Wiley-VCH. 345-366 (2012).
[3] Phan, T.S., Dulieu-Barton, J.M. & Temarel, P., Experimental Mechanics 46, 463-472 (2006).
[4] Fruehmann, R.K., Dulieu-Barton, J.M., Quinn, S., Peton-Walter, J. & Mousty, P.A.N. Modern Practice in Stress and Vibration (2012).
[5] Kirugulige, M.S., Tippur, H.V. & Denney, T.S., Applied Optics 46(22), 5083-5096 (2007).
[6] Risbet, M., Feissel, P., Roland, T., Brancherie, D. & Roelandt, J.-M., Procedia Engineering 2, 2219-2227 (2010).
[7] Fruehmann, R.K., Dulieu-Barton, J.M., Quinn, S. & Tyler, J.P., Optics and Lasers in Engineering. 68, 149-159 (2015).