Application of Digital Image Correlation (DIC) to torsional tests of a 40m wind turbine blade

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Abstract. This report discusses the application of 3D DIC to a large-scale structural test of a 40m wind turbine blade (WTB). The measurement, equipment and speckle pattern requirements are discussed as well as the unique challenges of applying DIC to large scale structural tests. The resulting measurements are presented, showing how they are used to validate numerical predictions of the response of the WTB to an applied torsional moment.

Introduction

The torsional response of WTB significantly impacts rotor stability, blade and turbine loading, turbine power output and structural integrity [1, 2]. Torsional deformation is typically coupled with bending deformation; thus, torsional deformation will always be present in operation. Aerodynamic forces which dominate the forces on the rotor are sensitive to small changes in angle of attack that could be caused by the blade twisting under load. Thus, the continued safe and efficient operation of wind turbines requires structural analysis models and tools that accurately capture the structural characteristics connected with the torsional dynamics such as the torsional stiffness distribution, elastic axis and flexural axis.

Several sources of uncertainty have the potential to introduce significant discrepancies between the modelled torsional response and the actual response. Depending on the approach taken and the restrictive assumptions adopted, some numerical modelling approaches have been shown to introduce large uncertainty and bias [3, 4]. Manufacturing variability is another considerable source of uncertainty. However, to date, examples of full-scale validation of the structural response are limited.

This paper discusses the application of DIC and resulting measurements from a series of torsional tests on a 40m WTB that will be used to validate Finite Element Model (FEM) predictions. The objective is to provide a full-field, high-fidelity dataset to supplement more conventional sensors used in WTB testing. Tests were performed in Winter 2023 at the Offshore Renewable Energy Catapult, UK, with the possibility of more tests in Summer 2023.

Test overview

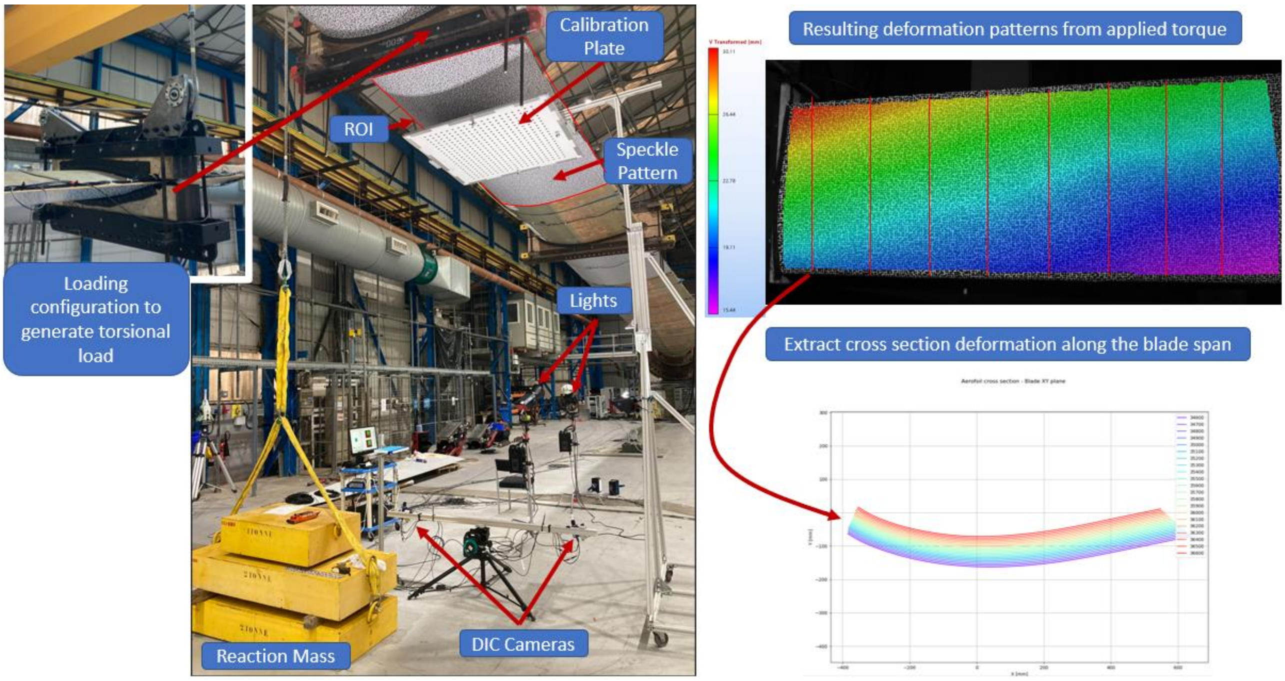

Fig. 1 – Test setup: (left) loading fixtures to generate torsional load, (centre) The 40m WTB with DIC setup, (right) - sample measured displacement field and cross section deformation extraction

Figure 1 shows the test setup. The aim is to sequentially introduce a pure torsional moment to the blade at highlighted locations and use the DIC system to measure the Quantities of Interest (QOI) to the required resolution over as much of a blade surface as possible. The QOIs will be used to compare against the FEM predictions.

Expected Response. The maximum displacement resulting from an applied torque is approximately two orders of magnitude smaller than the maximum displacement achievable by bending the blade. Maximum displacements of only a few centimetres may only be permissible in a torsional test, presenting a considerable challenge for large scale structural testing to ensure measurements have sufficient resolution over a large Region of Interest (ROI).

DIC setup

Only a single stereo camera pair was available for the tests. Thus, the setup had to be carefully designed. Virtual simulations of the test were performed to inform the choice of camera positioning, stereo angle, focal length, aperture setting, stand-off distance, calibration target, ROI, speckle sizing and lighting. A tool was developed to help navigate the many trade-offs to ensure measurements of the required resolution over the ROI could be delivered.

The scale of the structure brought many additional challenges. A combined surface area of approximately 22 m^2 had to be speckled consistently within a short space of time. Being able to map the measurements from the DIC reference frame into the blade reference frame also presented a considerable challenge and a method was developed to manage the transformation that could be integrated into the DIC workflow. This was crucial to being able to make a direct comparison between the DIC measurements and the FEM predictions.

Results

Displacement and strain fields are currently being compared to FEM predictions. Additional post processing of the DIC displacements also enables the underlying torsional response to be extracted at several spanwise locations along the blade. These provide insight into the rigid body response as well and any local deformation that might be present. The relative displacement between successive spanwise locations can also be used to estimate the local torsional stiffness of a section of blade providing a further valuable source of model validation.

Conclusions

3D full field measurements of a torsional test on a 40m WTB have been made using a single stereo camera pair. Application of DIC to large scale structural testing requires careful consideration of the measurement requirements, equipment selection and DIC speckle pattern. Simulations of the test with the DIC system in situ proved to be immensely valuable in helping to navigate the many decisions that need to be made to define a suitable setup capable of delivering the QOIs to the required resolution within the ROI. The resulting measurements provided detailed insight to the underlying deformation of the WTB resulting from an applied torque enabling rigorous validation of numerical models.

References

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