Compensation of Apparent Strain Data Due to Temperature Gradients in a Full-Scale Mechanical Test of a Composite Tidal Turbine Blade

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Abstract This work presents a methodology for compensating strain measurements affected by temperature gradients. The data was collected during a full-scale mechanical test of a composite tidal turbine blade at FastBlade, the world's first regenerative fatigue testing facility for tidal turbine blades.

Introduction

FastBlade is a testing facility where large slender structures (2-14 meters) can be tested under static or fatigue load (see Fig. 1). The facility is enabled by a unique Digital Displacement® Pumps system that features regenerative pumping and digital displacement hydraulics, allowing a high load (up to 1MN) accelerated (up to 1Hz) test [1]. The combination of these features can reduce testing energy by up to 75%, thus enabling testing to be delivered in several weeks rather than months; this renders such testing economic for blade developers. Nevertheless, mechanical and fatigue tests can last hours or days, and the testing of large structures requires, for its nature, vast space to fit, situations that make it challenging to keep the temperature stable during a test and which ultimately affects the strain measures.

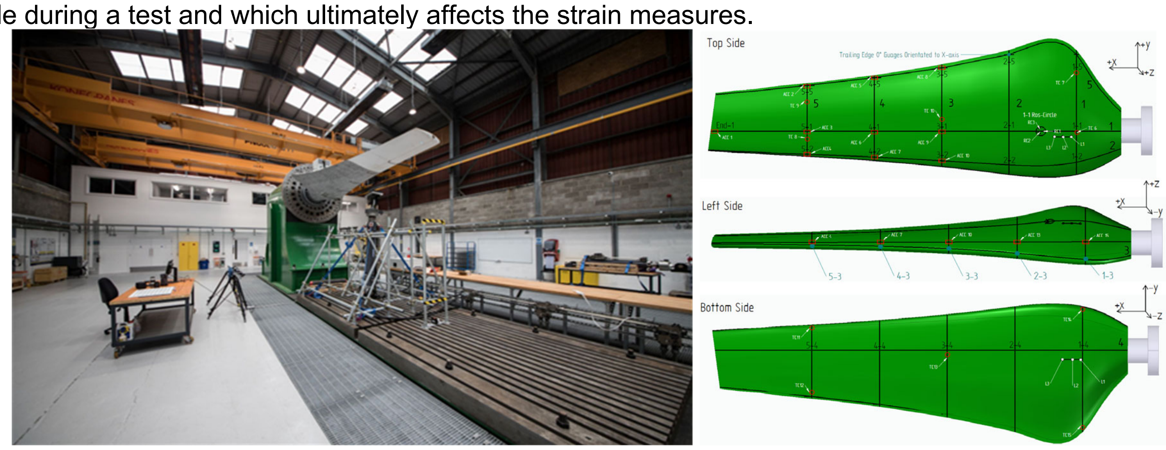

Fig 1. FastBlade facility (left-hand side) and sensor placement (right-hand side).

Background

The strain gauges deformation readings are a crucial section of the data FastBlade uses to analyse the behaviour of the specimen it is testing. There are 52 strain gauges and ten thermocouples logging data on the specimen's top and bottom (see Fig. 1). The Wheatstone bridge circuit converts the resistance change into a voltage output. However, if the lead wire experiences a temperature change due to outside temperature change and/or because of the large heaters hung from the ceiling (see Fig 1.). Then the thermal output of the bridge is altered, resulting in an apparent strain reading. Due to high-temperature gradients in the tests conducted at the facility, strain readings necessitate compensation.

Specimen information. The specimen under analysis is a blade 5.25 meters long, weighing 1588.59 kg (15584.07 N) and has a natural frequency of around 18Hz. The NACA 63-4XX aerofoil series define the cross-section. The thickness-to-chord ratio decreased from 55% near the blade root to a minimum of 18% at the tip. The innermost portion of the blade was taken to have a cylindrical cross-section with an implied thickness-to-chord ratio of 100%. The blade is part of the DeepGen tidal project, designed by Tidal Generation Limited (TGL) and manufactured by Aviation Enterprises Limited.

Data. The data used for this study is based on two static tests, one fatigue test following IEC TS 62600-3:2020 [2] and two temperature tests. The temperature tests were conducted without static nor fatigue load to ensure that the change in strain would only result from the temperature change of the specimen and environment. The strain information was logged at 2500 Hz, and the temperature at 1 Hz at the locations specified in Fig. 1. The strain gauge type is FRA-3-350-11 (350Ω), and the thermocouples used are K-type with 32 channels. In this work we present te results from the strain gauge at coordinate 2-1 on the blade, and thermocouple 10 (top side) are used for illustrative purposes. Is worth to mention that the sam methodology was applied to all the strain gauges.

Methods

To investigate the relation between strain and temperature, readings are plotted on the same graph against the time of the test. Fig 2. displays the behaviour of a thermocouple (red curve) and a strain gauge (blue curve) close to each other. It is possible to see a clear relationship between the two. Further signal processing is performed using a wavelet filter with the soft mode of the VisuShrink method in Python, which uses a universal threshold for all wavelet coefficients. As mentioned, temperature readings are taken at a slower rate (or frequency) than strain readings; hence it is necessary to resample the strain data into the temperature sample frequency. Once resampled, the temperature and strain data sets are plotted against each other, as shown in Fig. 2 (right-hand side). A lag in the stains' response was observed to the temperature changes recorded by the strain gauge. A series of time shifts between signals was performed based on these observations and further linearising the relationship between the two quantities. After this, a regression analysis is performed to determine the equation that explains the relationship between our variables to perform the temperature compensation. It is noticed that the relationship is not linear for most of the sensors. Therefore, a fourth-order polynomial fit is used, displayed in Fig. 2, right-hand side. Finally, after identifying the equation through regression, this can be applied to the data to remove the apparent strain in the readings.

Results

The changes in temperature experienced on the top side of the blade goes from 10 degrees Celsius up to 30 degrees Celsius, corresponding to a strain change from 0 metres to 0.00025 metres. Differently, the bottom side of the blade experienced a minor change from 6 degrees Celsius to 18 degrees Celsius, corresponding to a change in strain of 0.00012 metres. Once the signal processing is applied to the data, the results are promising. The R^2 factor calculated between the observed test data and the regression is 0.96 for this specific strain gauge and thermocouple pair. Moreover, the root mean squared error was 0.081. The equation is applied to the strain readings to remove the apparent strain, and the process is successful, resulting in a lower strain than previously measured.

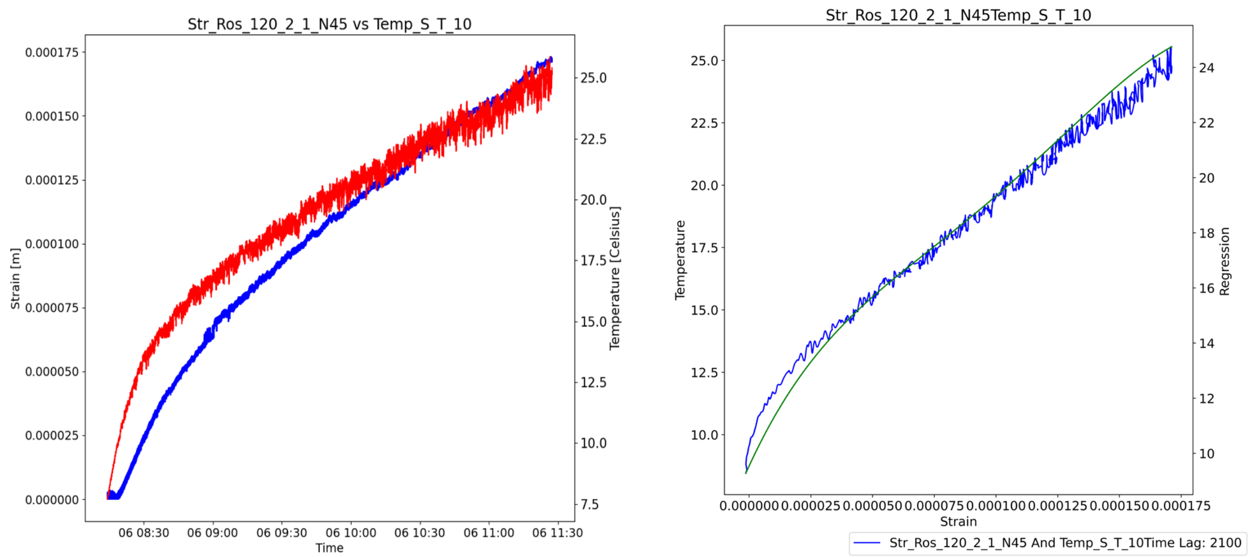

Fig 2. Strain and temperature data during no load test (left-hand side) and polynomial regression analysis (right-hand side).

Conclusions

The mechanical testing of full-scale turbine blades represents several challenges, like maintaining a stable temperature in the testing facility and across the structure under analysis. These temperature changes affect the strain measurements resulting in apparent strain due to the thermal output of the lead wire inside the gauge. To solve this problem, a model for temperature compensation is developed in this paper, which successfully identifies the equation relating the quantities which can be applied to the initial readings. The model utilises a wavelet filter, resampling, lag time interval and polynomial regression analysis, allowing to isolate of the effects of temperature from the ones due to loads.

References

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