10-2014

Dynamic Load and Response Prediction of HAWT Blades for Health Monitoring Application

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Abstract
Wind turbine blades of a Horizontal Axis Wind Turbine (HAWT) are prone to damage; some insurance agencies report that as much as 40% of all claims are from blade damage. While most claims are not very expensive in comparison to other HAWT component repairs, for example, repairing of the gel coat, others, like replacing the entire blade can be one of the most expensive tasks. As the world moves toward larger and longer blades to capture more wind energy this problem will continue to grow. Inspecting wind turbine blades presents a challenge with most techniques requiring a technician to repel down the blade for inspection using nondestructive evaluation techniques such as ultrasound or X-ray. While some US companies like General Electric propose to use robots to perform blade inspections, there is an alternate solution to this problem which requires continuous monitoring of the blades. There is an ongoing study at Iowa State University to explore a real-time monitoring and analysis of blade response using a new type of skin-mounted strain-gauge sensor onto the inside surface of the blade. This technique would allow for damage to be detected sooner in order to reduce the overall operations and maintenance cost of wind turbines.

Keywords
Aerospace Engineering

Disciplines
Aerodynamics and Fluid Mechanics | Civil Engineering | Construction Engineering and Management | Environmental Engineering | Other Aerospace Engineering

Comments
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Wind turbine blades of a Horizontal Axis Wind Turbine (HAWT) are prone to damage; some insurance agencies report that as much as 40% of all claims are from blade damage. While most claims are not very expensive in comparison to other HAWT component repairs, for example, repairing of the gel coat, others, like replacing the entire blade can be one of the most expensive tasks. As the world moves toward larger and longer blades to capture more wind energy this problem will continue to grow. Inspecting wind turbine blades presents a challenge with most techniques requiring a technician to repel down the blade for inspection using nondestructive evaluation techniques such as ultrasound or X-ray. While some US companies like General Electric propose to use robots to perform blade inspections, there is an alternate solution to this problem which requires continuous monitoring of the blades. There is an ongoing study at Iowa State University to explore a real-time monitoring and analysis of blade response using a new type of skin-mounted strain-gauge sensor onto the inside surface of the blade. This technique would allow for damage to be detected sooner in order to reduce the overall operations and maintenance cost of wind turbines.

The novel strain gauge that has been developed by one of the authors consists of a soft elastomeric capacitor (SEC) arranged in a network configuration. This skin-type configuration can be deployed easily on areas most prone to damage (Laflamme et al., 2013). Figure 1 shows a picture of a single strain gauge of dimensions 70 mm x 70 mm. However, in order for this method to provide useful physics-based features to enable condition-based maintenance of blades, there is a need to be able to predict the real-time load, stress distribution and response of a blade for a given wind condition which is the basis for this ongoing two-year project funded by the Iowa Energy Center.

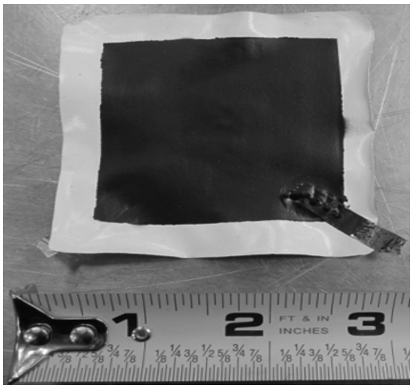

Figure 1　A single SEC (70 mm x 70 mm) (courtesy of Dr. Simon Laflamme)

The National Renewable Energy Laboratory (NREL) in the US has designed a family of S-series airfoils that are thick (high thickness to chord ratio), generate low-noise during operations

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and aerodynamically efficient with high lift-to-drag ratio, for use in 20-25 meter wind turbine blades. In this study, the S818, S830 and S831 airfoils were used to design a 20-meter HAWT blade, with S830 as the primary airfoil, to study the loads and response of a typical wind turbine blade. A time-domain formulation was used to determine the self-excited and buffeting loads on the S830 blade model whose profile is shown in Figure 2. The Rational functions that are used to predict the self-excited loads and the buffeting indicial functions that are used to predict the buffeting loads were extracted using a section-model of the S830 airfoil at different angles of attack (0, 3, 6 and 9 deg.) using recently developed techniques (Cao and Sarkar, 2012 and Chang et al., 2010). These tests were conducted in an open-return wind tunnel, the Bill James Wind Tunnel (0.91m W x 0.76m H) that is located in the WiST Lab at ISU. The Rational functions of the S830 were validated by extracting the corresponding flutter derivatives and comparing them with those of a symmetric airfoil, NACA0020 (Gan Chowdury and Sarkar, 2004).

The next task of this study involves testing of a full aeroelastic model of a wind turbine blade in intact condition and four other blades in a damaged condition with pre-determined damage of certain type and intensity. Data from the skin strain-gauge sensors will be primarily used to develop algorithms to detect the damage. A 1:12 scale aeroelastic model of a 20m blade has been designed using the S830 airfoil starting at 16.67% of the blade span (omitting the cylindrical root section and the transition section from cylinder to airfoil section). This blade model will be tested in both smooth and turbulent flows in the larger test section (2.44m W x 2.29m H) of the AABL Wind Tunnel located in the WiST Lab at ISU. The initial design of the model can be seen in Figure 3. The Rational functions of the 2D airfoil section as extracted from the section model tests will be used to estimate the flutter speed and response of the twisted blade model using the modal properties of the blade for validation of these functions using the experimental data.

The lateral or cross-wind (lift) and along-wind (drag) forces and the torsional (twist) load at the base of the model will be measured by a set of force transducers. A variety of distributed sensors along the span of the blade such as accelerometers, potentiometers, conventional strain gauges, and the capacitance-based skin sensors (Fig. 1) will be used for data collection. A set of pressure taps will be used to measure the surface pressures of the airfoil section of the model that will also help to validate the predicted aeroelastic loads using the identified Rational and indicial functions. This study will facilitate the development of a new structural health monitoring

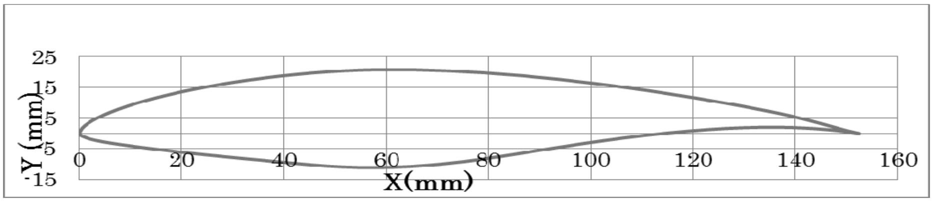

Figure 2 Profile of the S830 airfoil used in experimental tests

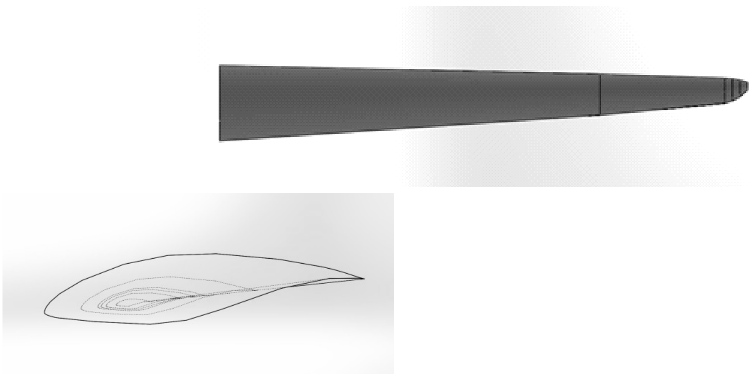

Figure 3 Initial design of full-blade model

method for HAWT blades and improve the understanding of how damage influences the response of the blades.

ACKNOWLEDGEMENT

This work is supported by Grant 13-02 from the Iowa Energy Center; its support is gratefully acknowledged.

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