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Smart Composite Wind Turbine Blades
- A Pilot Study

A Dissertation Submitted by

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Abstract

Wind energy is seen as a viable alternative energy option to meet future energy demands. The blades of wind turbines have been long recognised as the most critical component of the wind turbine system. The turbine blades interact with the wind flow to turn the wind turbine, in effect acting as a tool to extract the wind energy and turn it into electrical energy.

As the wind industry continues to explore new technologies, the turbine blade is a key aspect of better wind turbine designs. Harnessing greater wind power requires larger swept areas. Increasing the length of the turbine blades increases the swept area of a wind turbine, thereby improving the production of wind energy. However, longer turbine blades significantly add to the weight of the turbine, and they also suffer from larger bending deflections due to flapwise loads. The flapwise bending deflections not only result in a lower performance of electrical power generation but also increase in material degradation due to high fatigue loads and can significantly shorten the longevity for the turbine blade.

To overcome this excessive flapwise deflection, it is proposed that shape memory alloy (SMA) wires be used to return the turbine blade back to its optimal operational shape. The work presented here details the analytical and experimental work that was carried out to minimise blade flapping deflection using SMA.

This study proposes a way to overcome the wind blade deflection using shape memory alloy (SMA) wires. A finite element model has been developed for the simulation of the deflection response of a horizontal axis wind turbine blade using an SMA wire arrangement. The model was developed on the commercial finite element ABAQUS®, and focused on design and analysis, to predict the structural response. Experimental work was carried out to investigate the feasibility of the model based on a plate-like structure. An Artificial Neural Network (ANN) was used to predict the performance of the smart wind turbine blades.

From this study, the model of a smart wind turbine, incorporating SMA wires, was determined to be capable of recovering from large deflections. The coefficient of performance of the smart wind turbine blade was also determined to be higher than the coefficient for a conventional turbine blade. The results showed that by increasing the number of SMA wires, the actuation provided is sufficient to recover from significant blade deflection resulting in a significant increase in the lift produced by the blade. It was determined that the coefficient of performance for turbine blades with SMA wires is 0.45 compared to 0.42 for turbine blades without SMA. These findings will be a significant achievement in the development of a smart wind turbine blade.

It is expected that the use of smart wind turbine blades, incorporating SMA in their design, will not only increase the power output of the wind turbine but also prolong the lifetime of the turbine blade itself through a reduction of the bending deflections.

List of Publications Arising from this Study

Most of the discussion and results presented in the thesis are based on the following publications. Several passages in this thesis contain materials that have been copied verbatim, or with some adaptation, from thesis publications. All such copied materials were originally written by myself.

(i) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., "Smart Structure for Small Wind Turbine Blades", *The* 4^{th} *International Conference on Smart Materials and Nanotechnology in Engineering (SMN2013)*, Hotel Grand Chancellor Surfer Paradise, Gold Coast, Queensland, Australia, Volume 8793, pp1–10, 10–12 July 2013, Society of Photo-Optical Instrumentation Engineers (SPIE) http://dx.doi.org/10.1117/12.2027725

(ii) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., "Genetic Algorithm Based for Artificial Neural Network for Predicting the Deflection of Self-Straightening Wind Turbine Blade", *The* 3^{rd} *Malaysian Postgraduate Conference (MPC2013)* Sydney, New South Wales, Australia, MPC2013–27, pp233–242, 3–4 July 2013

(iii) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., "Development of Smart Wind Turbine Blades", *The* 8^{th} *Asian-Australasian Conference on Composite Materials (AACM8)*, Petronas Kuala Lumpur Convention Centre, Malaysia (KLCC), Kuala Lumpur, Malaysia, pp199–205, 6–8 November 2012, http://eprints.usq.edu.au/id/eprint/22295

(iv) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., “Design of Smart Structures for Wind Turbine Blades”, *The* 2^{nd} *Malaysian Postgraduate Conference (MPC2012)*, Bond University, Gold Coast, Queensland, Australia, pp20–36, 7–9 July 2012 , http://eprints.usq.edu.au/21673

(v) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., “Design and Analysis of a Smart Composite Beam for Small Wind Turbine Blade Construction”, *The Southern Region Engineering Conference (SREC)*, USQ, Toowoomba, Australia, 1 September 2012

(vi) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., “Smart Structure Wind Blade”, *Fibre-Reinforced Composites Development and Applications in Renewable Energy Workshop* , Composites Australia, USQ Toowoomba, Queensland, Australia, 4 June 2012

(vii) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., “Development of Smart Wind Turbine Blades”, *Engaged Research Evening Posters*, Toowoomba, Queensland, Australia, 26 April 2012

(viii) Supeni E.E., Epaarachchi J.A., Islam M.M. and Lau K.T., “Development of Artificial Neural Network in Predicting Performance of the Smart Wind Turbine Blade”, *Journal of Mechanical Engineering and Sciences (JMES)*, ISSN (Print): 2289-4659; e-ISSN: 2231-8380; Volume 6, pp. 734-744, June 2014

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged. The work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Notation

α	angle of attack, °
θ	angle of twist, °
υ	Poison ratio
σ	stress, Pa
Γ	vortex strength
W_A	resultant velocity, ms^{-1}
r	radius of the blade section considered, m
Ω	rotational speed of the turbine, $rads^{-1}$
U_0	velocity of the wind at tip, ms^{-1}
λ	tip speed ratio
ρ	density of air, kgm^{-3}
C_p	coefficient of power
$\triangle A$	small portion area of a wind turbine blade
L_A	lift force, N
V	wind velocity,ms^{-1}
$at.wt.$	atomic weight
$\mathrm{A_s}$	austenite start, °C
$\mathrm{A_f}$	austenite finish, °C

$\mathrm{M_s}$	martensite start, °C
$\mathrm{M_f}$	martensite finish, °C
$\mathrm{Ac_{func.}}$	active functional
ε_m^y	martensite twin strain
ε_m^d	martensite detwin strain
ε_m^y	martensite twin strain
ε_m^d	martensite detwin strain
E	Young's Modulus, MPa
$E_{m,t}$	Young's Modulus twin, MPa
$E_{m,d}$	Young's Modulus detwin, MPa
Δ	percentage difference, %
W	width, mm
D	depth, mm
H	height, mm
NW	number of SMA wires
L	applied load, N
I	applied current, Amp
N	line of vortices
d	deflection, mm
V	voltage, V
w	power, W
P_{wt}	power extracted from the wind, kW

Acronyms and Abbreviations

ANN	artificial neural network
AuCd	Aurum Cadmium
AuCu	Aurum Copper
BET	Blade Element Theory
CAD	computer aided design
CAE	computer aided engineering
CEEFC	Centre of Excellence Engineered in Fibre Composite
CuZn	Copper Zinc
EPS	expanded polystyrene
EWEA	European Wind Energy Association
FEA	finite element analysis
GFRP	glass fibre-reinforced polymer
GUI	graphical user interface
HAWT	horizontal axis wind turbine
IGES	initial graphics exchange specification
LM	Lavenberg-Marquardt
LVDT	linear variable differential transformer
MATLAB	Matrix Laboratory
MBP	multi-back propagation
ML	machine learning

MLP	multi-layer perceptron
MSE	mean square error
NARX	Non-linear autoregressive with Exogenous
NiTi	Nickel Titanium
NACA	National Advisory Committee for Aeronautics
Nitinol	Nickel Titanium Ordnance Laboratory
NREL	National Renewable Energy Laboratory
N/A	not applicable
PPE	personal protective equipment
PVC	Polyvinyl Chloride
R	correlation coefficient factor
SMA	shape memory alloy
SME	shape memory effect
SE	superelasticity
TSR	tip speed ratio
USQ	University of Southern Queensland
UPM	Universiti Putra Malaysia
UD	unidirectional
VAWT	vertical axis wind turbine