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Optimisation Methodology of a Full-Scale Active Twist Rotor Blade

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Abstract

This paper presents optimisation methodology for the design of the full scale rotor blade with an active twist to enhance its capability for vibration and noise reduction. This methodology is based on the 3Dfinite element model, planning of experiments and response surface technique to obtain high piezoelectric actuation forces and displacements with the minimal actuator weight and energy applied. To investigate an active twist of the helicopter rotor blade, the structural static analysis with thermal load using 3D finite element model was developed by finite element software ANSYS. Torsion angle obtained from the finite element simulation of helicopter rotor blades was successfully validated by experimental value to confirm the modelling accuracy.

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Keywords: active twist, macro fibre composite (MFC), helicopter rotor blade, optimisation

1. Introduction

The traditional vibration reduction technique was a passive approach using, with vibration isolators and absorbers. However, this methodology imparts undesirable weight penalties and insufficient vibration reduction. Later, new control techniques were developed. This strategy involves active approach such as Higher Harmonic

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Control and Individual Blade Control. Disadvantages of this concept are adverse power requirements, limitation on excitation frequencies in HHC and extreme mechanical complexity of hydraulic sliprings in IBC (Shin *et al.*, 2007). With an emergence of active materials, the Active Twist Rotor (ATR) concept was proposed. The actuators integrated and distributed into the rotor blade skin generate dynamic blade twist and camber adapted to the flight condition at any given time, which leads to significant vibration and noise reduction and improves flight performance.

The early studies are mostly experimental in nature with simple modelling and were undertaken to prove the concept of active twist control using piezoceramic materials. The key idea was to check ±2° of twist needed for suppressing vibration with minimum consumption of power. The first active twist rotor, using direct twist actuation, was developed by Chen and Chopra (1996). They built a Froude–scale model rotor blade with incorporated discrete dual-layer monolithic piezopatch elements embedded at +45° under the upper skin and -45° under the lower skin of the rotor blade. Different piezoceramic arrangements were analysed. The maximum twist at resonance frequencies were 0.35° and 1.1°.

With the emergence of piezo fibre technology the active twist concept was significantly improved. With this technology it is possible to create an active piezo ply within a composite laminate, such as Active Fibre Composites (AFC) and Macro Fibre Composites (MFC) actuators. The continuous piezo ply is structural more effective than the embedded monolithic piezo elements. Using the new actuator technology, a 1/6th Mach scale CH–47D blade model was built for wind tunnel testing at Boeing Helicopters (Philadelphia) with incorporated AFC (Rodgers *et al.*, 1997). Results of bench tests at frequencies up to 67.5 Hz demonstrated that a maximum twist of 1° to 1.5° peak-to-peak (pp) could be obtained.

In 1999, a joint venture from NASA, Army and MIT built and tested an active twist rotor with a structural design similar to the Boeing model rotor. Once more, the twist is generated by AFC actuators embedded into the rotor blade spar (Wilbur *et al.*, 2004). A four–bladed, aeroelastically scaled, ATR model was designed and fabricated to be tested in the heavy gas medium of a transonic wind tunnel to achieve better Mach–scale similarity. For the non–rotating results, the blade was mounted on the bench in a single–cantilevered condition. It was estimated that 1.1° to 1.4° maximum twist was generated for the 33–55 Hz frequency range at 1000 V electric excitation.

During a Collaborative research within the European Integrated Project “Integration of Technologies in Support of a Passenger and Environmentally Friendly Helicopter” (FRIENDCOPTER), twist blades were investigated more intensively. A series of blades was built using thin skin integrated actuators. At the first stage, several parameter studies for the optimisation of the skin lay-up were carried out (Riemenschneider *et al.*, 2004). Then demonstrator blades were designed and manufactured (Riemenschneider *et al.*, 2010). The baseline of the blade characteristics were taken from the well-known BO-105 model rotor blade. The actuators that were used are MFC, developed by NASA. These actuators are much more reliable than AFC actuators. In contrast to AFC, the rectangular PZT fiber of the MFC improved the maximum contact area between the PZT fibers and the interdigitated electrodes.

Cesnik and co–workers (2004a, 2004b) developed an optimisation framework to design an active blade that maximizes the static twist actuation while satisfying constraints on various blade requirements. The framework included UM/VABS for active cross section analysis, DYMORE for one dimensional geometrically exact beam analysis, a based cross–sectional parametric mesh generator and MATLAB’s gradient based optimizer. Using the proposed design and manufacturing processes, the active twist rotor blade in model was designed and fabricated. Experimental structural characteristics of new rotor blade were compared with design goals and experimental results were compared well with modelling predictions. A maximum measured twist of 1.58°pp was reached at half of the operating voltage while all the actuators were working (Shin *et al.*, 2008).

The objective of the present study is development of the methodology, based on the planning of experiments and response surface technique, for the optimal design of active rotor blades using MFC actuators to obtain high piezoelectric actuation forces and displacements with minimal actuator weight and energy applied.

2. Structure of helicopter rotor blade

The investigated full scale rotor blade with C−spar is based on the passive BO105 model scale rotor blade with C− sparand equipped with NACA23012 airfoils. The chord length *c* of 310 mm is in agreement with the original full