"Digital" SMA-Based Tracking Tabs for One-Per-Rev Vibration Reduction

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Abstract

A novel approach for providing one-per-rev vibration reduction using collections of discrete active tab devices was recently tested under an Army-sponsored research program. Each tab incorporates a patented bistable design that uses SMA wires for transitioning between one of two deflection positions, thereby providing a localized perturbation to the blade aerodynamics at the location of the trailing edge tab. By arranging several such tabs spanwise along the rotorblade, incremental adjustments may be made using these tabs to perform tracking adjustments on the blades, while in flight, avoiding the typical maintenance cycle of fly-measure-land-adjust-repeat for manual blade tracking. The device has been prototyped, and has been designed so that it may be retrofit on existing rotor blade systems, thereby providing active in-flight tracking capability to both existing and future rotorcraft.

BACKGROUND

Excessive vibration is perhaps the most fundamental and elusive problem affecting helicopter operating costs for both military and commercial aircraft[1,2]. Vibratory motion usually means oscillatory strain, which reduces the fatigue life of components, leading to increased weight of the total aircraft. Since fatigue life dictates the service life of a helicopter part, and life-limited components comprise the majority of parts on a helicopter, life-cycle costs grow with increased vibration as well. This vibration is largely due to oscillatory airloads, which are an undesired but unavoidable consequence of flying a rotor edgewise through the air. Design of helicopter components and systems to avoid vibratory motion is difficult, due to the complex aeroelastic interactions present in the rotor and helicopter fuselage structure. As a result, most production helicopters incorporate some form of vibration treatment that was often added after the first prototype aircraft was built (with a resultant reduction in payload capability). While most of these vibration absorbers or isolators are designed to eliminate harmonics of blade passing frequency (or, N/rev, where N is the number of blades), vibration may also be present at the rotor rotation frequency, if all of the rotor blades are not producing the same forces and moments at the hub during each revolution.

Mechanisms for 1/Rev Vibration

One-per-revolution (1/rev, or 1P) vibration arises from dissimilarities in rotor blade mass properties, aerodynamic contours, and to a lesser degree, structural stiffness. Mass nonuniformities between rotor blades produce classical dynamic imbalance problems due to the rotor center of gravity being located away from the shaft centerline. This problem is typically referred to as a "balance" problem for a rotor system. Aerodynamic contour mismatch results in differing airloads between blades, which is aggravated by high thrust and high forward speed conditions. Differences in airloads typically manifest themselves as the blades flying "out of track" as they spin about the shaft, best observed by the difference in the location of the blade tips at the same rotor azimuth location.

Elimination of the 1/rev vibration on Army helicopters would substantially reduce the costs required for maintenance and support. These costs include maintenance personnel hours, faulty rejection of functional parts, and defective parts replacement. It is estimated that a resulting 10% savings in the spare parts budget alone would net over $100M per year[3].

Vibration at 1/rev is currently addressed by the helicopter manufacturers by imposing strict quality standards on the production of helicopter rotor blades. Blades are often whirl-tower tested and matched to each other, and then shipped as sets to be flown together. Several manufacturers maintain the use of a master blade to which other blades are compared during whirl tower testing, and even have a master-master blade for balancing new master blades when a previous one has expended its useful life.

Maintaining blade-to-blade similarity is becoming particularly important with the use of composite materials as primary structure in rotor blades.

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