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An Offset Hub Active Vibration Control System for Mitigating Helicopter Vibrations during Power Loss: Simulation and Experimental Demonstration

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Abstract

In recent years, hub active vibration control (HAVC) technologies have been developed to attenuate blade pass frequency vibration on helicopters. While these systems provide superior vibration control with reduced weight compared to passive options, in the event of electrical power loss they can exacerbate the vibration problem in a manner that is problematic for helicopter and tiltrotor aircraft. This paper presents an offset hub active vibration control system (OHAVCS) designed to attenuate vibration during a power loss by offsetting the centers of rotation of two imbalance masses. The equations of motion for this system are developed using Lagrangian methods; analysis, simulation and experimental validation of these equations indicate that offsetting the imbalance masses effectively mitigates 1/Rev vibrations during a rotor hub power loss while continuing to cancel N/Rev vibrations during normal operation. These offsets create stabilizing centripetal torques that rotate each imbalance mass to a unique equilibrium angle. Experimental data also indicate that these offsets do not hinder control of the imbalance masses during normal (active) operation, though they do increase system power requirements.

1. Introduction

The primary source of helicopter vibration occurs at the blade pass frequency (N/Rev), defined to be the number of blades (N) times the hub rotational frequency (1/Rev) [1-3]. Blade pass frequency vibrations reduce crew comfort and increase maintenance demands and operating costs [4]. Two primary approaches to vibration attenuation are currently utilized: passive absorption technologies and active vibration control (AVC) systems [5-7]. Passive approaches utilize various forms of resonant masses (solids or even liquids) mounted on flexible supports (at the hub, at the airframe-gearbox connection, or within the airframe) tuned for specific frequencies. One common, weight-efficient passive approach uses bifilar pendulum absorbers (commonly called bifilars) to attenuate vibrations at the helicopter hub [8-12]; this method has also been applied to reciprocating engine crankshafts [13-14]. Bifilars attenuate up to 90% of N/Rev vibrations while accounting for approximately 1% of the helicopter gross weight [15-16]. Figure 1 shows a typical construction schematic: a set of tungsten masses attached to bifilar arms by two journal bearings. The bifilar's masses and dimensions are designed so that its natural frequency matches specific N/Rev vibration frequencies; the system requires no complex electronics and provides a reliable mechanical method of attenuating vibration. However, bifilars require journal bearing lubrication before every flight, create increased drag on the helicopter, and do not cancel vibration effectively during high acceleration helicopter maneuvers (due to large non-linear pendulum oscillations).