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# Pitch link loads reduction of variable speed rotors by variable tuning frequency fluidlastic isolators

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**Abstract** To reduce the pitch link loads of variable speed rotors, variable tuning frequency fluidlastic isolators are proposed. This isolator utilizes the variation of centrifugal force due to the change of rotor speed to change the tuning port area ratio, which can change the tuning frequency of the isolator. A rotor model including the model of fluidlastic isolator is coupled with a fuselage model to predict the steady responses of the rotor system in forward flight. The aeroelastic analyses indicate that distinct performance improvement in pitch link load control can be achieved by the utilization of variable frequency isolators compared with the constant tuning frequency isolators. The 4/rev (per revolution) pitch link load is observed to be reduced by 87.6% compared with the increase of 56.3% by the constant frequency isolator, when the rotor speed is reduced by 16.7%. The isolation ability at different rotor speeds in different flight states is investigated. To achieve overall load reduction within the whole range of rotor speed, the strategy of the variation of tuning frequency is adjusted. The results indicate that the 4/rev pitch link load within the whole rotor speed range is decreased.



## 1. Introduction

Varying rotor speed can be an effective means to improve rotorcraft performance, which has been successfully applied to A160, V-22 and X2 rotorcraft.[1,2] The reduction of rotor speed can decrease the blade tip speed and delay the occurrence of shock wave. However, it can increase the rotor advance ratio and the reverse inflow region. The increasing advance ratio causes the increase of higher harmonic pitch link loads due to dynamic stall,[3,4] which may cause fatigue, vibration and strength problems. It is highly necessary to control these troublesome pitch link loads.

Pitch link loads control is always a challenging topic in the research of helicopters. Kim et al. utilized multiple trailing edge flaps to control the blade loads and vibrations,[5] and up to 40% peak pitch link load reduction was observed in the analysis. John et al. described the development of an active pitch link of a swashplateless helicopter rotor, which utilized a piezohydraulic actuator to control pitch link loads.[6] Oxley et al. proposed the concept of smart spring to attenuate higher

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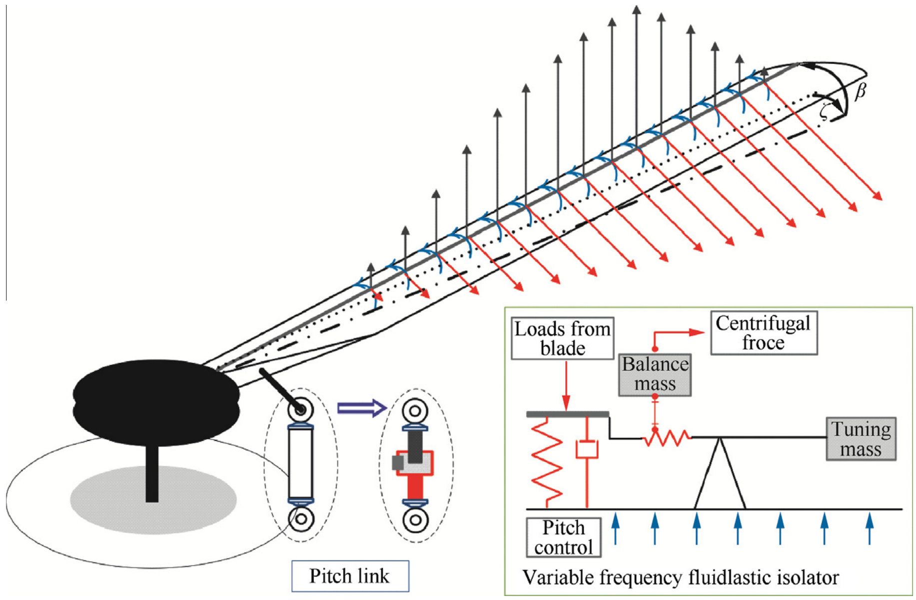


**Fig. 1** Configuration of variable tuning frequency fluidlastic pitch link isolator.

harmonic pitch link loads.[7] It could actively alter the boundary condition of a beam structure, which was incorporated at the root of the blade to control the vibrations. The analyses indicated that 56% of the 4/rev and 38% of the 8/rev harmonic loads were reduced. Han et al. proposed coupled fluidic pitch links to control multiple harmonic pitch link loads.[8] The frequency responses indicated the effectiveness to reduce these loads simultaneously. Scarborough et al. utilized coupled fluidic device to control pitch link loads.[9] The analyses of the two fluidic devices coupled with three different fluidic circuits illustrated that the load reductions at the targeted odd and even harmonics were at least 95% and 72%, respectively. Han et al. utilized fluidlastic isolators to control higher harmonic pitch link loads.[10] The results indicated that the 4/rev pitch link load could be distinctly reduced. The variation of rotor speed decreased the performance of the fluidlastic isolator. The previous research was focused on the pitch link loads control of constant rotor speed helicopter rotors. How to reduce the pitch link loads of variable speed rotors is still an untouched research topic.

Fluidlastic technology can provide unique vibration isolation and damping capabilities by combining fluids with bonded elastomeric elements.[11,12] This technology has been successfully applied to the model 427 helicopter to isolate the 4/rev vibration from the rotor to the airframe.[13] 94% 4/rev vertical vibration from the main rotor could be isolated. Fluidlastic isolators have been proposed for higher harmonic pitch link loads control.[10] Although this tuned device is an effective means to reduce higher harmonic pitch link loads, it is sensitive to the excitation frequency due to the variation of rotor speed. The change of rotor speed changes all the excitation frequencies of the rotor blades, which can distinctly lower the performance of the isolator. How to maintain the effectiveness of the isolation at different rotor speeds is an important and challenging topic.

In this work, variable tuning frequency fluidlastic isolators embedded in blade pitch links are proposed to reduce higher harmonic pitch link loads of variable speed rotors (see Fig. 1). This topic has not been investigated in the previous research. The balance mass is introduced in the fluidlastic isolator. The centrifugal force on the balance mass varies with the rotor speed, which causes the balance mass move in the radial direction. The move of the balance mass changes the tuning port area ratio of the fluidlastic isolator, which can change its tuning frequency. In this way, the fluidlastic isolator adjusts its tuning frequency following the rotor speed, which is utilized to reduce the pitch link loads of variable speed rotors. The influence of the flight states on the isolation ability is investigated. The strategy to vary the tuning frequency with the rotor speed for the performance improvement of the isolator is addressed.

## 2. Model

To evaluate the potential of variable frequency fluidlastic isolators in pitch link load control of variable speed rotors, the steady responses of the rotor system need to be calculated. To analyze the pitch link loads in steady flight, the model of the coupled rotor and fuselage system including a rotor model, a fuselage model and a propulsive trim method is derived. The rotor model includes a moderate deflection beam model as the blade structure model, blade kinematics, the Leishman–Beddoes aerodynamic model to predict the unsteady aerodynamics and the Pitt-Peters inflow model to calculate the induced velocity over the rotor disk. This rotor model is derived based on the generalized force formulation.[10,14,15] The hub force and moments generated by the rotor are balanced by the fuselage. The fuselage is treated as a rigid body with aerodynamics.

For the propulsive trim analysis, three pitch controls and two rotor attitude angles are set as the input variables to solve the three-force and two-moment equilibrium equations.[16] The forces and moments on the rotor and fuselage are shown in Fig. 2. The control input vector is $\boldsymbol{x} = [\theta_0 \quad \theta_{1c} \quad \theta_{1s} \quad \alpha_s \quad \phi_s]^T$, and the output vector is $\boldsymbol{y} = [y_1 \quad y_2 \quad y_3 \quad y_4 \quad y_5]^T = \boldsymbol{0}$. $\theta_0$, $\theta_{1c}$