Stability control of flexible rotors with induced strain materials

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Introduction

With fastly spinning rotors, severe vibration problems can be present that cannot be solved by passive means. A solution can be provided by active vibration control methods that employ active magnetic bearings, active balancing devices or, as in this research, rotor-fixed piezoelectric sheets.

Objective

The objective of this research is to investigate the feasibility of active rotors with integrated actuators, sensors and controllers that can stabilize their own bending vibrations, while being insensitive to stator vibrations and having almost no stationary parts.

Methods

The above mentioned active rotor concept is applied to a scale model of a helicopter tail rotor drive shaft (Fig.1a, 2). A parametric finite element model of a rotor with piezoelectric actuators and strain sensors is developed in Matlab®. For the scale model, an actuator setup is selected that enables control of the first and second bending vibration mode (Fig.1b,c).

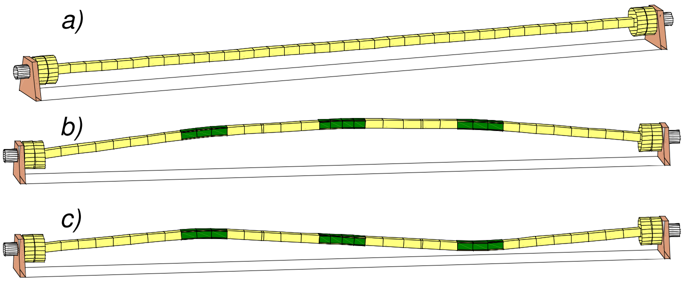

Fig. 1. Rotor model (piezoelectric actuators in green)

Several modal controllers are examined with the aid of simulations. Active damping and active balancing are found to be very effective for rotor stabilization. For active balancing, the unbalance ε of a mode is estimated online and nullified by the induction of an appropriate shape. For active damping, the actuator voltage v is specified as a function of the estimated modal deformation η, its derivative $\dot{\eta}$ and angular velocity ω. The total actuator voltage v is given by:

$$v = -k_v(i\omega\eta + \dot{\eta}) - k_f\varepsilon$$

An experimental setup is built for validation (Fig.2). A rotor with surface-mounted piezoelectric sheets is flexurally coupled to shafts that run in ball bearings. The rotor deformation is measured with stationary laser distance sensors and rotor-fixed strain sensors. A slipring assembly is used to transfer signals between the rotor and the stator. Experiment automation and control are implemented using a dSpace® system. Vibration control is limited to the first vibration mode.

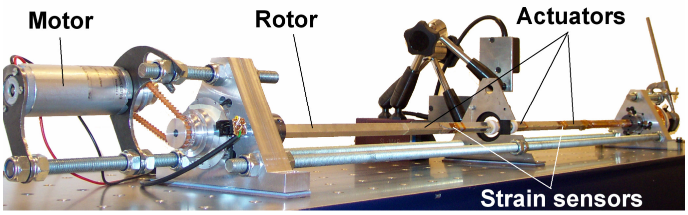

Fig. 2. Experimental setup

Results

The model predictions of the natural frequencies and actuator induced deformation are accurate within a few percent. The effectiveness of active balancing and active damping is successfully validated using control experiments. Fig.3a shows a rotational frequency profile achieved by motor speed control. Fig.3b shows (in blue) the corresponding vibration response of the scale model, which is dominated by the response to unbalance. Using active control, the maximum midshaft deflection is reduced from far more than 4000 μm to less than 150 μm (Fig.3b, red line).

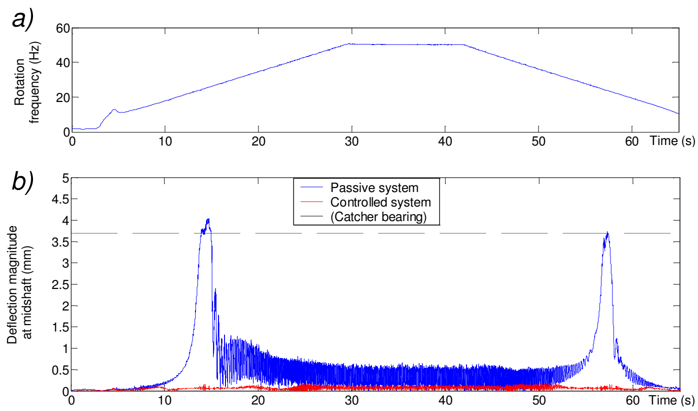

Fig. 3. Scale model response during rotation

Discussion

Rotor vibration problems can effectively be solved using rotor-fixed actuators and sensors. Further research is required on advanced control schemes and amplifier/controller miniaturization.