Vibration Control of a Compressor Blade Using Position and Velocity Feedback

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Position and velocity feedback controllers are applied in this work to reduce the oscillations of a rotating blade dynamical system running at an unsteady rotating speed. Both the primary resonance and the principal parametric resonance are controlled as they are the worst cases that were verified numerically. The two modes of vibrations are found to be powerfully linearly coupled, so we have applied the controller to only one mode and the other, coupled mode follows it. The overall nonlinear behaviour of the system with and without control is investigated through the multiple time scales method. Time history and different response curves of the controlled system are included to show the controller effect.

NOMENCLATURE

\[ \ddot{p}, \dot{p}, p \] Acceleration, velocity and position of the system first mode

\[ \ddot{q}, \dot{q}, q \] Acceleration, velocity and position of the system second mode

\[ \mu_1, \mu_2 \] Damping parameters of the system modes

\[ \omega \] System modes natural frequency

\[ \beta_{11}, \beta_{21}, \beta_{13}, \beta_{22}, \beta_{0} \] Coupling factors between the system modes

\[ \beta_5 \] Cubic nonlinearity factor of the system modes

\[ \beta_{14}, \beta_{24} \] Parametric excitation parameters

\[ f_0, f \] Constant rotating speed and magnitude of variable rotating speed

\[ \Omega \] Excitation frequency

\[ k_1, k_2 \] Position and velocity feedback gains

\[ \sigma_1, \sigma_2 \] Detuning parameters

\[ \varepsilon \] Small Perturbation Parameter.

1. INTRODUCTION

Vibration mitigation is an extremely important goal for longer lifetimes of structures and mechanical systems. These systems suffer from nonlinear vibrations due to different reasons, for example: geometric nonlinearities, nonlinear properties of materials, and nonlinear excitation forces. In the case of enrolling such a system in a main resonance state, it may produce large amplitudes, which lead to it damaging itself, or possibly damaging the adjacent systems. One of the systems that has unwanted vibrations is the rotating beam. Rotating beams are dynamical systems that are modelled as cantilever beams with many uses in robot manipulators, helicopter blades, and compressor blades. In addition, the rotating blades may suffer from large amplitude vibrations, resulting in catastrophic results, especially when operating at high speeds, which leads to huge centrifugal force. Yoo et al. established the model for pre-twisted rotating blades and made an analysis to clarify the characteristics of vibration when a concentrated mass is attached to it. Sinha investigated the characteristic dynamics of the same model, but with a radial blade and considering a Coulomb damping with centrifugal force affecting the whole system. Fazelzadeh et al. adopted the differential quadrature method, first-order shear deformation theory, and Galerkin’s technique to canvass on a rotating blade, which was thin-walled under a supersonic gas flow with a high temperature. Yao et al. utilized the Hamilton’s principle and isotropic constitutive law to conclude the governing equations of the beam. They analysed the dynamics of the beam at varying speeds under a supersonic gas flow and a high temperature, considering the internal resonances 1:1 and 2:1, respectively. Theoretical and experimental investigations of the rotating blades response are conducted to eliminate or suppress the vibrations that could seriously destroy the reported structure. Vadiraja and Sahasrabudhe applied macro fibre composites (MFC) actuators and sensors and adopted the higher shear deformation theory to suppress the vibrations of a rotating beam. Younesian and Esmailzadeh reduced the vibrations of a rotating beam by about 50% by applying an internal (time-increasing) tensile force. They adopted Hamilton’s principle for deriving the bending and longitudinal equations of a rotating blade. Other active control techniques have been applied to nonlinear dynamical systems and were very useful in reducing the vibrations. Fey et al. applied proportional and derivative feedback on a piecewise linear beam system with a one-sided spring element (flushing) for the steady-state oscillation reduction. They minimized the beam midpoint transversal amplitude at the primary resonance in a larger bandwidth of excitation. Warninski et al. analysed the use of suggested control algorithms to suppress the vibrations of a nonlinear composite beam and one of those algorithms was the position controller, which was terrific in reducing the vibrations. Muhammad et al. proposed a flexible manipulator (single-link) using the strategies, proportional derivative, and active force controllers. Eissa et al. studied the active vibration suppression of a nonlinear dynamical system via applying proportional and derivative controllers with and without the time delay ef-