Optimal Design of Nonlinear Squeeze Film Damper Using Hybrid Global Optimization Technique

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The optimal design of the squeeze film damper (SFD) for rotor system has been studied in previous researches. However, these researches have not been considering jumping or nonlinear phenomena of a rotor system with SFD. This paper represents an optimization technique for linear and nonlinear response of a simple rotor system with SFDs by using a hybrid GA–SA algorithm which combined enhanced genetic algorithm (GA) with simulated annealing algorithm (SA). The damper design parameters are the radius, length and radial clearance of the damper. The objective function is to minimize the transmitted load between SFD and foundation at the operating and critical speeds of the rotor system with SFD which has linear and nonlinear unbalance responses. The numerical results show that the transmitted load of the SFD is greatly reduced in linear and nonlinear responses for the rotor system.

Key Words: Squeeze Film Damper, Nonlinear Response, Optimal Design, Simulated Annealing Algorithm, Genetic Algorithm

1. Introduction

The squeeze film dampers (SFDs) are well known as dampers of aero–engine rotors to provide additional damping to rolling element bearings which themselves have little or no damping. SFDs are essential components of high–speed turbo–machinery since they offer the unique advantages of dissipation of vibration energy and isolation of structural components, as well as the capability to improve the dynamic stability characteristics of inherently unstable rotor–bearing systems.

In the design of modern aircraft engines, there is an increasing requirement for high–speed, light–weight and high performance. The required rotors exhibit a trend towards increased flexibility lead-
ing to a high sensitivity to imbalance with large vibration levels and reduced reliability. This means that the performance of SFD should be improved and be optimized.

When designing the SFD, its shape and oil viscosity used in the SFD are determined to obtain the optimum support damping at the operational speed which designers want to minimize vibration amplitude. Several researchers pointed out that the optimum support damping introduced by the SFD depends on whirling modes of the rotor (Thomsen and Andersen, 1974; Cunningham et al., 1975; Barrett et al., 1978; Satio and Kobayashi, 1982; Ahn et al., 1998). Designers expect a rotor system with SFD to have just linear response, but the rotor system has practically nonlinear response with large vibration amplitude on some condition unexpected in design stage (Mohan and Hahn, 1974; Gunter et al., 1977; Taylor and Kumar, 1980; Holmes and Dogan, 1982; Li and Taylor, 1987; Fen and Hahn, 1989; Zeidan and Vance, 1990; Jung et al., 1992; Yakoub and El-Shafei, 2001). Therefore, some researches have investigated in the bifurcation of the nonlinear response of the unbalanced rotor (Zhao et al., 1994; Zhang et al., 1998; Zhu et al., 2002; Inayat-Hussain et al., 2003).

To reduce vibration amplitude of a rotor system, optimal design of the SFD for rotor system has been studied in previous researches (Rabinowitz and Hahn, 1983; Chen et al., 1988; Nataraj and Ashrafuoon, 1993; Lin et al., 1998; El-Shafei, 2002; Ahn et al., 2003). These works have contributed a lot to the understanding of the dynamic behavior of SFD and provided very useful tools for engineering design practice. However, these researches reported in the literature have been related to just linear response but not to jumping or nonlinear phenomenon of a rotor system with SFD. When the rotor system has nonlinear response, vibration amplitude of the rotor becomes very large. Therefore, to completely stabilize the rotor system, designer should consider the linear and nonlinear response from practical problems of the unbalanced rotor system in the design stage of the SFD.

The objective of the optimum design problem is to find the optimum (maximum or minimum) value of the objective function in a given domain and the values of the design variables of a shape and performance, which the optimum is reached in this domain for the performance and efficiency of system. Today there exist very efficiently working local optimization methods for parameter optimization called the gradient-based methods (for examples, Nelder and Mead, 1965; Box, 1965; Powell, 1978; Rao, 1996). However, these conventional algorithms need the gradient information of the objective function to design variables. All the more, they may lose a global optimum solution because they are dependent on the starting point of searching and converge on the optimum solution, which is the nearest solution to the starting point, and cannot find all global optimum solutions. In order to overcome these disadvantages, many search algorithms have been developed for global optimization such as genetic algorithm (GA) (Goldberg, 1989) and simulated annealing (SA) (Kirkpatrick et al., 1983). They do not involve any gradient information and mathematical formulation but only forward analysis procedure. Unfortunately global optimization algorithms are highly time consuming, because they are based on the iterative strategy which updates unknown parameters gradually. Therefore, a fast and more efficient search algorithm has been strongly required for optimization in spite of rapid progress of computer technology.

An optimization problem is generally said to be difficult if it satisfies some or all of the following criteria: high dimension, many local minima, highly non-linear, non-smooth, noisy and discrete. Traditional gradient-based optimization techniques become stuck in local minima and fail to converge on a global minimum. In certain cases, particularly when facing complex optimization problems with numerous local optima, where traditional optimization methods fail to provide efficiently reliable results, GA can constitute an interesting alternative. Nevertheless, GA can suffer from excessively slow convergence before providing an accurate solution because of its fundamental requirement of using minimal a priori knowledge and not exploiting local information. Since genetic algorithms had been intro-