Bifurcation Analysis of High Speed Spindle Air Bearings

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Abstract
This paper employs a hybrid numerical method combining the differential transformation method and the finite difference method to study the bifurcation behavior of a high speed spindle air bearing (HSSAB) system. The analytical results reveal a complex dynamic behavior comprising periodic, sub-harmonic, and quasi-periodic responses of the rotor center. Furthermore, the results reveal the changes which take place in the dynamic behavior of the bearing system as the rotor mass and bearing number are increased. The current analytical results are found to be in good agreement with those of other numerical methods. Therefore, the proposed method provides an effective means of gaining insights into the nonlinear dynamics of HSSAB systems.

Keywords
Air bearing, bearing number, bifurcation, differential transformation method, quasi-periodic

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1. Introduction
Air bearings are characterized by low noise under rotation and by their low frictional losses. As a result, they are frequently employed within precision instruments, where they yield zero friction when the instruments are used as null devices, and within high-speed electrical motors. Compared with traditional oil bearings, air bearings have the advantages of lower heat generation, less contamination, and a higher precision. However, their major disadvantage is that they tend to be rather unstable, and this frequently restricts their permissible range of application (Ausman, 1963; Wildmann, 1968).

In 1985, Gero and Ettles evaluated the relative precision of the finite difference method (FDM) and the finite element method (FEM) approaches when applied to a steady, isoviscous, incompressible lubrication problem. In their study, it was assumed that the solution of a complicated coupled problem could be derived by solving a sequential series of simple, uncoupled, steady problems. The results for two-dimensional bearings demonstrated that the relative errors of the FDM solutions were smaller than those associated with the FEM approach. Furthermore, it was shown that the FDM approach was more rapid than the FEM technique, with an average CPU time of 0.15 sec. as compared to 0.17 sec. for the FEM method.

In 1994, Malik and Bert considered the differential quadrature method (DQM), and applied it for the first time to the solution of steady-state oil and air lubrication problems in self-acting hydrodynamic bearings. The quadrature solutions of the Reynolds equation for the case of incompressible lubrication were compared with the exact solutions of finite-length bearings. Furthermore, the quadrature solutions of the compressible Reynolds equation for finite-length plain journal bearings were compared with those obtained using the FED and FEM approaches.

Sundararajan and Noah proposed a simple shooting scheme integrated with an arc-length continuation algorithm for the investigation of periodically forced rotor systems. Using this model, the authors predicted the occurrence of periodic, quasi-periodic and chaotic motion for various ranges of the rotor speed. In 2007, Wang provided a further understanding of relative short gas film rotor-bearing systems and showed the dynamic behavior of a system with respect to rotor mass and bearing number.

The remainder of this study is organized as follows. Section 2 develops a mathematical model describing the...