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Stability analysis of a ball–rod–spring automatic balancer

Chung-Jen Lu*, Ming-Cheng Wang

Department of Mechanical Engineering, National Taiwan University, No. 1 Roosevelt Road, Section 4, Taipei 10617, Taiwan, Republic of China

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ABSTRACT

The traditional ball-type automatic balancer, which consists of several balls moving along a fixed circular orbit, has been applied to different fields for rotational vibration reduction. Under proper working conditions, the balls will counter-balance the rotor by positing to appropriate locations. This particular equilibrium configuration is referred to as the perfect balancing configuration. The unbalance vibrations at steady state can be totally suppressed only if the perfect balancing configuration is stable. The stability of the perfect balancing configuration depends on the parameters of the system. To achieve perfect balancing, the system parameters must lie in the stable region of the perfect balancing configuration in the parameter space. An automatic balancer with a larger stable region of the perfect balancing configuration will be more robust. This paper provides a detailed analysis of a new design of auto-balancer, the ball–rod–spring balancer, which is aimed to increase the stable region of the perfect balancing configuration. A theoretical model of a rotor packed with a two-unit ball–rod–spring balancer is constructed. Closed form formulae of the equilibrium configurations are presented. The stability of each equilibrium configuration is investigated both analytically and numerically. Results of numerical analysis confirm that the stable region of the perfect balancing configuration of the new design is larger than that of the traditional fixed orbit balancer.

1. Introduction

Eccentric unbalance is the major source of vibrations in rotating machinery. The vibrations caused by a fixed amount of unbalance can be reduced effectively to a satisfactory level by the standard balancing procedure. However, under some circumstance, e.g. optical disk drives and washing machines, the unbalance may change with operation conditions. In this case, it is desirable to have an automatic balancing system (ABS) that can suppress the rotational vibrations due to any amount of unbalance automatically. One of the most popular ABS's employed in industry is the ball-type auto-balancer, which has been successfully applied to different fields, e.g. optical disk drives [1–6] and hand-held power tools [7]. Many researchers have studied the dynamical characteristics of the ball-type balancer [8–12]. A brief review of the early history of the ball-type ABS has been provided by Lee and Moorham [8].

A ball-type auto-balancer consists of several balls moving along a circular orbit. Under proper conditions, the balls will move to specific equilibrium positions where the unbalance vibrations are totally suppressed. This particular configuration is referred to as the perfect balancing configuration. It is well known that a dynamical system can stay at an equilibrium configuration only if the equilibrium configuration is stable. Specifically, to achieve perfect balancing, the system parameters under working conditions must lie in the stable regions of the perfect balancing configuration in the parameter space. Previous studies [4,10,12–14] indicate that the stable region of the perfect balancing configuration and the performance of the balancer are sensitive to the system parameters. An auto-balancer with a wider stable region can tolerate larger amount of variations in the parameters and is hence more robust. Motivated by the idea that the stable region may be broadened by introducing an extra degree of freedom to the balls, Lu [15] proposed a modified balancer called the ball–rod–spring balancer. The modified balancer is composed of several ball–rod–spring units. Each unit consists of a ball sliding along a rod that rotates about the spindle. The motion of the ball along the rod is restrained by a linear spring. In this way, the ball can move not only in the circumferential direction but also along the radial direction. Preliminary numerical investigation on an one-unit ball–rod–spring balancer shows that the modified balancer has a larger stable region of the perfect balancing configuration [16]. Because at least two balls are required to automatically counter balance arbitrary amount of unbalance, this paper extends the results of [16] to investigate the characteristics of a two-unit ball–rod–spring balancer. Emphasis is put on the analytical study of the stability of the equilibrium configurations and the comparison of the modified and the traditional fixed orbit balancers.

This paper is organized as follows: It first shows the mathematical model for a rotating disk equipped with a two-unit ball–rod–spring

* Corresponding author.
E-mail address: cjlu@ntu.edu.tw (C.-J. Lu).

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