Journal of Sound and Vibration 424 (2018) 48–63

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Moving mode shape function approach for spinning disk and asymmetric disc brake squeal

Jaeyoung Kang

Department of Mechanical Engineering, College of Engineering, INHA University, Inchon, South Korea

A R T I C L E I N F O

Article history:
Received 27 March 2017
Received in revised form 23 February 2018
Accepted 14 March 2018

Keywords:
Spinning disk
Brake squeal
Moving mode shape function
Asymmetric disc
Floquet theory

A B S T R A C T

The solution approach of an asymmetric spinning disk under stationary friction loads requires the mode shape function fixed in the disk in the assumed mode method when the equations of motion is described in the space-fixed frame. This model description will be termed the 'moving mode shape function approach' and it allows us to formulate the stationary contact load problem in both the axisymmetric and asymmetric disk cases.
Numerical results show that the eigenvalues of the time-periodic axisymmetric disk system are time-invariant. When the axisymmetry of the disk is broken, the positive real parts of the eigenvalues highly vary with the rotation of the disk in the slow speeds in such application as disc brake squeal. By using the Floquet stability analysis, it is also shown that breaking the axisymmetry of the disc alters the stability boundaries of the system.

1. Introduction

The transverse vibration in a rotating disk has been widely studied in such application as the computer disk drive, turbine rotor and automotive brake disc. Depending on the field of application, contact loading conditions on a rotating disk vary from the freely, stiffness- and friction-loads to the spring-mass-damper unit at the point contact or finite contact area. In the literature, the corresponding equations of motion (EOM) have been described in either the disk-fixed or space-fixed frame.

In the disk-fixed frame, the freely-spinning disk was firstly studied by Lamb and Southwell [1]. The rotation effect on the natural frequencies of the transverse vibration in the spinning disk was examined in the disk-fixed frame where the frequencies grow with the spinning speed due to the in-plane stresses by rotation [1–4]. When the EOM is derived in the disk-fixed frame, the gyroscopic effect due to rotation does not arise. When the spinning disk is subjected to stationary loads, the disk-fixed coordinate system leads to the moving load problem in which the spinning disk acts like a stationary disk and the stationary loads turns to move in a backward direction. This moving load term takes a role of excitation leading to internal resonance as reviewed in Refs. [5,6]. Or, it turns to become the eigenvalue problem through the matrix transformation from time-varying system into time-invariant one [7]. The transverse vibration of an eccentric or imperfect spinning disk was also studied in the disk-fixed frame without any loads [8] or with a spring contact load [9]. This topic will not be treated in this study.

In the space-fixed frame, the gyroscopic term is derived in a freely-spinning disk. In the presence of the gyroscopic term, the two wave frequencies split into the forward travelling wave (FTW) and backward travelling wave (BTW) frequencies with the spinning speed [10,11]. At the critical speed at which the BTW frequency decreases to zero, the system becomes unstable

E-mail address: kangj@inha.ac.kr.

https://doi.org/10.1016/j.jsv.2018.03.016

in the presence of a stationary contact load. For the spinning disk under the stationary contact loads, the transverse deflection of the spinning disk can be transformed into that of the stationary disk by the assumption of axisymmetry and the coordinate transformation $\theta = \varphi + \Omega t$ in the space-fixed frame (in Figs. 1 and 2). Then, the stability of the spinning disk under the stationary loads has been widely studied in the space-fixed frame [12–18]. The FTW/BTW frequencies and their critical speeds have been also experimentally validated in the high speed applications by using a space-fixed probe [19,20].

In the brake application, a brake disc is subjected to stationary friction loads over the finite contact area [21,22]. For simplification, the disc was often modeled to be stationary due to the neglect of rotation effects [23–25]. Recently, the rotating disc has been brought into the brake squeal model in the space-fixed frame [26–29]. One essential difference from the high-speed spinning disk under a point contact load is that the rotating speed is no more the sole critical parameter in the stability of the system. Instead, there are many other important parameters such as friction characteristics, contact stiffness, contact area, disk dimension, asymmetry, any nonlinear parameters, and so on, to be considered in the brake squeal model.

The spinning axisymmetric disk model in the space-fixed frame was well established in theory and validated by a space-fixed probe in experiment. However, the spinning asymmetric disks under friction loading has rarely been studied. In this research, the general model description for the high-speed spinning disk under various contact conditions and slowly-rotating brake disc will be suggested in the space-fixed frame no matter whether it is axisymmetric or not. Hereafter, the coordinate system used in this study will be the space-fixed frame.

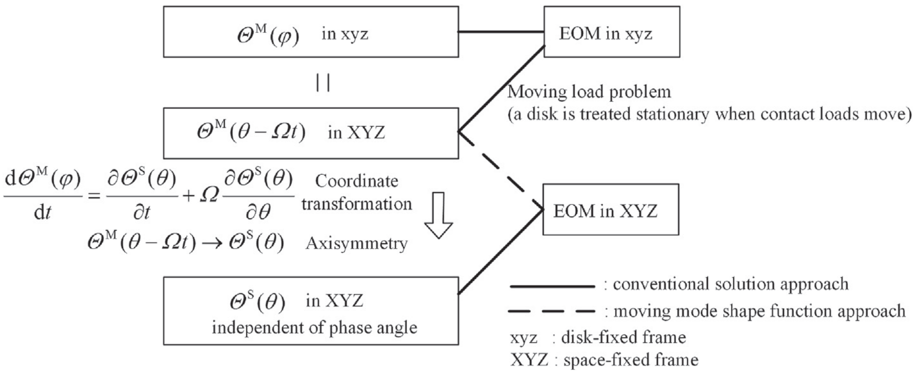

Fig. 1. Scheme of solution approach on spinning disks; in moving load problem, EOM is described in xyz which is treated stationary, thus, XYZ is considered fixed to rotating contact loads.

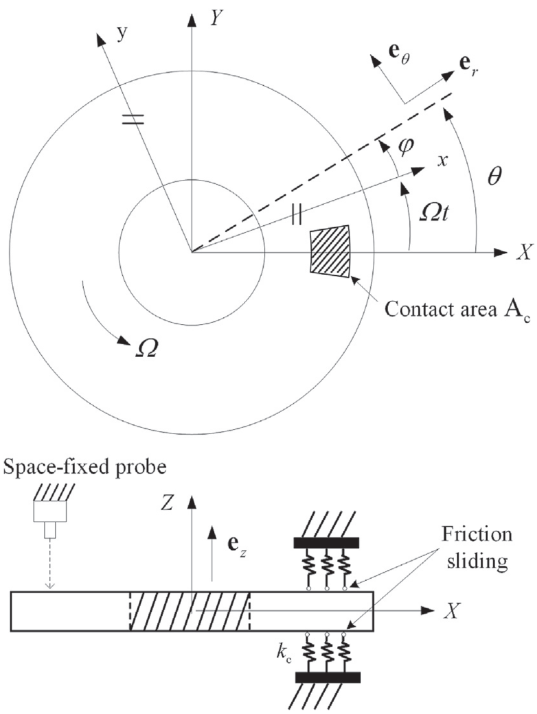

Fig. 2. Configuration of a spinning disk subjected to the distributed stiffness- and friction-load.