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Modeling of automotive drum brakes for squeal and parameter sensitivity analysis

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Abstract

Many fundamental studies have been conducted to explain the occurrence of squeal in disc and drum brake systems. The elimination of brake squeal, however, still remains a challenging area of research. Here, a numerical modeling approach is developed for investigating the onset of squeal in a drum brake system. The brake system model is based on the modal information extracted from finite element models for individual brake components. The component models of drum and shoes are coupled by the shoe lining material which is modeled as springs located at the centroids of discretized drum and shoe interface elements. The developed multi degree of freedom coupled brake system model is a linear non-self-adjoint system. Its vibrational characteristics are determined by a complex eigenvalue analysis. The study shows that both the frequency separation between two system modes due to static coupling and their associated mode shapes play an important role in mode merging. Mode merging and veering are identified as two important features of modes exhibiting strong interactions, and those modes are likely candidates that lead to coupled-mode instability. Techniques are developed for a parameter sensitivity analysis with respect to lining stiffness and the stiffness of the brake actuation system. The influence of lining friction coefficient on the propensity to squeal is also discussed.

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1. Introduction

Automotive brake noise and vibration control has become increasingly important for the improvement of vehicle quietness and passenger comfort. Over the years, brake noise has been classified by frequency contents and given various names such as grunt, judder, moan, groan, squeal, squeak and so on. In a recent review on disc brake squeal, Kinkaid et al. [1] stated that there has not been a precise definition of brake squeal. Since Nishiwaki [2] showed that groan and squeal are generated by the same phenomenon of dynamic instability, both low- and high-frequency noise can be studied by using the same modeling and analysis techniques. Brake squeal here is defined as any type of elastic instability that involves elastic modes of various brake components and is within the audible range of frequencies.

Systematic research on brake squeal can be traced back to the 1950s and still is an active subject for current researchers and engineers. The structure of brakes which consist of several components is complicated, and the fugitive nature of friction makes the problem more difficult. Research on brake squeal has been conducted using theoretical, experimental, and computational approaches. Many theoretical approaches have been presented to explore the squeal mechanisms. Early attempts to explain brake squeal emphasized that the negative slope of the friction coefficient with respect to the relative velocity caused the self-excited vibration. Spurr [3] proposed the sprag-slip model to introduce a new mechanism called geometry instability, without including the friction characteristic. Millner [4] also reported that brake squeal may occur even if the friction coefficient is constant. North [5] first presented a simple 2-dof model, in which the friction leads to an asymmetric stiffness coupling indicating non-conservative forces and the instability may occur. This mechanism was developed and advanced by many other investigators, and in this approach it is believed that brake squeal is mainly caused by dynamic instability of the brake system with variable friction forces [6,7].

In recent years the main focus on brake squeal problems has shifted from fundamental theoretical research to more practical and problem-solving oriented efforts. Instead of a simple schematic model, the brake system model tends to include more brake components, and the effects of design parameters on the stability can be investigated. Liles [8] created a linear system model based on the modal information of the disc brake components, and performed a complex eigenvalue analysis to solve the equations of motion. Guan and Jiang [9] constructed a coupled linear model including all disc brake components and identified the substructure modes which have great influence on the system stability. Chowdhary et al. [10] developed an assumed modes model for squeal prediction of a disc brake, and found that the separation between the frequencies is an important factor in determining the onset of flutter-type instability. Ouyang et al. [11] considered the effects of rotation of the disc, and the friction-induced vibration of the disc brake was treated as a moving load problem. With the improvement of numerical techniques, Hamabe et al. [12] and Nack [13] directly conducted a complex eigenvalue analysis with a finite element (FE) model of a brake system including the friction force. In their work on disc brake squeal using FE analysis, Lee et al. [14] performed a nonlinear contact analysis to determine the pressure distribution at the friction interface followed by system linearization and a complex modal analysis. Thus, in their study, the contact stiffness was dependent on local contact pressure.

In the present work, a numerical approach is presented to study the drum brake squeal. FE models are first created for brake components including the drum and the shoes. The shoe lining is