Effects of Young's Modulus on Disc Brake Squeal using Finite Element Analysis

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This paper is concerned with the disc brake squeal problem of passenger cars. The objective of this study is to develop a finite element model of the disc brake assembly in order to improve the understanding of the influence of Young's modulus on squeal generation. A detailed finite element model of the whole disc brake assembly that integrates the wheel hub and steering knuckle is developed and validated by using experimental modal analysis. Stability analysis of the disc brake assembly is conducted to find unstable frequencies. A parametric study is carried out to look into the effect of changing Young's modulus of each brake's components on squeal generation. The simulation results indicate that Young's modulus of the disc brake components plays an important role in generating the squeal noise.

1. INTRODUCTION

Passenger cars have historically been one of the essential methods of ground transportation for people who want to move from one place to another. The braking system acts as one of the most fundamental safety-critical components in modern passenger cars. Therefore, the braking system of a vehicle is a significant system, especially when the vehicles are slowing down or stopping. Due to the braking operation, the brake system generates an unwanted high frequency sound called squeal noise. It occurs in the frequency range between 1 and 16 kHz and leads to customer dissatisfaction and increases warranty costs. Although substantial research has been conducted into predicting and eliminating brake squeal since the 1930s, it is still rather difficult to predict its occurrence.[1] As described in some of the recent review papers,[2–5] theories on brake squeal mechanisms have been put forward on six major classes: stick-slip, sprag-slip, negative friction velocity slope, hammering excitation, splitting the doublet modes, and mode coupling of structures. These mechanisms are essential for better understanding of squeal noise.

In recent years, the finite element (FE) method has become the preferred method to study brake squeals. The capabilities of FE models, with a huge number of freedom, have enabled an accurate representation of the brake system. The analysis of disc brake squeal using the FE model could reflect each detail of the brake design, while this demanded a lot of effort to do significant changes in the geometry of components.[6] Due to a general lack of confidence in FE models, the dynamic testing of structures had become a standard procedure for model validation and updating. Over the past years, modal testing and analysis had become a fast- developing technique for the experimental evaluation of the dynamic properties of structures.[7] Several types of analyses had been performed on disc brake systems through FEA, in an attempt to understand the noise and to develop a predictive design tool. There were two numerical methods that are used to study this problem: transient dynamic analysis[8,9] and complex eigenvalue analysis.[10–13] Currently, the complex eigenvalue method is the most commonly preferred method. Generally, the existence of complex eigenvalues with positive real parts indicated the presence of instability and the magnitude of the real part is used to represent the level of system instability or squeal propensity.

Reduction and elimination of the brake squeal was an important task for the improvement of the vehicle passengers' comfort. Many researchers, in their studies on brake systems tried to reduce squeal noise by changing the factors associated with the brake squeal. For example, Liles[14] found that shorter pads, damping, a softer disc, and a stiffer back plate could reduce squeal, while in contrast, a higher friction coefficient and wear of the friction materials were prone to squeal. Lee et al.[15] reported that reducing back plate thickness led to less uniform contact pressure distributions and consequently increased the squeal propensity. Kung et al.[10], in their simulations, showed that instability of the disc brake was dependent upon a range of disc Young's modulus. Liu et al.[12] commented that the squeal could be reduced by decreasing the friction coefficient, increasing the stiffness of the disc, using damping material on the back of the pads, and modifying the shape of the brake pads. Recently, Nouby et al.[16] introduced a combined approach of complex eigenvalue analysis (CEA) and designed experiments to get optimal design for the brake system. They reported that the brake squeal propensity could be reduced by increasing Young's modulus of the back plate and by modifying the shape of the friction material by adding chamfer and slots.

In FEA, several researchers varied the geometric details of the brake assembly model. For instance, some researchers[12,17] considered only the disc brake and two pads. Zhu et al.[18] added the finger and piston to the FE model. Dai and Teik[19] developed a FE model that consisted of a rotor, a caliper, a mounting bracket, a piston, and brake pads to analyze the design of the disc brake pad structure for squeal noise reduction. Some authors[20–22] used a more detailed FE model, which consisted of a disc, a piston, a caliper, a carrier, piston and finger pads, two bolts and two guide pins.

An extension of the FE models discussed earlier in this work