A DYNAMIC MODEL FOR A DISC EXCITED BY VERTICALLY MISALIGNED, ROTATING, FRICTIONAL SLIDERS

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ABSTRACT: This paper presents a dynamic model for a disc subjected to two sliders rotating in the circumferential direction over the top and bottom surfaces of the disc. The two sliders are vertically misaligned and each is a mass-spring-damper system with friction between the slider and the disc. The moving loads produced by misaligned sliders can destabilise the whole system. Stability analysis is carried out in a simulated example. This model is meant to explain the friction mechanism for generating unstable vibration in many applications involving rotating discs.

KEY WORDS: friction, vibration, dynamic model, disc brake, moving load

1 INTRODUCTION

Vehicle disc brakes often generate unwanted vibration and noise, and cause discomfort. A particular type of noise, known as squeal, is very annoying and very difficult to get rid of. Active research into vehicle disc brake squeal has been going on since the late 1950's. Modelling and simulation is necessary for designing quiet brakes and for treating noisy brakes.

Squeal is theoretically identified as vibrations with unstable frequencies above 1kHz. So a plausible model has to make use of proper physics and produce eigenvalues with positive real parts. There are a number of ways for friction to produce unstable vibrations, which are normally referred to as mechanisms. Mention is made here of some popular ones.

Friction is seen to decrease when sliding occurs. Mills[1] suggested that this was responsible for generating squeal. However, this idea was discounted later by North[2] and recently by Eriksson[3]. The stick-slip vibration[4] was once a suspect. Now it is widely accepted that the stick-slip vibration produces a low frequency noise, such as moan, according to Lang and Smals[5]. Friction can produce asymmetrical off-diagonal terms in the stiffness matrix and thus leads to a complex eigenvalue problem with positive real parts[2]. Friction modelled as a follower force was put forward by North[2], and advanced by Mottershead and co-workers[6~8]. Since the disc rotates past the pads in a disc brake and the moving loads are known to be capable of generating instability, a moving load model of a disc brake was proposed by Ouyang et al.[9,10]. Other mechanisms of friction-induced vibrations in disc brakes were reviewed by Yang and Gibson[11] and recently and thoroughly by Kinkaid et al.[12].

This paper presents a simple model for disc brakes generating squeal. It combines the moving load concept and a new way of incorporating friction into the structural dynamics model. A simulated example is analysed and some design parameters are investigated. It is shown that a right design can reduce the dynamic instability and thus improve the noise performance of a disc brake.

2 THE FORCES AT THE DISC/PADS INTERFACE

A whole disc brake system is shown in Fig.1. A schematic view of the disc brake system is presented in Fig.2.

Although the piston line pressure is centred on the back plate of the piston-pad, the normal force due
to the pressure at the disc/piston-pad interface is not centred, owing to the sliding friction between the disc and the pad. The location of the interfacial pressure centre can be approximately determined via a lengthy nonlinear sliding contact analysis \[13,14\]. Such an analysis reveals that the interfacial pressure centre is always ahead of the pad centre line towards the leading edge. A simple estimate can be made of the distance between the centre of the pad and the normal force at the disc/pad interface, as shown in Fig.3.

Because of the trailing edge constraint to the pad, this reactive force \( f_2 \) takes up nearly all the friction force \( f_1 \) at the disc/piston-pad interface while the friction force at the piston/back plate interface is negligibly small, that is, \( f_3 \approx 0 \) (for symbols not defined in the text, please refer to the Appendix). The moment equilibrium at the trailing edge gives

\[
d \approx \mu h_p
\]

A similar but less accurate estimate of the distance between the piston line pressure and the normal compressive force at the disc/finger-pad interface can also be made. The location of this normal force at the disc/finger-pad interface is inward in the \( r \) direction and nearly centred in the circumferential direction, compared with the location of the normal force at the disc/piston-pad interface. As a result, the radial and circumferential positions of the two mass-spring-damper sliders as a simple model of the two pads are different, thus producing a vertical misalignment in the radial and circumferential directions. Even though this misalignment is not large, it may bring about changes on the dynamic instability of the system. This will be clearly seen in the simulated example.

3 DISC SUBJECTED TO MISALIGNED SLIDERS

In the following study, the brake disc is approximated as a thin, flat plate and the pads as sliders each with a vertical mass, spring and damper. Only the transverse vibration of the disc will be considered. The low speed range where squeal tends to appear allows the centripetal and gyroscopic effects of the rotating disc to be safely omitted. For the sake of convenience, the two sliders are rotated around the disc instead of the disc being rotated as in reality. The simple disc brake model is shown in Fig.4.