Dynamic forces transmitted during suppression of automotive brake squeal

K. Cunefare[a], V. Rastelli[b], N. Montbrun[b], J. Aller[b] and M. Dizrasa[a]

[a] Georgia Institute of Technology, Atlanta, USA
[b] Universidad Simón Bolívar, Caracas, Venezuela

Most researchers characterize brake squeal as a vibration of the brake rotor that produces an irritating noise to automobile passengers. Recently, the concept of dither control was successfully used to suppress the resonant vibration of components of a brake system, thereby eliminating its acoustic disturbance. Dither control is a high frequency periodic disturbance signal introduced into a brake system to quench friction-induced oscillations. This paper presents results of the measurement of dynamic forces transmitted to the inboard pad of a floating caliper brake system during suppression of squeal using dither control. A stack of piezoelectric elements was placed inside the brake piston to induce a high frequency displacement to the inboard pad. A 20 kHz voltage was applied over the piezoelectric stack to dither the brake's normal clamping force. Measurements of the dynamic force transmitted to the brake pad were made with a load cell that was placed in line with the stack inside the caliper. The dynamic force was measured during squeal and during its control. Squeal suppression through dither control typically required the application of a 200 Newton modulation to the static normal force.

INTRODUCTION

This paper presents an experimental investigation for the suppression of automobile disc brake squeal using active control based on the concept of dither [1,2,3]. It has been shown that a harmonic vibration, with a frequency higher than the squeal frequency, applied into the brake system through the brake pad was able to eliminate the feedback between the rotor and pads, which generated the squeal. An ultrasonic harmonic control signal was able to eliminate rotor squeal independent of frequency [4]. Even though the sound pressure level at the control frequency increased with the activation of the control system, an ultrasonic frequency above human hearing allowed the brake squeal to be eliminated without the resulting rotor vibration being heard. A load cell fixed in line with the vibration actuator in the caliper piston was used to monitor the exact dynamic force being applied during the elimination of brake squeal.

EXPERIMENTAL HARDWARE AND SOFTWARE

A commercial disc brake system was used in this research to develop the active control system. The brake system utilized a floating-type caliper, and a brake noise dynamometer was used to perform brake noise tests. A 40 Hp electric motor generated the constant rotational speed for the brake rotor, and a controlled linear actuator supplied the hydraulic pressure to the brake piston. A pressure transducer measured brake fluid pressure, while a thermocouple monitored the brake pad temperature. Together, these components helped create the brake dynamometer [4,5]. A stack of piezoelectric (PZT) elements was chosen to induce a high frequency harmonic vibration into the brake system in order to force the vibration of the system at a higher frequency than the squeal vibration. A special steel cage was designed to house the stack of piezoelectric actuators and a load cell was employed to monitor dynamic forces. The cage was designed to be self-centered into the brake pad and caliper piston.

Transducers for measuring squeal conditions

A gage pressure transducer measured the static brake pressure. Motor rotational speed (rpm) was displayed on the digital indicator on the motor control panel, while brake pad temperature was monitored by a thermocouple. Sound pressure was measured using a Type 1, free field, 1/2-inch microphone, with preamplifier. A Polytec PSV-200 scanning vibrometer was used to monitor the displacement of the external brake pad during brake squeal. The dynamic force over the internal brake pad was measured through a load cell, with a charge amplifier. The signals from the microphone-preamplifier and from the load cell-charge amplifier were then processed with data acquisition software that could show both the spectra of sound and dynamic load.

Data acquisition was controlled by LabVIEW software from National Instruments. The data acquisition hardware responsible for monitoring and maintaining brake squeal conditions was composed of four key components, which included an analog input card, a thermocouple input card, an analog output card, and a digital servo drive for the linear actuator motor.

EXPERIMENTAL PROCEDURE

The procedure for quantifying brake squeal consisted of controlling two basic inputs, rotor speed and brake pressure, and recording three basic outputs: sound pressures, dynamic load and surface pad displacement, plus pad temperature. Increasing or decreasing the brake pressure on the rotor indirectly controlled pad temperature. Constant rotor speed was maintained through the motor control panel, allowing selection of any desired rpm. A linear actuator controlled static brake pressure. For the data presented here, the mean brake clamping load was estimated to be 1600 N.

Signal Spectra

The dynamic force spectrum measured with the load cell are shown in the Figure 1, without control and full controlled. Figures 2 and 3 present the corresponding noise and vibration spectra, indicating that dither successfully suppressed the squeal.

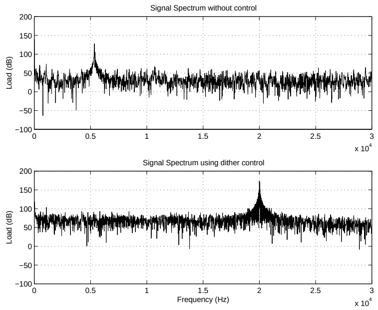

FIGURE 1. Dynamic Force Spectrum without control and full controlled.

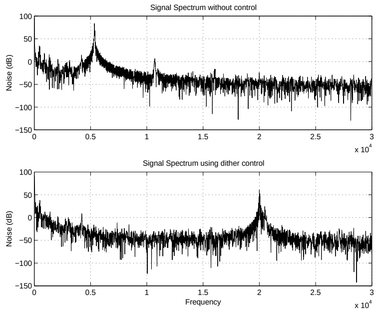

FIGURE 2. Noise Spectrum without control and full controlled.

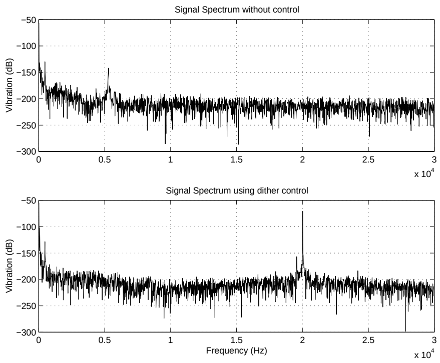

FIGURE 3. Vibration Spectrum without control and full controlled.

The force spectrum shows that the dynamic forces induced into the brake pad to control the squeal are high compared to the original forces generated during normal squeal conditions (without control). However, the modulation is smaller than the mean clamping load.

The tradeoff of inducing an ultrasonic frequency in the brake system was to eliminate the squeal noise and change it for an inaudible 20 kHz noise. The resulting sound level of the brake system was reduced to the background noise level.

CONCLUSIONS

Dither control successfully suppresses squeal. The required modulation of the normal clamping force is smaller than the mean.

The next step in this line of work is to measure the brake torque, during squeal and under dither control, in order to determine if the brake torque is affected by the dither control.

REFERENCES

1. Morgul, O., “On the control of some chaotic systems by using dither”, *Physics Letters A*, Vol. 262, 1999, p. 144-151.
2. Patra, K. C., and Pati, B. B., “An investigation of forced oscillation for signal stabilisation of two-dimensional nonlinear system”, *Systems and Control Letters*, Vol. 35, 1998, p. 229 – 236.
3. Pervozanski, A., and Canudas-de-Wit, C., “Vibrational smoothing in systems with dynamic friction”, *Preprints of the 4th IFAC Nonlinear Control Systems Design Symposium 1998*, Vol. 2, 1998, p. 557 – 562.
4. Graf, A., "Active Control of Automotive Disc Brake Rotor Squeal Using Dither," Masters Thesis supervised by Dr. Kenneth A. Cunefare. The Georgia Institute of Technology, 2000.
5. Rye, R., "Investigation of Brake Squeal via Sound Intensity and Laser Vibrometry," Masters Thesis supervised by Dr. Kenneth A. Cunefare. Georgia Institute of Technology, 2000.