Burst Mode Dither Control of Automotive Brake Squeal

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Recent research has demonstrated that the application of open-loop dither control to a brake provides an effective means of suppressing brake squeal. Dither control is a method by which high frequency disturbances are introduced into a system. Dither suppresses the friction induced squeal response at lower frequencies, thus eliminating audible brake squeal. Dither control when applied at 100% duty cycle has been shown to be an effective means of suppressing brake squeal. This paper documents an investigation into the use burst-mode dither control for suppression of brake squeal. Burst mode dither control is characterized by duty cycles of less than 100%. Dither is introduced to a brake by placing a piezoelectric stack actuator in the piston of a floating caliper brake. The piezoelectric stack actuator is driven by a 20 kHz burst mode signal, and the impact upon the squeal is assessed. Burst mode dither with duty cycles as low as 50% are shown to be as effective in suppressing brake squeal as dithering at 100% duty cycle.

INTRODUCTION

This paper presents an experimental investigation into the application of active control based on the concept of dither for the suppression of automotive disk brake squeal. Dither is a high frequency periodic disturbance signal introduced into a system to stabilize nonlinear self-oscillations, or limit cycles, caused by friction. The high frequency, relative to the frequency that is being controlled, and the periodic nature of the dither signal effectively averages the nonlinear self-oscillations [1,2,3]. The system exhibits forced oscillations at the dither frequency, as well as oscillations at the undesired frequency, as the dither amplitude is increased. Finally, synchronization occurs for certain amplitude of dither. Dither is commonly applied to a system using open-loop control as stated by Morgul [1]. Open loop control is simple to implement because it does not require complex sensing and control systems, only a signal generator and a fixed gain power amplifier.

The results from prior research showed that a harmonic vibration, with a frequency higher than the squeal frequency, input into the brake system through the brake pad was able to eliminate the feedback between the rotor and pads, at the squeal frequency, which generated squeal [4]. An ultrasonic harmonic control signal was able to eliminate rotor squeal independent of frequency. 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. The control system was also observed to prevent squeal from being generated in the first place. A control vibration at an ultrasonic frequency, applied to the rotor before squeal conditions were reached, prevented the brake system from generating squeal as the brake pressure was increased to the squeal condition. The control vibration was not audible and the squeal was not generated. Therefore, the brake system did not produce any noise that would be offensive to the driver or passengers of an automobile.

EXPERIMENTAL HARDWARE AND SOFTWARE

The general description of the experimental apparatus used in the conduct of this research has been presented in the paper “Dynamic forces transmitted during suppression of automotive brake squeal,” presented in this conference, and based on two master theses completed at The Georgia Institute of Technology [4,5]. The principal components are: 27.4 cm disk with single piston floating caliper, 40 Hp brake dynamometer with controlled speed and brake line pressure, Polytec PSV 200 scanning laser vibrometer and data acquisition systems. A stack of piezoelectric (PZT) elements was chosen to induce the required 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. Measurements of the dynamics forces transmitted to the inboard pad of a floating caliper brake system during suppression of squeal were made in order to determine its magnitude.

As the power output of the amplifier used to drive the piezoelectric actuators was high with 100% duty cycle, a different approach was needed to obtain noise control while reducing the power requirements of the system. A solution was attained using a 20 kHz burst mode signal to drive the actuator, at less than 100% duty cycle.

TESTING OF BURST CONFIGURATION

The squeal suppression system was tested at different sets of burst count and burst frequency in order to determine the minimum amount of energy needed to suppress the squeal. All tests used a 20 kHz dither signal. Tests began at 100% duty cycle, with steps of decreasing 10%, at different burst count, as detailed in Table 1. The system was working (suppressing squeal) until 50% duty cycle reached. Below that point, the suppression was not achieved, regardless of the length of the burst signal or the frequency of the burst rate.

TABLE 1. Squeal suppression vs. duty cycle.

Duty Cycle	Suppression
90%	Yes
80%	Yes
70%	Yes
60%	Yes
50%	Yes
45%	No
40%	No
30%	No

The duty cycle was related to the burst rate, burst count and burst frequency.

Signal Spectra

Signal spectra of combinations of duty cycle vs. burst count was analyzed in order to obtain the minimum duty cycle that suppresses the squeal. Figures 1, 2 and 3 present noise, load and vibration spectrum with 50% duty cycle and 100 burst count.

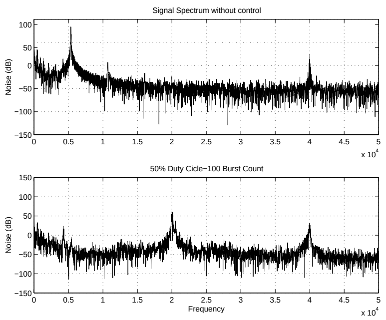

FIGURE 1: Noise spectrum with 50% duty cycle and 100 cycle burst count.

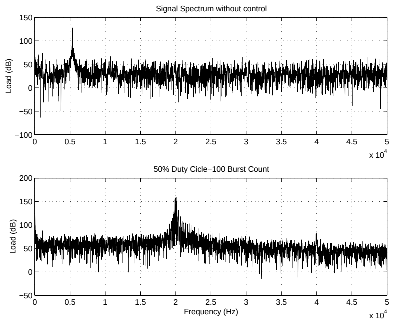

FIGURE 2: Dynamic Force spectrum with 50% duty cycle and 100 cycle burst count.

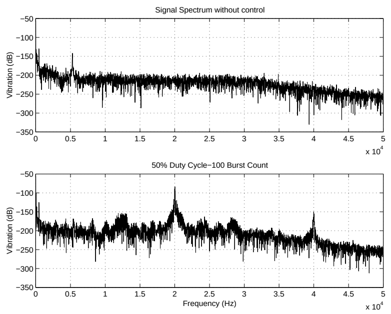

FIGURE 3: Vibration spectrum with 50% duty cycle and 100 cycle burst count.

CONCLUSIONS

Burst technique was successful in the suppression of rotor mode squeal, as long as the duty cycle was equal or greater of 50%. At duty cycles of 45% or less, the suppression was not complete or impossible to attain. The next step in this line of research must be towards optimizing and reducing the dimensions of the actuators and dither control hardware.

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