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Brake Noise Data Acquisition and Analysis System.

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ABSTRACT

AN EMBEDDED PC-BASED HARDWARE AND SOFTWARE SYSTEM HAS BEEN DEVELOPED TO AUTOMATE THE DATA ACQUISITION AND ANALYSIS OF BRAKE SQUEAL. THE DEVELOPED SYSTEM INTEGRATES ADVANCED SIGNAL CONDITIONING HARDWARE AND SOFTWARE TO ACQUIRE BRAKE NOISE AND VIBRATION DATA RAPIDLY, CONSISTENTLY AND OBJECTIVELY. A SPECIAL PEAK-PICKING ALGORITHM IS USED TO DETERMINE WHEN BRAKE NOISE OCCURS DURING A STOP EVENT AND ACTUALLY DEFINE FROM WHICH CORNER OF THE VEHICLE IT ORIGINATES. A SPECIAL NOISE-RATING TABLE IS FEATURED TO ENABLE THE USER TO DEVELOP CORRELATIONS BETWEEN DRIVER RATINGS AND OBJECTIVE MEASUREMENTS.

1. Introduction

Automotive brake noise has become increasingly important for the improvement of vehicle quietness and passenger comfort. An enormous noise control challenge is inherent in the complexity of disc and drum brake friction elements that are held in contact with rotating elements under controlled loading conditions. Brake system development for noise, like any other vehicle development process, is heavily dependent on expensive and time-consuming vehicle and dynamometer based evaluations. In this article we make a case for the continued development of standardized methods for identifying and counting noise occurrences on the road. Removing the subjectivity from the counting process and arriving at reliable and repeatable descriptions of the brake noise propensity of a particular design is seen as the first critical step to a true understanding of brake noise generation. In particular will an on-vehicle data acquisition system with on-going feature improvements, both in hardware and in software design, will be discussed in this paper.

In the automotive industry, warranty associated with brake noise is among the highest of any system in the vehicle. In response to this, manufacturers (both OEMs and brake suppliers) have invested millions of dollars in new equipment, facilities and staff to better understand their strategies forward in the design cycle. The brake engineering industry has begun to recognize the importance of acquiring fundamental understanding of brake noise mechanisms. These mechanisms include an understanding of the complex interdependency between the friction materials (composition, geometry, metrology), brake system components, boundary conditions at the friction interface and between the brake system and the vehicle, and finally the path that directs the noise into the vehicle. All of which may be subject to temperature and humidity variations, manufacturing tolerances, wear, and of course the inherent non-linearity of toleranced joints, elastomeric mounts, and sliding elements.

The first step to understanding complex brake noise issues is to accurately and repeatably describe what the system is doing with respect to all of the variables that might affect brake noise. It is important to discern objectively which corner of the vehicle is noisy and determine the noise propensity and the conditions under which noise is generated, such as:(1) the evolution of temperature distribution, pressure distribution, and speed distribution in time, (2) the percentage of noisy stops, (3) the most common frequencies and amplitudes of noise. Brake noise tends to span the entire audible range in the frequency spectra. At low frequencies, there are creep-groan, grunt, moan, and judder. At middle to high frequencies, there are any varieties of squeal noises, which occur singly, or in harmonic series and with all manners of duration and periodicity. It is clear that addressing these challenges with a data acquisition tool that is capable of accurately capturing all types of noise events and reducing the data to meaningful statistics is mandatory.

Therefore, armed with a statistical description of vehicle behavior, it should then be possible to construct dynamometer based tests that offer statistical similitude to the road test. Although, how to simulate reality is a controversy that is likely to rage on for some time assuring an ongoing need for vehicle based brake noise correlation and validation.

2. ON-Vehicle Testing

Considerable on-vehicle testing is performed all over the world specifically for brake noise certification. Some OEMs and friction material companies do their own testing on flat track. However, city traffic testing (CTT) is common with some companies in U.S. and in Europe. CTT for brake noise is conducted in several cities including Los Angeles (LACT), Denver (DCT), Chicago, Detroit (DST/DMT) and Minneapolis (MCT). The more popular of these procedures is the LACT procedure. The LACT test for noise evolved out of what was originally a test for performance and wear in mild temperature and humidity conditions with altitude changes up to 3000 ft. Similar tests are performed in some cities at high altitudes with colder and more humid conditions. Both the LACT and the high altitude tests are commonly used to evaluate brake wear, noise characteristics for brake squeal, creep-groan, and wheel dirt generation of brake linings. The test route accumulates 2000 - 5000 miles of testing over an 8 to 20 day period without removal of any brake components. The vehicles accumulate approximately 250 miles per day through a combination of city, canyon and freeway traffic. All the standards for CTTs specify the need to record all information related to the performance and noise characteristics of the brake system in specific data presentation formats.

Accomplishing the data acquisition requirements of such laborious test procedures demand a sophisticated on-vehicle data acquisition system. A practical system, therefore, should act as a passive listening device, gathering all of the necessary data, which will help make decisions about noise source, frequency, duration, and other related variables. In effect, it should divorce driver skill from the process and give the brake engineer a device which will record data under user defined trigger conditions. The system should have superior data management capability and a succinct reporting format. It should be able to quickly show the brake engineer, which corner is noisy and at what frequencies the noise occurs empowering the engineer to move to the solution phase of the project as quickly as possible.

3. Integrated Brake Noise System

Roush Anatrol Division of Roush Industries was approached internally by a group wishing to add noise testing to their existing brake performance test business. Working with this group of experienced brake test professionals, a specification for a high-performance brake noise acquisition system was defined and the first BrakeDAQ system was produced.

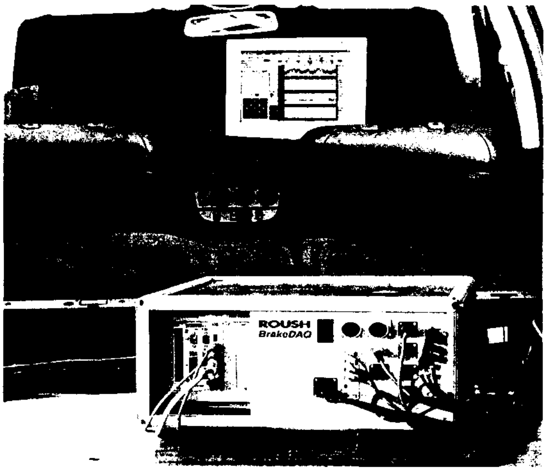

Figure 1 BrakeDAQ, an On-Vehicle Data Acquisition System (BrakeDAQ is exclusively based on software and hardware from National Instruments Corporation)

Figure 1 shows the BrakeDAQ system (version V.0) in a typical vehicle installation. A particular innovation that was first introduced in BrakeDAQ, is the use of accelerometers at each of the wheels in place of outboard microphones. The accelerometers permit a vehicle self-noise event to be easily discriminated from extraneous traffic noises. A correlation algorithm matches the frequencies of the sound in the vehicle with the vibration spectra at each wheel to determine the offending corner.

The BrakeDAQ system is comprised of several

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functional elements. The most significant ones include: Channel Configuration, Driver Display, Noise Rating Table, Peak-Picking Algorithm, Replay, Noise Summary Display, and Reporting Formats. Channel configuration is where the user inputs all the necessary signal handling parameters and the various test control settings in an easy to use and organized manner.

3.1 Drivers Display

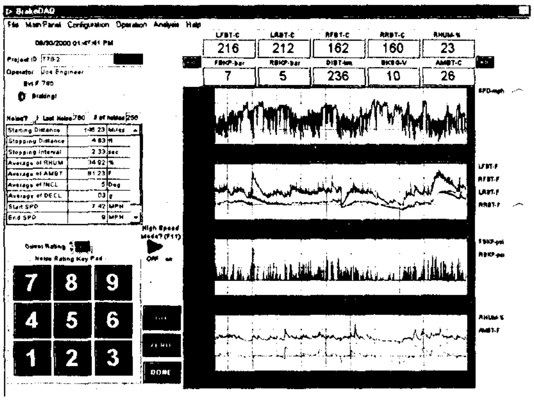

Figure 2 – Drivers display

Figure 2 shows a typical Driver' s Display. The driver display layout is easily configurable for the engineer to be able to observe the brake system parameters, such as vehicle speed, brake temperatures and pressures, and ambient humidity, in real time. The panel is also designed to alert the engineer with programmed messages, provision for accepting driver' s comments, and the capability to accept driver based noise ratings

3.2 Noise-Rating Table

Figure 3 depicts a typical Noise Rating Table configuration. The noise-rating table is used to determine the objective rating when the BrakeDAQ system identifies a brake squeal. The frequency and the noise level together pinpoint an exact rating located in the table. The true power of this method lies in its flexibility; each system configuration is unique and can be customized to closely match the users' preferences and sensitivity to noise. Therefore, the same objective rating system can be applied to all vehicles in a particular test to avoid typical human variance, and to conduct an accurate comparison

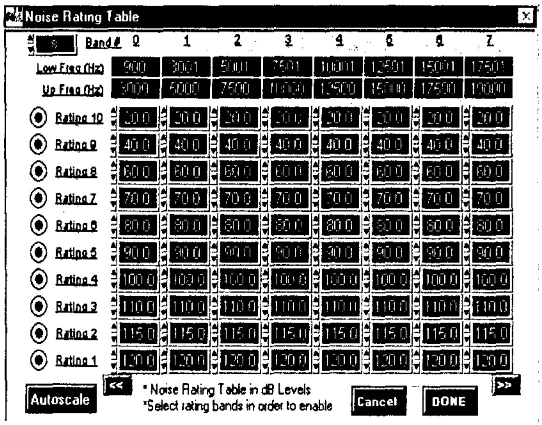

Figure 3 Noise Rating Table

3.3 Peak Picking

The peak picking algorithm utilized by the BrakeDAQ system considers many variables to ensure accuracy, repeatability, and speed. The microphone signal acquired from within the vehicle cabin is analyzed first; if a peak is not found, then the analysis for that particular event is complete, as no noise can exist. If a peak is found, several characteristics of the peak including peak maximum value, height of the peak beyond neighboring data, and peak sharpness are analyzed. Once again, if a microphone peak does not meet all of the strict criteria, the peak is dismissed and no noise is identified. If a peak identified on the microphone and meets the various criteria, then the signals on the acclerometers are analyzed. The acclerometer signals having their own unique pattern are held to equally strict yet completely different criteria. Once the peak analysis is complete and peaks have been identified on at least one of the accelerometers and the microphone, yet another analysis is performed to determine if the potential brake squeal is generated from the test vehicle, or some other source. The relationship of the peaks on the microphone and the accelerometer signals is analyzed for frequency, magnitude, and damping. If this test is passed, then finally a squeal is identified. Its frequency, SPL in dBs, and location on the vehicle are recorded along with other pertinent information.

3.4 Replay and Noise Summary Display

Figure 4 shows the Replay Panel, which allows immediate review of noisy test data on an event by event basis (each event further sub-divided into sub-events). The middle bar graph (sub-events graph) shows sub-event noise rating versus sub-event number. Once a particular event is selected, the sub-events graph shows the number of sub-events it contains. Data from each sub-event can then be reviewed from the five graphs showing the acceleration spectrum associated with the corresponding corner of the vehicle and the noise spectrum from a microphone positioned near the driver' s right ear (DRE).

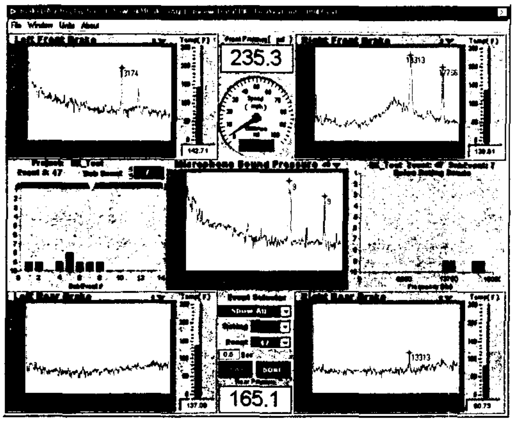

Figure 4- Replay Panel

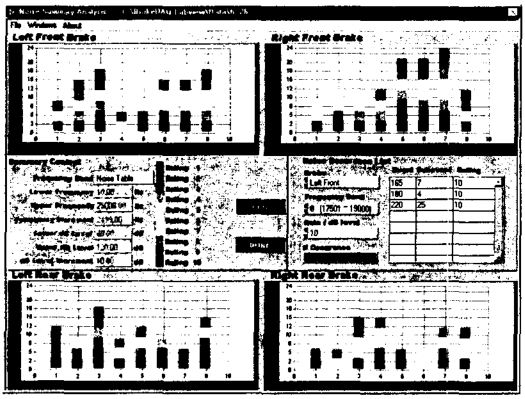

Figure 5 - Noise Summary Display

Figure 5 shows a noise summary statistic generated at the end of a day' s test. The four corner graphs describe the total number of noise occurrences at each corner of the vehicle in terms of noise levèls and user defined frequency bands. This feature is a powerful tool that can be used by the brake engineer to quickly discern the statistical severity of the noise issue.

Brake tests generate enormous amount of data, and BrakeDAQ is designed to permit the user to maximize productivity by creating custom reports using both pre-defined and user-defined data reduction macros. A typical example using a user-defined macro is shown in Figure 6.

4 Conclusions

BrakeDAQ is currently being upgraded for making measurements for brake performance and brake judder. Considerable design modifications are planned to improve both hardware and software flexibility.

Whatever the direction of future brake noise testing may be, the reference will always be the vehicle on the road. The question will always be " Is the vehicle quiet?" or " Is the Vehicle Noisy?" , and these questions will always be answered through the perception of the human ear. We have come a long way towards adding scientific rigor to this process by tapping the incredible capabilities of new generations of high-performance and low-cost signal processing equipment. Years of brake testing expertise packaged into practical applications like BrakeDAQ are helping to move the technology of quiet brakes forward. Every day, more and more useful variables can be recorded and understood in an on-vehicle situation that can influence noise and vibration issues. Advanced friction information can be easily determined on the vehicle and correlation with noise and vibration can be effectively studied in greater detail than ever before. Human ears will still guide the process, but clearly science is catching up.

References

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