Jasna Glisovic [1]
Jovanka Lukic [1]
Danijela Miloradovic [1]
Dobrivoje Catic [1]

1) University of Kragujevac, Faculty of Engineering, Serbia
jaca@kg.ac.rs

RESEARCH OF THE JUSTIFICATION FOR THE HIGH WARRANTY COSTS DUE TO DISC BRAKE NOISE

Abstract: *Development of the braking system includes optimization of many aspects of its performance, including the propensity to generate noise, in order to meet the demands of customers. Modern vehicles, with a generally high share of the front (disc) with regard to rear (drum) brakes during braking process and with small wheels, require from disc brakes even greater braking torque, leading to a higher frequency of occurrence of noise and vibration. This, with significant driver's subjective perception of the problem, related to the general quality increase in other aspects of vehicle design, has led to large-scale reclamation costs within the warranty periods that could no longer be ignored. In addition, brake noise is unpleasant, on the one hand, for passengers, as well as those in the immediate vicinity - it can also become a problem and a kind of environment "pollution". It is understandable the existence of great interest, and money invested in resolution of these issues.*

Keywords: *Disc Brakes, Brake Noise, Quality, Warranty Costs*

1. INTRODUCTION

Vehicle NVH (Noise, Vibration and Harshness) characteristics not only contribute to the luxury level of the car, they also have an impact on customer satisfaction, warranty cost, brand image and company's efforts to gain a competitive edge in the automotive market.

There are many sources and causes of noise and vibration in a vehicle (Figure 1)- engine, driveline, tires, brakes, wind and electrical drives. While some NVH characteristics are actually admired in certain cases (such as the characteristic noise of a certain brand's engine or even the sound of the door when slammed), most noise and vibration in the vehicle must be minimised in order to ensure a totally comfortable driving experience. Brake system is another important source of noise and vibration [1].

Brake noise is currently a high priority topic in vehicle noise prevention. Brake noises can be classified into three categories based on the frequencies at which they occur: 1) brake groan at below 100 Hz, 2) brake moan in 100-1000 Hz range, and 3) brake squeal at above 1000 Hz. Brake squeal can be described as an irritating sound with a main frequency between 1 and 20 kHz, generated by the brake components. It is predominantly generated at low speeds (below 30 km/h) and at low brake pressures (brake line pressures below 20 bar). Typical squeal situations are stopping at a red light or in a parking spot. The similarities between brakes and stringed instruments are striking, disregarding brake squeal being unwanted and out of tune. The geometry of the brake assembly, or the instrument, controls the frequency of the emitted sound and the friction between the rubbing parts supplies the energy needed to maintain a sound. These noises generally accompany structural instability caused by some, if not all, of the following phenomena: 1) non-conservative forces, 2) negative slope in friction velocity characteristic, and 3) stick-slip (l). In addition to the aforementioned phenomena, coupled resonance of brake components is also a necessary condition of the brake noise generation. There are thus two ways to prevent the sound. One is to modify or damp the resonant system, the violin string and box or the disc and pads. You can fill the violin box with some soft stuffing and you can glue damping rubber shims on the back plate of the brake pads. The second way to prevent sound is to change the friction mechanism so that the necessary conditions for sound generation are never accomplished. On the violin it is relatively simple, you just do not put resin on the bow. In a brake it is, however, more difficult. However, generation of brake squeal is under the influence of many other frictional characteristics other than the friction level, so it is possible to design a brake with a high friction coefficient, and continue to have a low tendency to squeal [2]. The industry achieved great success in detecting and to some degree good understanding of the mechanisms of these NVH attributes. However, many challenges still exist regarding how to control and prevent them at the component design level [4].

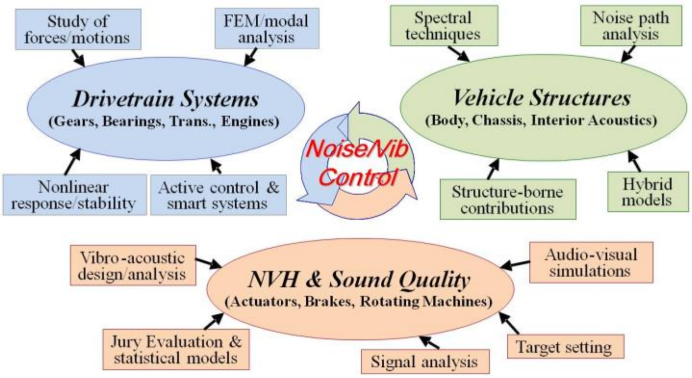

Figure 1. Automotive NVH[3]

Modern vehicles, with a generally high share of the front (disc) with regard to rear (drum) brakes during braking process and with small wheels, require from the disc brakes even greater braking torque, leading to a higher frequency of occurrence of noise and vibration. This, together with greater subjective driver perception of the problem, associated with a general increase in refinement in other aspects of vehicle design, has led to a scale of warranty costs which can no longer be ignored. The warranty data shown in Figure 2. emphasises the importance of the noise and vibration problem in relation to all reported problems faults for five European cars [5].

Development of the braking system includes optimization of many aspects of its performance, including the propensity to brake noise, in order to meet the demands of customers. Brake noise is often perceived by most consumers as a sign of poor quality and reliability of the product. Besides, brake noise is an irritant to both car passengers, as well as those in the immediate vicinity - it can also become a problem as a kind of "pollution" of the environment. Then, excessive wear due to high vibration, and micro-cracks caused by waves traveling through the friction material, are the problems in terms of maintenance costs, and more importantly, the safety issues in everyday traffic. Therefore, it is understandable that a lot of interest exists in, and money is spent on, resolving these issues [6].

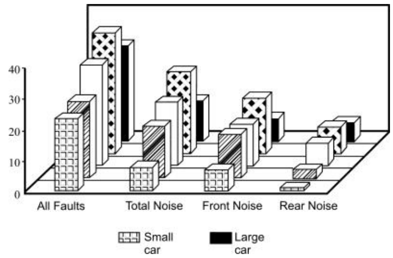

Figure 2. Market research data showing severity of brake noise problem (failures per 100 vehicles) [5]

Data show that even in 1930s brake noise emerged as one among the top ten problems of noise in a survey conducted in New York, and even today continues to be a source of boring irritation. Furthermore, Abendroth and Wernitz [7] noted that many friction material suppliers had to spend up to 50 percent of their engineering budgets on the NVH issues. J. D. Power survey released in 2002 shows that 60% of warranty costs related to brakes were those due to brake noise. Vadar et al. [8], shows that a single Los Angeles city traffic test will absorb up to six weeks of critical prototype development time, require 300–500 man hours of driver and engineering effort and costs up to $25,000.

Warranty costs are increased due to this impression. Sources from the industry practice suggests that the warranty costs due to the brake noise, vibration and harshness (NVH) including brake squeal have recently estimated up to billion dollars each year for the automotive industry of North America only ([6], [7]).

2. EXPERIMENTAL RESEARCH

Even if every noise during a vehicle test is recorded with a data acquisition device, the majority of the release procedures of a new brake system-at least in Europe-are based solely on the subjective noise ratings of the drivers during a vehicle test. These vehicle tests are expensive, time consuming, and usually occur too late to affect any structural changes if noise is detected on a test vehicle brakes. That's why the leading manufacturers have developed laboratory dynamometer tests that can shorten the brake noise development cycle and provide accurate and objective statistical data to evaluate brake noise performance. Results from the laboratory can be used to quickly affect the structural changes to optimize the brake noise performance. Inertia dynamometers are used to test the single brake assembly up to the whole mechanical brake system, often also including suspension. Dynamometers are used in different operational modes. During a test procedure, the time between the brake applications is either firmly specified (time controlled mode) or the next brake application is started when a specific (e. g. disc) temperature is reached (temperature controlled mode), independent of the cooling time in the latter case. For special test procedures, the control parameter during a brake application is either brake line pressure (pressure controlled) or the brake torque (torque controlled), besides the initial and final velocity and in the case of temperature control also initial temperature.

Brake noise dynamometer developed in the Laboratory for testing the IC engines at the Faculty of Engineering in Kragujevac is shown in Figure 3. It is possible to comprehend the effects of vehicle inertia, due to the disc that is mounted on the rotating shaft. Disc's inertia is equivalent to the linear inertia of the vehicle, thus ensuring stable operation at low speeds that are relevant in terms of brake noise.

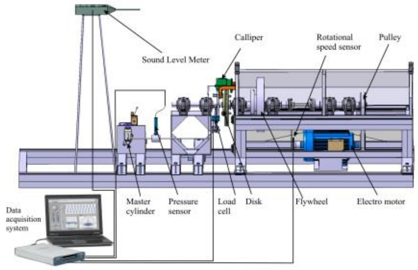

Figure 3. Brake Noise Dynamometer[9]

Brake noise dynamometer consists from following functional units: test bench with electric motor, power transmission and disc; electric power installations; the installation for activation of disc brakes *i.e.* applying the braking pressure and measuring equipment.

The components of the measuring block formed to record the activation pressure in the cylinder of disc brake, *p*, brake torque, M_k, RPM of disc brakes, *n*, and the sound pressure level, *SPL*, as well as the connections of individual components are shown in photography in Figure 4.

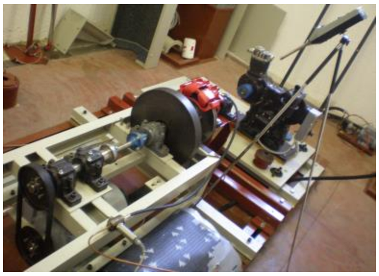

Figure 4. Photo of laboratory installations designed for the brake noise investigation

The developed test procedure includes two categories of tests: braking with a constant rotation speed of the disc and different braking pressure and braking with a constant pressure and at different speeds.

Tests that have been carried out correspond to braking with clutch-off *i.e.* with interrupted power transmission.

In some braking regime (e.g. low brake pressure and high initial engine speed) there is only partial braking *i.e.* partial declining of disc's speed from the initial speed of v_1 to end speed of v_2 , while in other cases, it was braking until stopping of the disc brake.

Measuring signals from all sensors are then led to National Instruments NI USB-type-6341 data acquisition system (Figure 14) which in interface with LabVIEW 2010 software, collects, analyzes and represents in real-time and stores the measurement results.

During experimental research measuring value with the maximum change rate in time is the sound pressure level so its characteristic sets sampling speed. An examined high-frequency disc brake squeal has a maximum expected frequency of 20 kHz because it is the human audible range limit. According to Nyquist-Shannon sampling it is required that the sampling frequency must be at least twice higher than the frequency of the signal that we want to transfer to digital form, otherwise aliasing effect occurs. Therefore, the selected sample frequency was 50 kHz. So the data sampling period was $2 \cdot 10^{-5}$ s.

Selected time period of signal recording was 5 s, and this is, with respect that the duration of the braking process is maximum 1 s, a sufficient period to capture the processes before and after the brake (the level of environmental noise, influence of the drive unit noise, the effect of residual braking to stopping time of the disc).

3. RESULTS OF RESEARCH IN TIME DOMAIN

The main indicator of the braking efficiency is the braking torque, and it is important to determine whether the occurrence of squealing noise and decline of the braking efficiency are correlated.

Analysis of interaction between changes of the braking torque and sound pressure levels (SPL) was performed for the following measuring range of brake pressure (0.5 MPa, 2.5 MPa and 3.0 MPa).

A sudden change of sound pressure level at 0.325 s can be seen in Figure 5, which refers to a mode of maximum brake pressure of 2.5 MPa, and enlarged window is shown in Figure 6.

Enlarged window (time interval from 0.32 to 0.325 s) in Figure 6. indicates existence of an influence of the occurrence of disc brake squealing on the decline of the braking system efficiency that is expressed by reducing the braking torque.

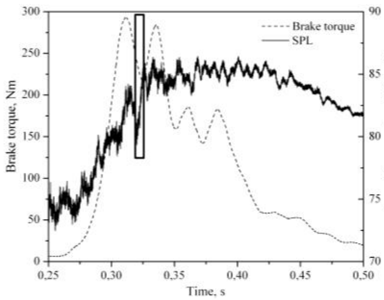

Figure 5. The braking torque and SPL-maximum pressure of 2.5 MPa and an initial speed of 714 rpm (v=70 km/h)[9]

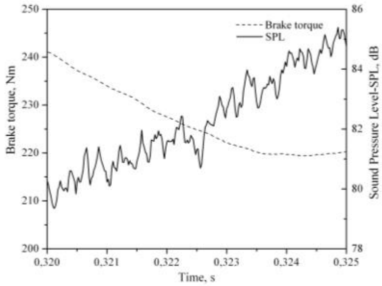

Figure 6. Influence of the brake noise's appearance on the brake efficiency for maximum pressure of 2.5 MPa and an initial speed of 714 rpm (v=70 km/h)

The same procedure was repeated for the highest pressure of 3.0 MPa, and again, it is observed several significant changes in sound pressure levels in the area of maximum braking torque. This is very important in terms of justification of customer complaints on the quality of brake systems during the appearance of squealing of brakes.

The influence of different regimes of maximum brake pressure on the braking torque variation during braking is shown in Figure 7. It is clear that the braking torque follows to a large degree the form of changes in the brake pressure, and when maximum pressure is low (0,5 and 1,0 MPa) the residual braking torque is shown (partially activated brakes).

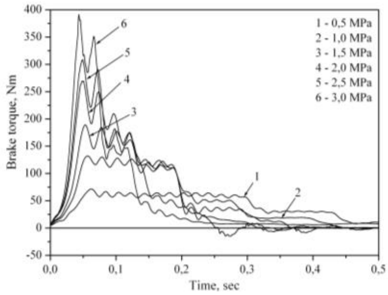

Figure 7. Variation of the braking torque for the initial disc speed of 765 rpm (v=75 km/h[9])

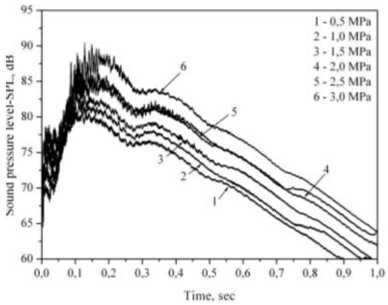

Figure 8. Variations of the sound pressure levels for the initial disc speed of 765 rpm (v=75 km/h)[9]

The sound pressure level, *SPL*, is the most important quantity for estimation of the occurrence of brake squeal. With the variation of the maximum braking torque, the expected increase in noise level is present and it exceeds the threshold of 70 dB in all regimes (Figure 8).

In the regime of the highest test pressure of 3,0 MPa, the intensive variations which correspond to squeal noise are observed. This is better evaluated in the frequency domain by analysis of the power spectra of the sound pressure levels.

5. CONCLUSION

After the experimental research on the developed brake dynamometer is carried out, analysis in the time and frequency domain is performed. The research of the oscillatory and sound phenomena of brake mechanisms shows their influence on the braking efficiency. Analysis of different braking modes indicates on the existence of influence of phenomena of squealing disc brake on the decline of the brake system's efficiency expressed by reducing the braking torque. This correlation is not present in the whole time period, but only in some periods. This is very important in terms of justification of customer complaints on the quality of brake systems during the appearance of scruealing of brakes. The influence of different braking modes on the occurrence of the brake squeal: braking until stopping and braking to slow down to certain disc speed i.e. vehicle speed, is also considered.

REFERENCES:

[1] Abdul-Hafiz, A. *Vehicle Noise, Vibration and Harshness, Focus on Brake System,* Retrieved February 13, 2013, from: http://www.autofocusasia.com/production_manufacturing/vehiclenoise_vibration.htm

[2] Eriksson, M. (2000). *Friction and contact phenomena of disc brakes related to squeal* (PhD Thesis, Acta Universitatis Upsaliensis, Uppsala).

[3] *Vibro-Acoustics and Sound Quality Research Laboratory*, Retrieved March 11, 2013, from: http://www.min.uc.edu/tlim/research/automotive-nvh

[4] Chen, S. E., & Her, J. Y. (1998). *Brake Noise Challenge In Automobile Industry*, 16th ICA Seattle, USA.

[5] Crolla, D. A. & Lang, A. M. (1991). Brake noise and vibration – the state of the art. *Vehicle Technology, 18*, in Tribology Series, 165-174.

[6] Oberst, S., & Lai, J. C. S. (2008). *New Approaches for Understanding the Mechanisms of Brake Squeal*. Proceedings from the International Conference Acoustics 2008, Australia, 1-8.

[7] Abendroth, H., & Wernitz, B. (2000). The integrated test concept: Dyno-vehicle, performance-noise. *SAE Technical Paper Series, 2000-01-2774*.

[8] Vadari, V., Albright, M., & Edgar, D. (2001). An introduction to brake noise engineering, *Sound and Vibration*.

[9] Glisovic, J. (2012). *Theoretical and experimental research of high-frequency noise of disc brakes* (PhD Thesis, University of Kragujevac, Faculty of Engineering, Serbia), in Serbian.

Acknowledgment: This paper was realized within the researching project “The research of vehicle safety as part of a cybernetic system: Driver-Vehicle-Environment” ref. no. 35041, funded by Ministry of Education, Science and Technological Development of the Republic of Serbia.