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DISCUSSION OF THE CHARACTERISTICS OF BRAKE JUDDER AND THE NECESSARY DATA ACQUISITION SYSTEM FOR COMPLETE ANALYSIS

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ABSTRACT

Brake judder is becoming an increasing concern within the automotive industry. Much research into brake judder relies on simulated dynamometer work without correlation to actual vehicle data.
A data acquisition system has been used to collect data from on vehicle brake testing. The data has been compiled and analysed using different methods to provide an effective means of validating future work carried out on an in house brake dynamometer.

Keywords Brake, Judder, Drone, Thermo-elastic

1 INTRODUCTION

There are two types of brake judder; hot judder and cold judder. Each can be split into many different types, but essentially hot judder is caused during braking and is due to differential thermal expansion of the rotor material, thermo elastic instabilities, surface film transfer and hot spots, whilst cold judder is caused by off brake wear such as corrosion. Jacobsson (2003) and De Vries et al (1992) have described these causes and effects in detail. However essentially brake judder is caused by thickness variations on the brake disc surface which can be transmitted as either a brake torque variation (BTV) or a brake pressure variation (BPV). The aim of this work is to measure the BPV and BTV on vehicle and to try and assess the development of brake judder.
It is essential for any research to have accurate and appropriate data for validation purposes. Without this, results can become misleading and important factors can be missed. The validation work presented here will be used to enable a more accurate study of brake judder to take place.

Brake judder can make itself known in a range of ways. The most common are:

- Drone, which is an audible noise usually caused by hotspots on the brake disc

- Steering and body vibration, where the vibrations are caused due to excitations within the suspension caused when the brake judder occurs at the same frequency as the natural frequency of the suspension components.

- Pedal vibration, caused by BPV due to the brake pads passing over deformations on the brake disc surface.

2 TEST EQUIPMENT

The vehicle was equipped with a range of transducers to provide a wealth of data for analysis.
The test equipment consisted of:

- Embedded thermocouples in the front brake discs measuring inner and outer friction ring temperatures
- Sliding thermocouple on the rear brake for calibration purposes
- Pressure transducers independently measuring left and right front caliper brake line pressures (figure1)
- Biaxial accelerometers mounted on the pad back plates measuring in plane (tangential to disc revolution) and out of plane vibration.
- Accelerometers mounted on the calipers measuring in plane vibration
- Thermocouples mounted on the pad back plates for calibration purposes

And transducers to measure the following:

- Ambient air temperature
- Vehicle velocity
- Vehicle deceleration
- Pedal travel
- Pedal effort

Measurement of out of plane pad vibration should correlate with BPV whilst in plane pad vibration will show BTV.

Data was recorded at 1000Hz and stored directly to a laptop. The acquisition system can be seen in figure 2. Whilst subjective scores for brake drone and pedal, body and steering vibration were recorded as a quick and effective measure of the severity of the brake judder.

3 TEST PROCEDURE

All testing was carried out on vehicle to provide the most realistic conditions. The test procedure involved initial bedding in of the brake system followed by a sequence of 20 low deceleration (0.2 – 0.4g) braking events from 240kph to 50kph to induce judder into the brakes. The relatively high starting velocity and low deceleration dissipates a large amount of energy through the brake rotors. This was followed up by a series of similar braking events the main purpose of which was to assess the severity of the brake judder.

4 EXPERIMENTAL RESULTS

Disc revolutions were partitioned out from the test data for each recorded braking event and stored in data sets for pressure variation and in plane and out of plane vibration. This allowed analysis of judder development, but also enabled Fourier analysis to be performed to enable a more detailed analysis of judder development. Fourier analysis may be able to highlight any excitation frequencies within the suspension caused by judder and also aid correlation. Using a constant tolerance value the least dominant frequencies were filtered out (figure 3) to provide the most representative form of the original signal using the least number of frequencies. The final few stops were used as a guideline to select the correct tolerance value which was then applied to all the data sets. Obviously for the earlier stops the signal from the Fourier analysis will be less representative due to the much lower brake judder present. However the most dominant frequencies are still picked up.

Fourier analysis for the pressure signals (figure 4) shows a significant fall in the number of dominant frequencies following long periods of cooling (stops 21 and 26). This is possibly a sign of the brake disc going through thermo-elastic deformation and relaxing back to its original un-deformed shape during cooling. This observation is present for both the left and right hand brake disc.

Cross correlation between pressure and in plane and out of plane pad vibrations was poor with no common frequencies being picked up. This is possibly due to the large amount of noise present within the vibration measurements due to the road surface and vehicle movement. However a frequency of around 200Hz was consistently shown throughout all tests for out of plane vibration (figure 5).

Judder is shown to develop from second order (two pulses per revolution) to a much higher order, possibly 8^{th} from analysis of the brake pressure data (figure 6). The relative strength of the pressure variation has also increased which correlates well with the recorded subjective scores. The recorded subjective brake judder scores became worse with increasing disc temperature which was also highlighted by the increasing number of dominant frequencies.

Surface scanning of several of the disc spots present on the brake disc show that the thickness variation in the friction ring surface over the disc spots is 14microns which is large enough to cause brake judder as suggested by Jacobsson (2003).

5 CONCLUSIONS

Testing has produced a large amount of highly useful data for validation purposes. Further testing on an in house dynamometer, where conditions can be controlled, will aid correlation between vibration and pressure measurements. Disc thickness variations will also be measured dynamically. Noise within accelerometer signals will be kept to a minimum due to the controllable environment.

Whilst initial surface scans of individual disc spots have shown them to be large enough to produce judder a forthcoming full surface scan of the disc will allow comparison between the disc thickness variation and BPV measurements.

6 REFERENCES

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DE VRIES, A., WAGNER M. (1992), *The Brake Judder Phenomenon*. SAE, 920554

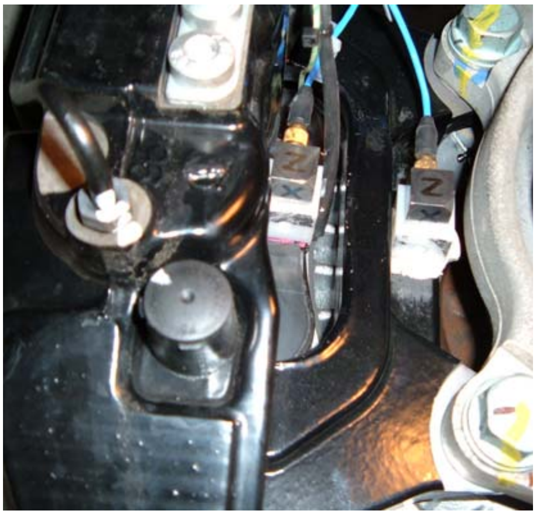

Figure 1: Caliper and back plate accelerometer positions

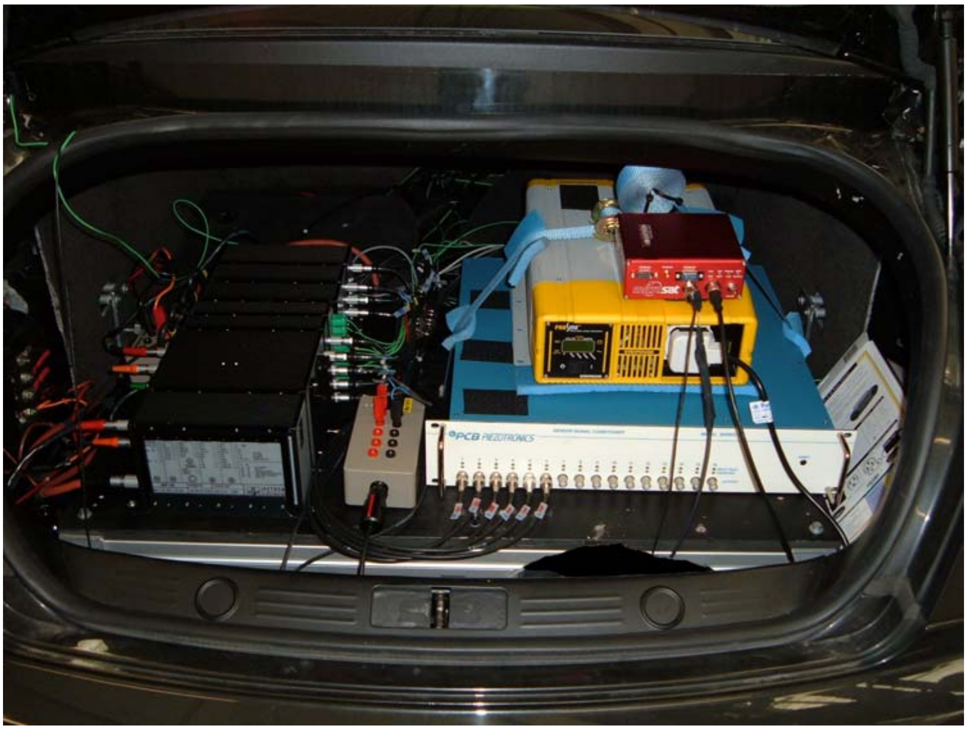

Figure 2: On board acquisition system

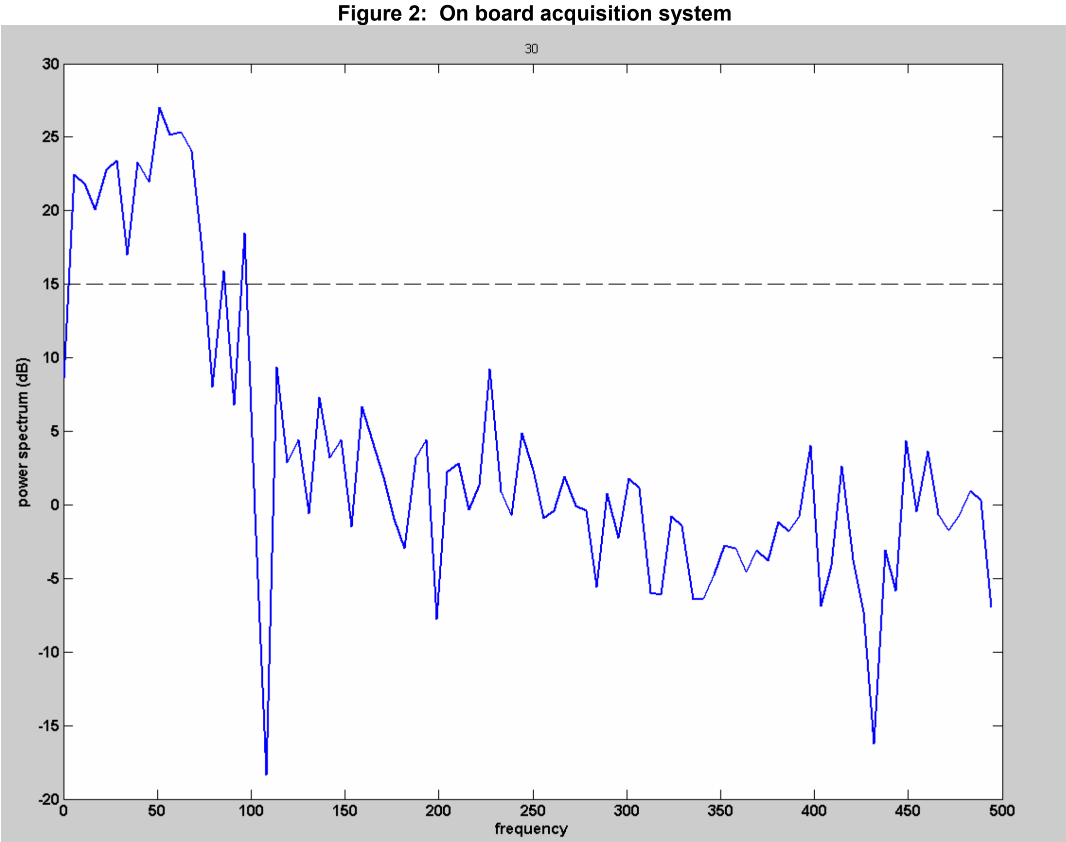

Figure 3: Fourier analysis showing tolerancing method

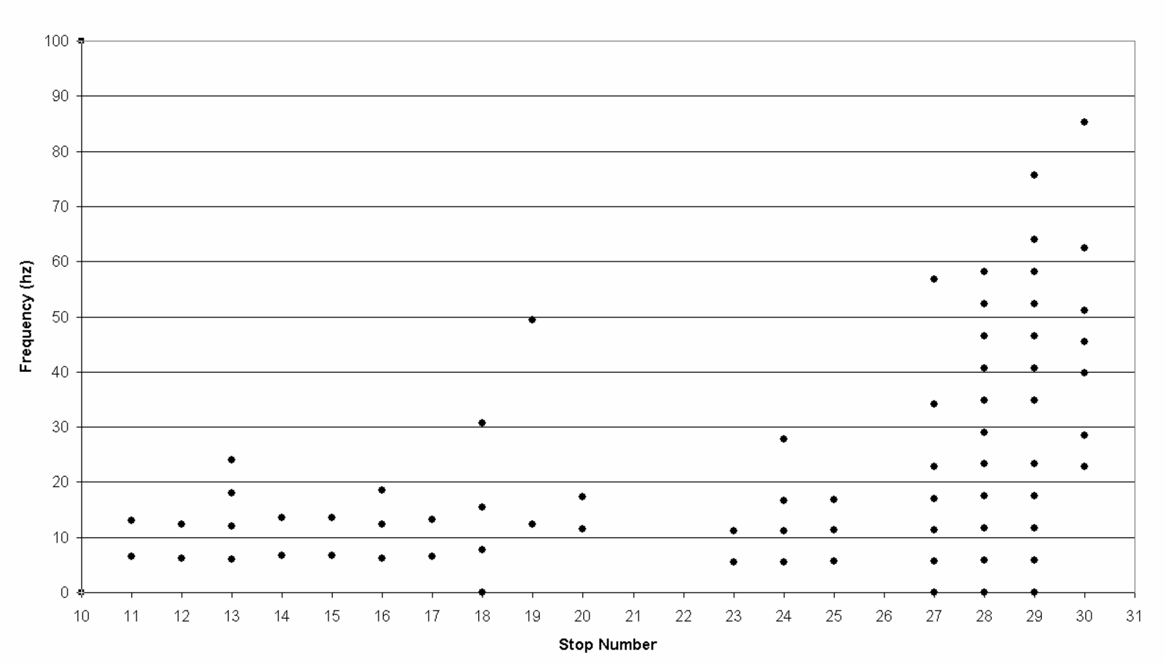

Figure 4: Right hand disc pressure dominant Fourier frequencies

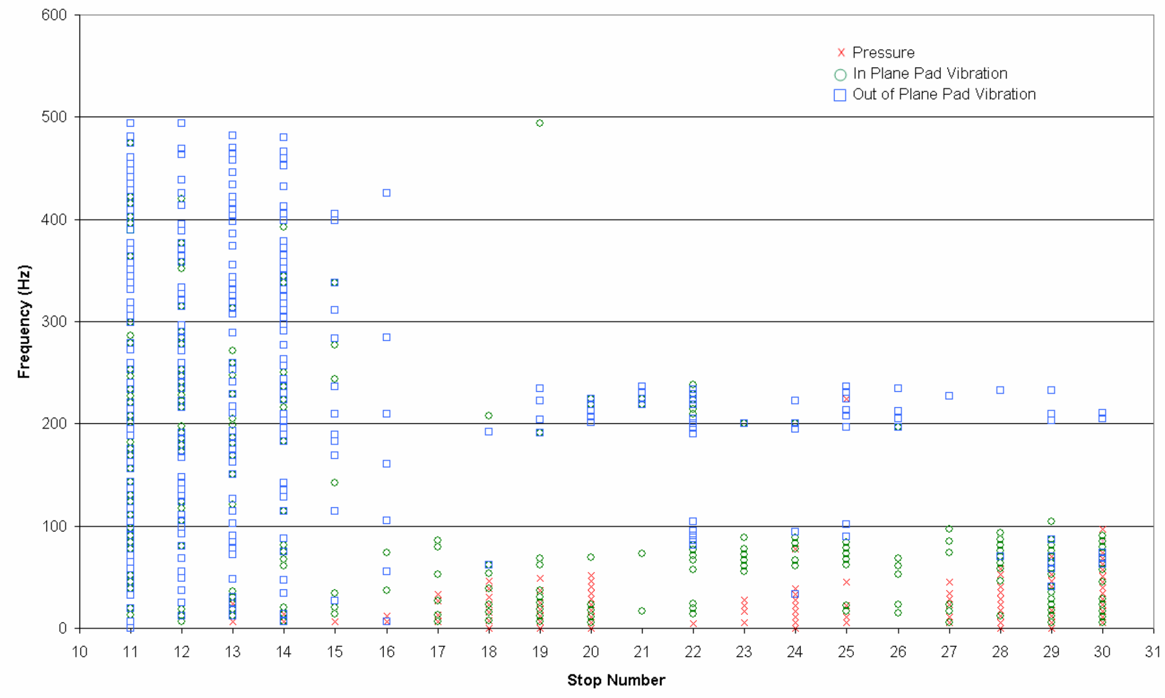

Figure 5: Cross correlation between Pressure variation and in plane and out of plane vibration

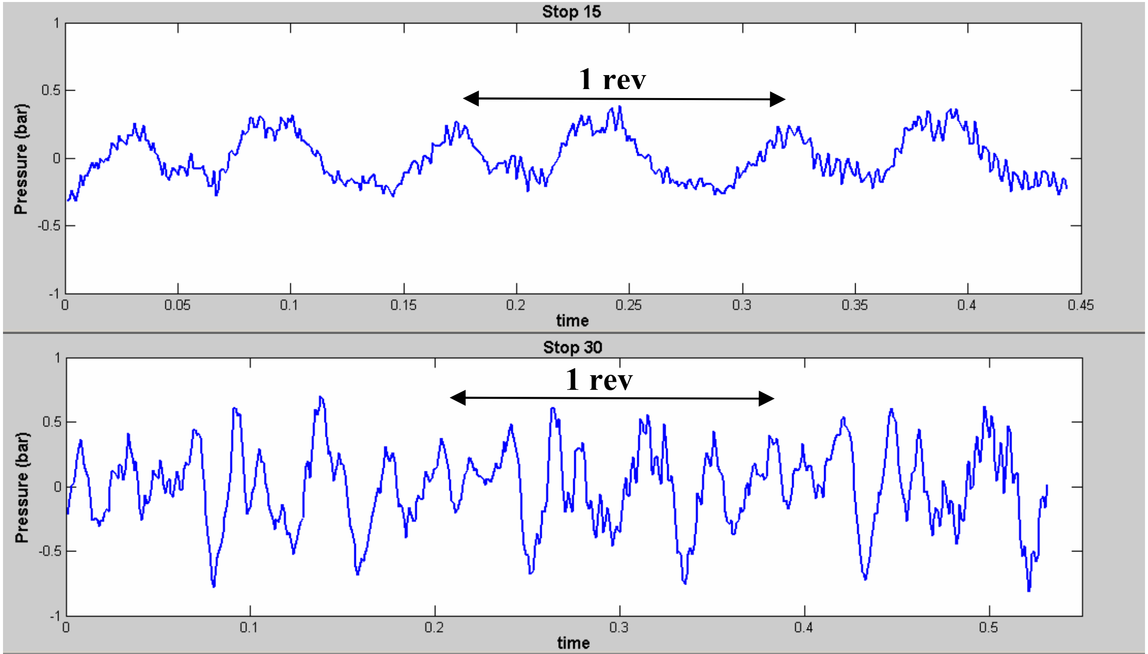

Figure 6: Development of brake pressure variation between stop 15 and stop 30