Determination of Automotive Brake Disc Thickness Variation To analyses Judder Issue

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Abstract: Now a day's Vehicles are becoming more powerful and resulting high speed. But due to road limitation sudden braking is also repeated in RWUP condition and because of that minor variation in brake disc causes vehicle brake juddering and results in driver discomfort & poor confidence. It is directly affecting on business performance. Even though advanced technologies are available in market still it is impossible to designed brake disc with zero variation. Vehicle juddering has become of major concern to automobile manufacturer world wide and braking performance not consistent due to brake disc variation. Brake Pad that will enable engineers to better understand the causes of DTV & Stick-slip the initiator of low & high frequency vibration in motor vehicle brake. DTV is caused by disc brake pad wearing the brake disc, at their point of maximum run-out through continual light rubbing whilst the brake of the vehicle is not applied, thus wearing two relatively thinner areas of the disc- one on each rubbing face- at diametrically opposite points.
If sufficient thickness variation is generated in the region of 10 to 20 µm the vehicle will judder at the time of braking. The precise Threshold value varies from model to model being dependent upon the general compliance built into the vehicle's braking and suspension and steering systems. Brake judder experienced due to DTV is termed cold judder since it does not depend on the distortions of the brake disc and/or resin deposition from the face of the disc during high thermal inputs. The brake disc run-out the installed values of the run-out depend upon many factors associated with design and build quality of the vehicle such as the square ness of the disc hub interface, the fastening of the rotor to the hub, the machining accuracy and deflation of the stub axle, the type of the wheel bearings that are used etc. Typical values of installed disc run out encountered in passenger cars are as below :-

Table 1. Specification of Typical run out in Car's-

Type of Vehicle	Typical run-out value
Small family car	100 microns (0.10 mm)
Medium family car	80 microns (0.08 mm)
Luxury car	50 microns (0.05 mm)

When the vehicle is in use, the dynamic loading produced when accelerating and cornering can increase the values of run-out dramatically & up to 2 mm (2000 microns) have been recorded in extreme cases.

INDEX TERM -Brake pressure variation, brake vibrations, cold judder, disc thickness variation, disc brake, hot judder, judder.

I)Introduction

From ancient span vehicle judder caused by DTV has become major concern. Judder usually perceived by driver as minor to severe vibrations transferred through the chassis during braking[1-9]. Judder is classified into 2 types i.e. hot (thermal) & cold judder. Hot judder is result of longer more moderate braking from high speed where the vehicle does not come to a complete stop[13]. It occurs when we decelerate from speed of 120 km/h to about 60km/h, which results in severe vibrations being transmitted to the driver. These vibration results uneven thermal distributions believed to be the result of phenomena called hot spots. Hot spots are classified as concentrated thermal regions that alternates both the sides of the disc that distort it in such way that produces a sinusoidal waviness around at its corners. As brake pads comes in contact with sinusoidal surface during braking severe vibration are induced as a result and crate perilous situation for the person driving the vehicle[11,12,14-16].
Cold judder is result of uneven disc wear patterns or DTV. These variations in disc thickness are usually result of extensive vehicle road usage. DTV is ascribed to the following causes waviness of the disc, misalignment of the axis (run out), elastic deflection, thermal distortion, wear & thermal material transfers[3,15-17]. Whereas many companies are currently involved in research in this area, this is probably due to judder having inherent difficulties and the relative shortage of analytical model that can predict its behavior satisfactorily[23].

II)Scope

The Scope of this paper is to investigate the brake disc thickness variation and its influence on low frequency (10-60 Hz). Rigid body vibration commonly knowns as brake judder/shudder[6,8,10]. It is limited to low frequency vibration.

III)Objective

To develop experimental system or method that will enable us to study DTV and the factors that may contribute to its development such as Disc run out, contact pressure, dynamic braking conditions, temperature on disc surface, other disc surface condition, driving style etc. To come up with guidance to develop these systems towards assisting brake developers towards the minimization of the brake judder and its effects in motor vehicles. To move possible direction for future work[21]

IV)Literature

In literature review of DTV following point are important,

Types of Vibration in Brake System- Vibration in automotive brake system is classified as per their dominant frequency (Hz). It varies from low rigid body judder vibration to high stick-slip self-excited vibration.

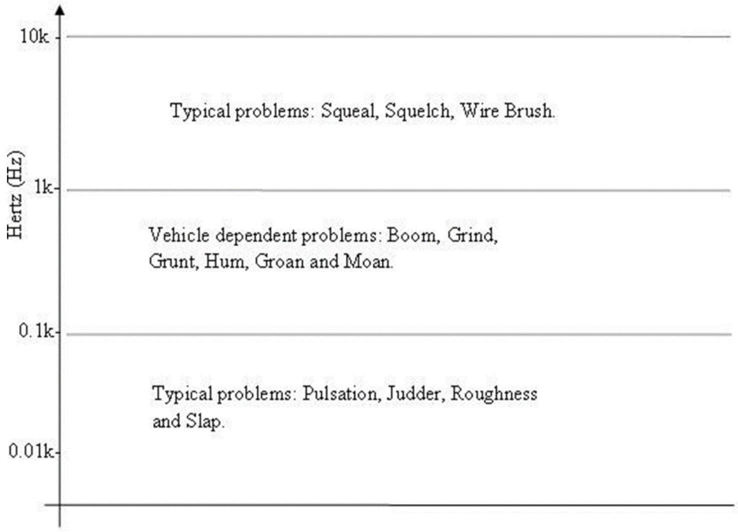

Figure 1. vibrations grouped by representative frequency [21]

Approaches used to study DTV- Based on mechanism and vibration study, vibrations are very complex in nature thus a number of different approaches formulated to assist researcher in the study of these phenomena, namely cause, effect, system and frequency sweep.

Cause Approach- Cause of a phenomenon called Thermal Elastic Instability (TEI) is believed to be the result of brake disc material irregularities, such as Hot- Spots.

Effect Approach- Application of this approach is to study the paths of vibrations takes from the source of the vibration, through the vehicle chassis, to the driver[7].

System Approach- With this approach vehicle considered as one large system with several smaller sub systems. When it applies to vehicle idea is to systematically investigate the interactions between the sub systems.

Frequency Sweep Approach- This Approach involves taking measurements whilst the wheel speed is changing. Analysis and measurement are made of judder at a constant speed; brake line pressure and temperature to simplify analysis[7].

Causes (Excitation Mechanism)- DTV is variation in thickness in brake disc. There are main cases of DTV & those are 1) A disc with one thin spot & 2) A disc with two thin spot as shown in(fig 1.2) In this section, DTV is classified as per how the wear was produced & it is of two types i.e. Off Brake wear (Off-BW) & On Brake wear (On-BW). OFF-BW DTV generation is only because of uneven wear which leads to judder. The Conditions and assumptions for off-BW are as follows:-

1) Discs are installed with level of lateral runout; this runout will vary from car to car & design to design.

2) The amount of caliper roll back is generally not enough to completely remove contact between friction material & disc whilst the brakes are in off brake condition.

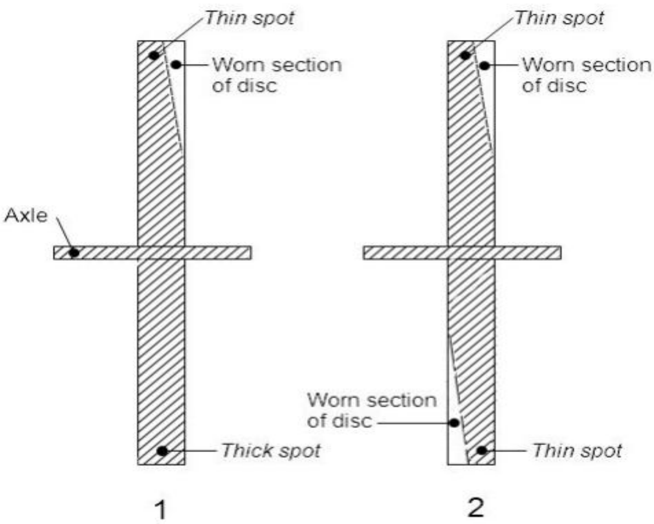

Figure 2- 1) Disc with one thin spot &
2) Disc with two thin spot[20,23]

3) Whilst car is moving and brakes are in off brake condition, the disc comes in contact with friction material at the highest point of the lateral run out & disc gets worn away in this area.

On-Brake Wear- As friction material of pad is in contact with disc & on brake condition causes negligible uneven wear to the disc compared to off brake condition. During manufacturing, casting and machining operation can result waviness of the disc surface and errors in installation of wheels & bearing leads to DTV generation[32].

Effects (Transfer mechanism)- These effects can be analyzed by two methods i.e. System approach & Frequency Approach.

System Approach- Transfer of initial excitation from brake system through vehicle was most important factor[2]. We know that range of vibration for judder to occur is typically between 10-60 Hz & termed as low frequency vibration. Thus, resonance between that of the excitation mechanism and chassis must occur within this range. When vehicle is running at 95 km/h, natural frequency of the suspension has been found approximately 14 Hz[6] & brake disc excitation also comes in the same range[23].

Frequency Approach- Cold judder seems to be the result of run out initiated DTV, the reason is that frequency of vibration at the critical speed is multiple wheel speed runout generate DTV with one thin section, would produce one pulse response per revolution. If the disc has two thinner sections, frequency would be double.

Disc and Friction Material- Disc introduced in 1960 and discs are constructed by grey cast iron and having excellent wear properties & pads with asbestos friction material. Even today also grey cast iron is still used. In modern disc ingredients and machining processes are changed. Asbestos material has been deserted in most of the part of world because asbestos contained pads cause a fatal lung disease called asbestosis. Cast iron material were material designed to provide high thermal conductivity and the ability to withstand heating and cooling cycles and it also reduces hot spotting, thermal stress & no carbide formation. From last couple of year carbons fibre discs and their derivatives are being used for high performance motor vehicles particularly in racing at substantial cost. Now a day's introduction of environmentally friendly organic friction material has caused a re-emergence of hot spotting and judder[23].

Analytical Techniques- Hohmann[19] use the ADINA FEA package to analyze the contact conditions that may occur as a result of a stick-slip motion in brakes. The pressure distribution of contact area, are believed to be particularly important in the study of DTV[20].

V)Methodology

Based on various inputs, activities are divided into-

Instrumentation on Vehicle- In DTV measurement we measure inboard and outboard thickness induced runout (TIR), Disc Thickness variation (DTV) and drag torque of brake disc on the vehicle. For measurement, we need a motor driven wheel drive adapter, two capacitive, non-contact probes and vertical line beam laser. The specification of instrument used in DTV measurement are as follows-

Table 2. Specification of Instruments-

Motor Speed	0 - 5 RPM continuous
Drive Motor Torque	0 -85 Nm continuous
Probe Range	2.54 mm, +/- 0.25% FS
Probe Type	Capacitive, non-contact w/90° quick disconnect cable.
Wheel Drive Adaptor	Adjustable to fit all lug patterns.
Alignment Laser	Vertical line beam
Head Height Range	0.43 – 0.76 m

Wheel drive adaptor mounted on fixture plate that attached on the wheel hub (as shown in fig 2). and two capacitive probes are mounted on vehicle with help bracket and this bracket is mounted on knuckle (in fig 4& 5).

Figure 3. Wheel drive adaptor with fixture plate

Figure 4. Capacitive probe with bracket (Inner side)

Figure 5. Capacitive probe with bracket (outer side)

DTV Measurement (Traditional & Modern techniques)- DTV is measurement using brake disc micrometer and dial indicator are traditional technique.

Brake Disc Micrometer- it is specialized micrometer designed for this purpose. It's throat deep will be deep enough to measure disc thickness at several points across the disc. This gauge will have one or more pointed anvil tips that allow you to measure true thickness of the disc, starting at the bottom of any deep grooves. Measure the disc thickness by marking the rotor in at least 8 to 10 equally spaced intervals. A disc that's in good condition shows variations in thickness of no more than 1 to 3 microns[23]. There should be no more than 1 micron in variation between the reading on new disc. The micrometer used for this is shown in fig 6 -

Figure 6. Brake Disc Micrometer

Dial Indicator- Rotate the hub bearing assembly by hand. Check for roughness, play or noise from bearing. The hub is directly affected by the condition of the bearing. If a dial indicator measurement of bearing end play is greater than 4 microns, the bearing is suspect. A worn or loose wheel bearing will contribute to hub and disc runout. Set the dial indicator to zero, next turn disc at least twice and observe the high and low spot of runout. Mark these spots on the disc. If disc shows runout greater than 50 microns or if the readings are inconsistent corrective action may be needed. Some poorly manufactured disc may reach or exceeds this limit with brand new[23]. It working process is (shown in fig 7) -

Figure 7. Dial Indicator with Brake Disc

Portable vehicle DTV and Drag Tester- It is modern technique. Disc thickness variation measurement is a system for quality inspection of rotating disc. The DTV application semi-automatically acquires thickness profiles of rotating disc with Link software. The thickness D1 and the 360° rotations are calculated automatically from the measurement values of the displacement sensors A1 and A2. If the distance (measure C) between both the capacitive displacement sensor is known, brake disc thickness & is calculated as follows (refer fig 8) -

D1 = C - (A1 + A2).

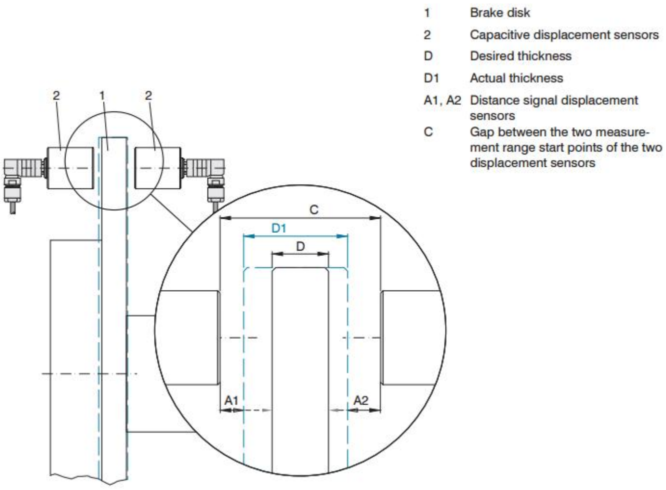

Figure 8. Brake Disc Thickness Calculation

While using Portable DTV measurement instrument in software we have to give command to system for auto mode & ON condition. Once command is given wheel will rotate to 360° twice with the help of wheel drive adaptor & probe will detect the runout at spaced interval at disc top, bottom and mid location. For each location, we have to take at least three reading, it reflects the repeatability and accuracy in reading. In test condition, it shows the actual values & graphs as shown in fig 9.

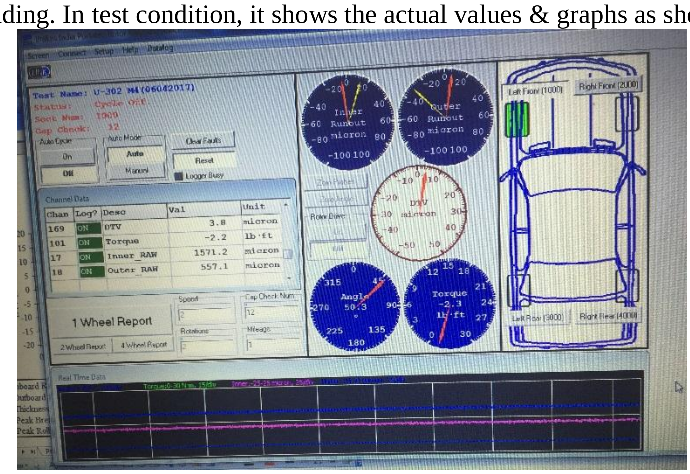

Figure 9. Actual Disc Thickness Variation measurement software

DTV Data Analysis- Once DTV measurement data is acquired the next important parameter is analysis of this data. We acquired data in total 3 vehicles for both LH & RH side disc at Top, Bottom and Mid location. It shows that top side run out is higher than bottom side at each disc. And also, total thickness variation of disc at each location is within 5 microns in each vehicle (fig 9, 10, 11).

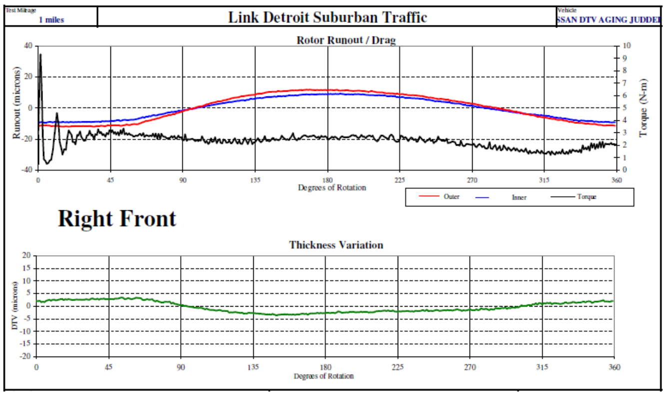

Figure 10. Disc Thickness Variation measurement for RH side at Disc Top[23]

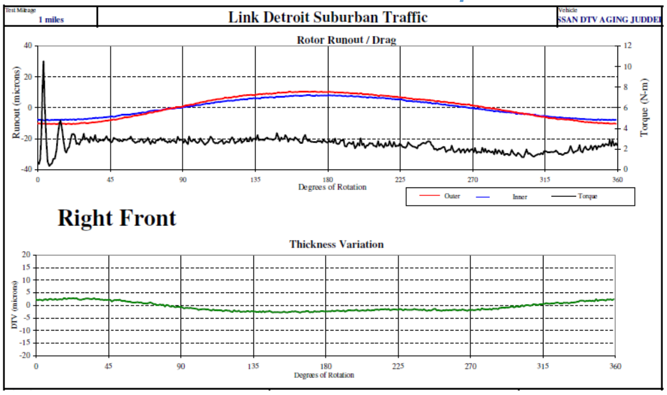

Figure 11. Disc Thickness Variation measurement for RH side at Disc Middle[23]

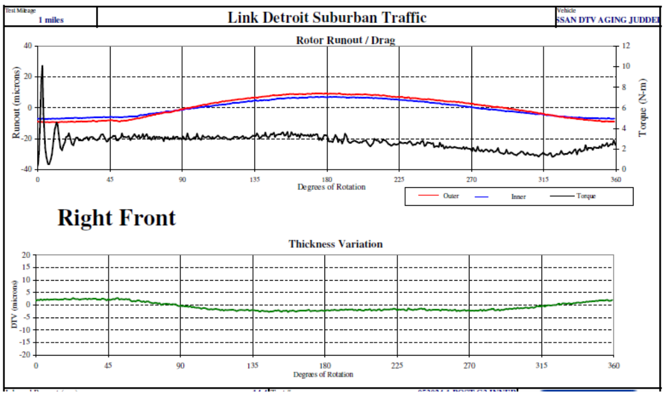

Figure 12. Disc Thickness Variation measurement for RH side at Disc Bottom

VI)Results

We have monitored brake performance and measured brake disc thickness after every 10k km interval. This disc thickness variation observed only 2 microns in 10k km running. Vehicle judder/shudder concern reported in between vehicle running, it can be captured immediate by verifying disc thickness and runout variation. Degradation of disc thickness monitored and verified time to time on vehicle. This exercise is user friendly. Manufacturing consistency can be captured by verifying on random vehicles. This exercise also important for project before delivering product to market & also reduces field failure of judder/shudder.

VII)Impacts

Worldwide Judder and shudder concern in automobile are minimize by controlling the brake disc thickness variation & disc runout. This is resulting in safety vehicle handling, improved driver confidence. Brake stability at higher speed. Improve vehicle controlling at high speed & product.

VIII)Conclusions

The development and validation of brake disc is a great feat in engineering research. This paper will enable engineers to better understand the disc thickness and runout variation. This also enable engineers to better understand causes of DTV and stick-slip the initiator of low & high frequency vibration in brakes.It helps to measures inboard and outboard run-out and disc thickness variation of a rotor on the vehicle. It portability easily allows in field measurement. An ultimate goal of this paper is to reduce judder/ shudder by monitoring disc runouts and thickness variation.

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