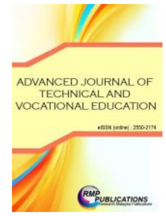
Advanced Journal of Technical and Vocational Education, 1 (4): 28-32, 2017
e-ISSN: 2550-2174

DOI: 10.26666/rmp.ajtve.2017.4.7



Statistical Analysis on Noise and Surface Contact Condition with the Effect of External Grit Particles on Squealing Disc Brake

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Abstract: Research in recent years has begun to relate noise issue on brake system with the effect of particles from the road surface. Researchers believe that dust, airborne particle, tire particle (tire dust), non-exhaust emission brake dust, road paint, diesel exhaust particles, road construction materials, or car catalyst materials has a potential relation of the squeal occurrence. This paper is trying to investigate the effect of external particles to the occurrence of squeal. The squeal experiment will be held using SAE J2521 standard operation procedure. Two types of non-asbestos organic (NAO) brake pad will be tested on a brake dynamometer test rig. Two different types of external particles, namely road grit particles and silica sand particles with a size between 100 to 400 μm will be used and fed into the disc brake end corner. Statistical analysis of brake squeal test data will be implemented to seek correlation between friction coefficient and sound pressure levels and between types and sizes of particles and sound pressure levels. Result found that most of the sample demonstrate a squeal occurrence by the absence of small particle during braking.

Key words: : *Brake squeal, Brake Pad, Road grit particle, Silica sand, and Statistical analysis*

INTRODUCTION

The comfort features of cars brakes hold an important place in customer requirements. This is true where whenever a new car is developed designers are faced with the challenging of creating brake system which produces as little noise as possible. One of the most critical issues is squealing disc brakes. Despite the research of brake squeal has been focused on experimental, numerical and analytical study, some researchers have look into the use of other analysis methods as define by Hoffmann and Gaul [1], Kukutschová et al. [2] and Mat Lazim et al. [3] proposed a non-conventional analysis technique, such as the incorporation of uncertainties by considering probability measurement, statistics and noise index. Sheriff [4] used basic statistical geometrical parameters of standard deviation and mean radius of asperities (harness) of sliding surface from squeal index formulation to measure the surface topography of squealing disc brake and to determine the mechanism of squealing triggering/varnishing. Nouby et al [5] on their experiment investigated the factor that influence brake disc squeal through a statistical technique to find the relationships between the negative damping ratio and the various factors of the disc brake using multiple variable regression analysis. They construct the relationship between the brake squeal and the brake pad through various geometrical configurations with the influences of Young's modulus, thickness, chamfer and distance between two slots, slot width and angle of the slot. They correlate the statistical analysis with a mathematical prediction model based on the most influencing factor using variance analysis (ANOVA) to verify the significance of the factors. From the result, they found that brake squeal tendency tends to reduce by increasing Young's modulus of the back plate and modifying the shape of friction material. Oberst and Lai [6], study the usefulness of descriptive statistics, and established technique to analyse brake squeal data and

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to evaluate the correlation between the time-averaged friction coefficient and the peak sound pressure level. The experimental results were evaluated base on: The noise index calculation and cumulative noise distribution. The noise index calculation is evaluated by summing up the weighted numbers occurrences with specific frequency and reflects the peak sound pressure level (SPL) of noise occurrences using a weighting factor. While for cumulative noise distribution is used to establish the acceptability of the brake system in term of squeal. The descriptive statistical to establish and explore the rarely use and usefulness of statistical analysis to analyze brake squeal data based on the SAE 2521 [7] standard. Two types statistical analyses were done namely basic statistical analysis and statistical correlation analysis. The results show the nonlinear character of brake squeal and indicate the potential of using nonlinear statistical analysis tools to analyze disc brake squeal. This experiment is aim to find a correlation between squeal parameter behavior with types and sizes of particles and sound pressure levels through statistical analysis of brake squeal test data.

EXPERIMENT

This investigation provides an informative statistical analysis of brake squeal test data to seek correlation between friction coefficient and sound pressure levels and between types and sizes of particles and sound pressure levels. The experimental test rig used is shown in Fig. 1. The brake dynamometer consists of three phase 11kW motor coupled with 6:1 cycle speed reducer. Three-phase Toshiba inverter is used to control the speed of the motor. Brake disc is connected directly with the motor through a coupling with 30mm diameter of output shaft. A small hopper is fitted at the middle shaft support to hold and disperse the external particles. Two external particles feeder tube is attached to the hopper and shield by a transparent cover to direct the particles to the gap between the brake pad and the disc at both piston side and finger side.

Figure 1: Brake squeal dynamometer test rig

Table 1: Test Rig Brake Dynamometer

Types	AC Motor Brake Dynamometer
Power Output (Max)	11 kW
Max Brake Line Pressure	20 bars
Maximum Torque	413 Nm
Data Recorded	16 Channel Dewetron FFT Analyzer Of Data Acquisition System (DAQ)

Table 1 represent drag type brake noise dynamometer used as an experimental test rig which applies variable load on the engine and measures the engine's ability to move or hold the rpm as related to the braking force applied. The dynamometer connected to a computer which records the applied braking torque and calculates the power output of the engine based on information from a load cell unit or strain gauge and speed from the tachometer. Sumitomo type drive motor was used to drive the brake system and main shaft from drive motor was connected to the adapter or flange which acts as a hub like in the real vehicle. The maximum power output for this AC motor is 11 kW. The power available from the motor matching with the power absorbed by the brake with a hydraulic pressure 20 bars where the maximum brake line pressure for squeal occurrence. The maximum torque is 413 Nm.

Squeal Test Procedure

Table 2 shows the configuration of the braking squeal tests. Squeal test procedure consists of two different tests which is the bedding in process procedure while the second procedure is a drag noise braking test. The drag tests consist of a constant angular speed with various applied pressure for the short braking test. Prior to the main braking testing, warming up (bedding-in) process is conducted. It is to deposit an even layer of friction material, or transfer layer, on the rubbing surface of the rotor disc. This process need to be done at low disc speed (6 rad/s) with a brake pressure of between 3-10 bar [8] for half an hour as describe in table 2.

Table 2. Parameter in bedding and squealing drag tests

Initial Condition	Bedding	Drag Test
Initial Speed	57.3 rpm (6 rad/s)	50 rpm (5.23 rad/s)
Initial Temperature	50 ^oC	50 ^oC
Number of Braking	Varied	Varied
Pressure	3 to 10 bar	1 to 10 bar
SLM	-	≥70 dBA
Humidity Range	20% to 90% RH	20% to 90% RH

Statistical analysis

Statistical analysis is use to study the probability and significant correlation of external grit particle effect of pad surface topography on squeal generation. Generally, brake squeal is uncertainty noises emerge at low sliding speed and breaking. Hence the analysis on statistical characteristics through the variations of friction surface topography, friction material composition and roughness parameter will answer a linear correlation between particle effects with brake squeal. In this work, the descriptive statistical is used to study the central tendency which include mean, median and mode and the variability of the data which include the variance (standard deviation), the normality (normal or lognormal distribution), the skewness and kurtosis, histogram and quartile plot.

RESULT AND DISCUSSION

Basic statistical analysis involves arithmetic mean which analysis the type of variables, determine the types of data and measure the central tendency of the data. Basic statistical analysis is also involved variance analysis which to measure the distribution of the data in terms of how close the data are to the middle of the distribution. The variance analysis for the test will use the dispersion parameter using empirical standard deviation.

Mean and Standard Deviation of Coefficient of Friction Result

The result of double bar chart of Figure 2 and 3 shows means value and standard deviation of coefficient of friction result of pad sample with and without particle effect. The red row represents sample of silica sand effect and the blue row represents road particle effect with different size 100-150, 150-200, and 300-400 µm.

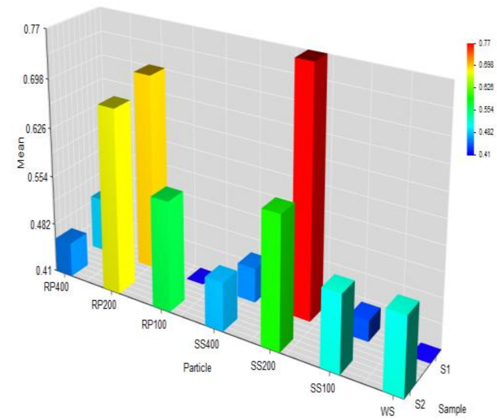

Figure 2 Mean value coefficient of friction for pad sample 1 (a) and sample 2 (b), without and with silica sand and road particle effect size of 100-150, 150-200 and 300-400 µm

The mean value of friction coefficient as presented in Figure 2 indicates that without particle effect is 0.4. During the presence of the external particle, the average mean value tends to increase with the increasing of particle size. For sample with a particle size range between 100 to 150 µm, 150-200 µm and 300 to 400 µm the mean value of silica sand effect with is 0.43, 0.76 and 0.46 while for road particle size the mean value is 0.41, 0.7 and 0.49. Prior with the result of mean value of COF the standard deviation on Figure 3 shows that an average value is close to the mean of the data set, on average. Figure 3 indicate that the SD value is 0.075 for pad sample 1 and 0.073 for pad sample 2 without particle effect and fall close to the mean for pad samples with particle size 100-150, 150-200 and 300-400 µm.

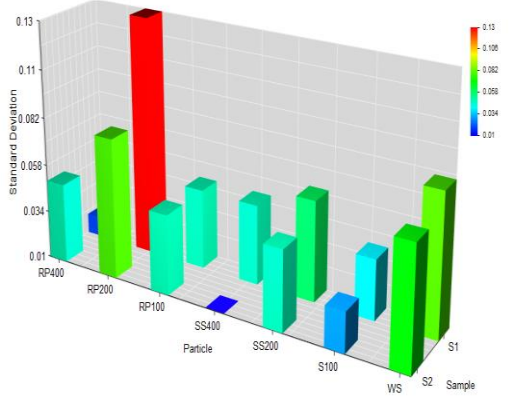

Figure 3 Standard deviation of coefficient of friction for pad samples 1 and sample 2 without particle effect, with silica sand and road particles effect size of 100-150, 150-200 and 300-400 µm

Hypothesis and Significant Test

In order to understand the relationship of measurement value between of two variables with and without particle effect of samples the hypothesis testing is required. Through hypothesis analysis, an assumption about a population parameter is analysis via significance test by developing the testing. This study will analyze the relationship between COF value of pad samples without particle effect and with particle effect (silica sand and road particle). The result will determine either to the existence of external particle will promote the squeal occurrence. Since the experimental data are in form of interval and ratio and the data are in normal distribution, statistical t-test is will be used for the hypothesis analysis of a significant level for the experiment or p = 0.05 (5%), Lilliefors (1967). Hypothesis testing for the analysis is;

(i) **Null hypothesis (Ho)**: P = 0.05, there is no relationship between COF value of pad samples without particle effect with COF value with silica sand and road particle effect.
(ii) **Alternative hypothesis (Ha):** P ≠ 0.5, there is a relationship between COF value of pad samples without particle effect with COF value with silica sand and road particle effect.

Table 3 represent the result of significant t-test analysis of all pad samples. The relationship between variables without and with particle effect is based on P value (Sig. 2-tailed). The statistical t-test of friction coefficient (CoF) exhibit a significant P value in almost sample test with less than 0.05 thus the null hypothesis (Ho) is rejected. Therefore, it is agreed that there is a relationship between the COF value of pad samples without particle effect with COF value with silica sand and road particle effect. However, two samples showing high P value higher than 0.05 as showed in table 3. The significant t-test table 3 for COF pad sample 1 and 2 silica sand particles size 100 to 150 µm and 300 to 400 µm with P value 0.40 and 0.62 hence the result fail to reject Ho at 95 % significant level. The rejection Ho at 95% significant level does not mean the COF data of some samples showing no relationship, high P value means the significant level occurred in lower percentage level as describe in Lilliefors [9].

Table 3: Significant T-Test for COF Data of Pad Sample 1 and 2

Paired Sample (COF)	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	95% Confidence Interval of the Difference				
			Lower	Upper			
WS1 - SS100S1	.010	.056	-.020	.040	.724	15	.480
WS1 - SS200S1	-.380	.112	-.409	-.351	-26.274	59	.000
WS1 - SS400S1	-.036	.055	-.054	-.018	-4.038	37	.000
WS1 - RP100S1	-.039	.074	-.054	-.024	-5.157	95	.000
WS1 - RP200S1	-.260	.148	-.321	-.199	-8.793	24	.000
WS1 - RP400S1	-.038	.052	-.068	-.008	-2.755	13	.016

CONCLUSION

The results of the squeal experimental testing and statistical qualitative analysis with the effect of external particles are summarized in table 3. It can be concluded that;

1. Most of the pad sample demonstrate an acceptable absolute noise causing by the absence of small particle during braking sliding process of pad and disc.
2. However, the level of friction coefficient (COF) reduce from 70 to 95 dBA without particles effect to 70 to 80 dBA with particle effect. This shown that small particle contributes to change the friction layer of friction surface and change the mechanical behavior of pad forming a new layer by the compaction of external particles embedded, agglomerates closing all hole, pores and wears area contribute in reducing the noise level during the squeal occurrence.
3. Although the squeal test and statistical qualitative analysis showing a good agreement on confirming the occurrence of noise with the cause of external particle disturbance during braking and sliding process further investigation is needed to explain the transformation friction surface during the presence of external particles.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknologi Malaysia and Ministry of Higher Education (MOHE) for providing research grant under GUP Tier 1 (Vot. 00H37) and GUP Tier 2 (Vot. 00J45).

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