Reduction of Drum Brake Squeal Noise Using Constrained Layer Damping (CLD)

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Abstract

Brake noise, particularly squeal is the most annoying and disturbing sound to the people. With a large number of motorcycles used in Malaysia, the level of squeal noise can be very high, especially during busy or heavy traffics due to high numbers of braking applications. Thus, this paper aims to reduce potential squeal noises generated by a rear drum brake assembly of motorcycles using constrained layer damping (CLD). A three dimensional finite element (FE) model of the drum brake assembly that consists of a drum and two brake shoes is developed and analysed. Complex eigenvalue analysis (CEA) is employed to determine stability of the drum brake assembly, where positive real parts of the eigenvalues indicate an unstable modes and its associated imaginary parts indicate an unstable (squeal) frequencies. In order to reduce squeal noise, four constrained layer damping (CLD) models have been proposed and assessed. The complex eigenvalue results show that the CLD2 and CLD4 models can fully eliminate unstable mode at a frequency of 6120 Hz, while in frequency of 2051Hz the positive real part has been reduced from +222 to +199 for CLD2 and +182 for CLD4. The CEA results indicate that proper CLD designs can be used to reduce drum brake squeal noise in the motorcycles.

Keywords. Drum brake, Motorcycle, Finite element, Complex eigenvalue, Squeal noise, Constrained layer damping (CLD)

1 Introduction

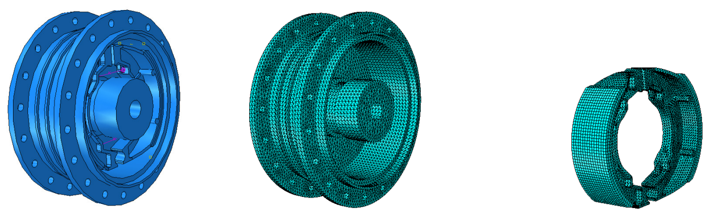
Brake squeal has been one of the major noise issues facing by many car makers as well as motorcycle manufacturers [1]. Brake squeal is the most annoying noise for the peoples and it usually generated at a frequency above 1 kHz and at a sound pressure level of 78 dBA and above [2]. Thus, it becomes a huge challenge for brake engineers to find a practical solution in reducing squeal noise. There are a number of techniques have been introduced in order to reduce brake squeal in passenger cars [3-7]. They are constrained layer damping (CLD) or brake insulator [3,4], structural modifications [5-6] and active noise control [7]. It is seen that the CLD or brake insulator is mostly preferred by many car makers and brake suppliers due to its capability to suppress squeal noises and cost effective compared to other squeal reduction techniques.

With a large number of motorcycles used in Malaysia, it can be expected that the level of squeal noise emanating from the brake units is high and very disturbing to the people. Thus, it is significant to reduce or even better to eliminate it in order to provide quiet and comfortable living and working areas. Brake insulators are typically made of a rubber material that sandwiched by steel plates. Singh et al. [3] discussed on the design, selection and implementation of a brake insulator to control disc brake squeal for passenger cars. Two insulator designs were examined, namely a multi-constraining layer and a single constraining layer. The test results showed that both insulators capable of reducing the squeal noise. Triches et al. [4] attempted to suppress a squeal generated at a frequency range between 1 kHz to 7 kHz using CLD. Several types of CLD were tested and the proposed CLDs effectively reduced the squeal level by 20 dBA.

Based on the success results obtained by the previous researchers [3,4] in reducing squeal noise in passenger cars using CLD, this paper is also adopting a similar approach in order to prevent squeal noise in motorcycles. Four CLD models are proposed and their effectiveness against squeal noise are evaluated using complex eigenvalue analysis.

2 Finite element model and stability analysis

A three dimensional model of the drum brake assembly that consists of a drum, two brake shoes and two retraction springs is shown in Figure 1, whilst all four proposed CLD models are given in Table 1. Figure 2 shows the locations of the CLD and retraction springs. A complete list of mechanical properties of brake components and CLD is given in Table 2.



(a) CAD model (b) FE model of the drum (c) FE model of the shoes

Figure 1. A 3D-drum brake model

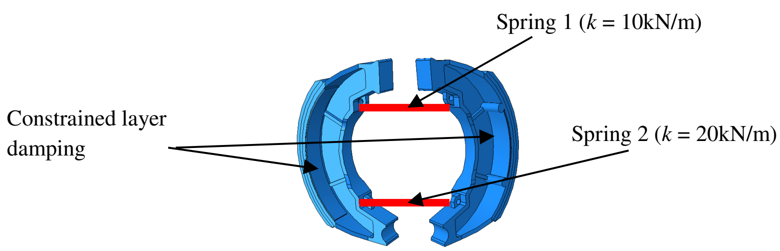


Figure 2. Location of the CLD and retraction springs

Table 1. Constrained layer damping (CLD) designs

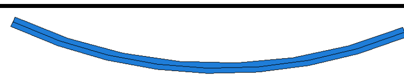
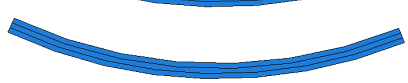
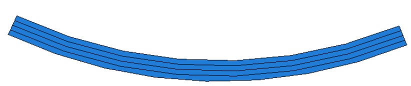
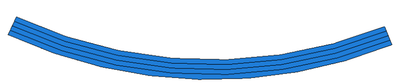
CLD Design	Model	Configuration: Top to bottom	Thickness (mm)
CLD1 2 layers		Rubber Steel	0.5 each layer
CLD2 3 layers		Steel Rubber Steel	0.5 each layer
CLD3 4 layers		Steel Rubber Rubber Steel	0.5 each layer
CLD4 4 layers		Rubber Steel Rubber Steel	0.5 each layer

Table 2. Mechanical properties of the drum brake components and CLD

Components	Young's Modulus (GPa)	Density (kg/m^3)	Poisson's ratio
Drum	69	2720	0.3
Shoe	69	2720	0.3
Friction material	8	2500	0.3
CLD thin steel layer	210	7850	0.3
CLD thin rubber	9.7	1000	0.48

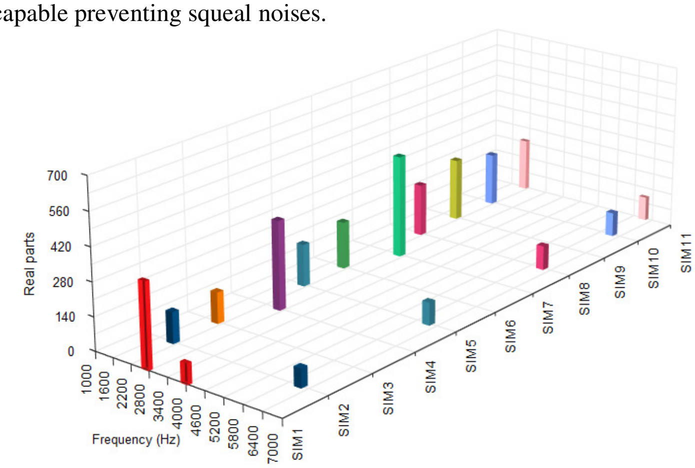
Stability of the drum brake assembly is determined using complex eigenvalue analysis, where the brake system is said to be unstable if the real part of the eigenvalues indicates a positive value. In this work, a total of eleven (11) simulations of the drum brake model without CLD model is performed at different operating conditions as tabulated in Table 3. Then, the drum brake model with CLD models at a certain operating condition is also examined (see Table 3).

Table 3. Operating conditions of brake squeal simulation

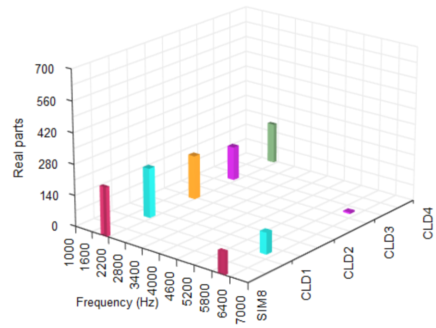
Simulation No	Speed (rad/s)	Actuation Distance (mm)	Friction coefficient
SIM1	9	2	0.3
SIM2	9	3	0.3
SIM3	9	4	0.3
SIM4	9	2	0.4
SIM5	9	3	0.4
SIM6	9	4	0.4
SIM7	9	2	0.5
SIM8	9	3	0.5
SIM9	9	4	0.5
SIM10	6	3	0.5
SIM11	4	2	0.5
CLD1	9	3	0.5
CLD2	9	3	0.5
CLD3	9	3	0.5
CLD4	9	3	0.5

3 Results and Discussion

Firstly, complex eigenvalue analysis that available in ABAQUS software is performed in the drum brake model without the CLD model. From the complex eigenvalue results as shown in Figure 3(a), it is found that SIM2, SIM5,SIM8, SIM10 and SIM11 produce two identical unstable frequencies of 2042Hz and 6140Hz.Meanwhile, SIM3,SIM4,SIM6,SIM7 and SIM9 are seen to generate one unstable frequency in the region of 2032Hz-2641Hz. In SIM1, there are two unstable frequencies predicted, i.e. at 2699Hz and 3981Hz. The operating conditions of SIM1, SIM4 and SIM7 are the same (speed = 9 rad/s and actuation distance = 2mm) except for the friction coefficient (μ = 0.3). It shows that with a lower friction coefficient of μ = 0.3, there is a tendency for the drum mode to be coupled with the shoes mode at 3981Hz. However, at μ = 0.4 and μ = 0.5 these modes are no longer close to each other. Another significant finding is that the drum rotating speed did not change the squeal noise generation and this can be seen in SIM8, SIM10 and SIM11. Secondly, complex eigenvalue analysis is performed for the drum brake model with the CLD models. In the analysis, similar operating conditions of SIM8 are used to assess effectiveness of the four CLD models. From Figure 3(b), it can be seen that CLD2 and CLD4 are effectively eliminating unstable frequency at 6130Hz and they are also capable of reducing real parts (frequency of 2051Hz) from +222 to +199 for CLD2 and +182 for CLD4. Unfortunately, CLD1 and CLD3 are not capable preventing squeal noises.



(a) Unstable frequencies at different operating conditions



(b) Unstable frequencies of the drum brake with and without CLD model

Figure 3. Complex eigenvalue results of the drum brake system

4 Conclusion

The aim of this paper is to assess the effectiveness of CLD designs against squeal noise. There are four CLD designs being proposed and then analysed using complex eigenvalue analysis. The results show that only the CLD2 and CLD4 models are capable to counter squeal noise, where one of the unstable frequencies, i.e. at 6130Hz is totally eliminated whilst another unstable frequency (2051Hz) has its real part reduced by 10% for CLD 2 model and 18% for CLD4 model.

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