Attenuation of Motorcycle Handle Vibration using Suspended Handlebar

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Abstract. Motorcycle rider is exposed to the handle vibration. Extended exposure to high level of handle vibration can result is hand-arm vibration syndrome (HAVs). In South East Asia the majority of the motorcycle are powered by single cylinder small displacement (70 – 125 cc) engines. This paper describes the modal analysis of a small single cylinder underbone type motorcycle widely used in the rural and urban for commuting to workplace. A suspended handlebar is developed by mounting the handlebar on rubber mounts. Transmissibility measurement are carried out for static and on the road condition. There are conditions where transmissibility is above unity due to resonance for the existing handlebar and this condition is overcome by the suspended handlebar except at frequency of 25 Hz. This was below the operating frequency range of the motorcycle engine of cruising speed (50 – 60 Hz). On the road tests show that the handlebar is effectively attenuate with the installation of the engine mounts. Maximum attenuation of 79 % is achieved at 3300 – 3400 rpm which give HAV of 3.41 m/s².

1. Introduction
Motorcycles are important type of transportation especially in rural areas and high traffic road. Motorcycle riders are easily exposed with high level of vibration transmitted from the motorcycle handlebar in certain cases can be greater than the limit value set by the European Directive (2002/44/EC). Methods must be found to reduce vibration if the vibration exposure is greater than the action limit value of 2.5 m/s². The Directive also requires that the vibration exposure to be less than 5.0 m/s². The International Standard ISO 5349 [1] & [2] suggests that a person who is exposed to vibration at the vibration exposure limit value and vibration action limit value will have a 10% chance of getting finger blanching after 5.8 years and 12 years of vibration exposure, respectively. In 1996 and 2016, the vibration on the motorcycle handle is reported in the range from 2.2 to 4.9 m/s² [3] and from 3.82 to 9.77 m/s² [4] at the lower range of frequency spectrum. The an anti-vibration gloves have been proven to be general ineffective especially in the lower weighted acceleration spectrum [5]. The prevalence of finger blanching is found to be at 4.2% among police traffic motorcyclists in Japan [3], indicating that the vibration transmitted to the hand poses a serious long term health risks. This includes the disorder of the vascular, muscle, neurological and bone and joint. Another aspect of motorcycle handle vibration is the discomfort to the rider. These are usually based on perceptions and many survey-based studies have confirmed the influence of vibration on the comfort of the rider. A study showed that over 50% of respondents (both female and male respondents) reported hand and arm discomfort whereas motorcycle operation will always be accompanied by vibration, which will make the rider and his passenger feel unpleasant[8] & [7]. A study based survey on has shown that musculoskeletal disorders are prevalent...
among the occupational motorcyclist and most of the vibration came from the handlebar and the foot rest [8], [9].

The study presented here is to reduce the vibration transmission from the motorcycle to the rider hands by installing a suspended handlebar. The approach is to carry out pre-evaluation using the laboratory transmissibility test. To characterize and study the effect of varying stiffness and damping values of the suspended handlebar, structural dynamic modification (SDM) is used to determine the maximum transmissibility attenuation with the stiffness and damping values of the rubber mounts.

2. Methodology

In this analysis a single cylinder four stroke engine with 70 cc engine displacement is used. The dynamic characteristics of the handlebar is important and can be obtained from the experimental modal analysis (He and Fu 2001). The dimensions of the motorcycle handlebar are measured and modelled in the LMS Test Lab using the geometry workbench. Figure 1(a) shows measurement nodes located on the motorcycle stock and suspended handlebars labelled with stickers. Modal analysis was carried for the motorcycle handlebar mounted on the motorcycle structure. A small light weight accelerometer (Dytran 3055B2T) was used to measure the vibration response while an impact hammer (Krisler 9724A5000) excite the motorcycle handlebar. Both are connected to the 8-channel LMS SCADAS mobile. The accelerometers are calibrated using the calibration exciter type 4294 Brüel & Kjær.

Transmissibility measurement of both stock and suspended handlebar is carried out to quantify the attenuation level. Two accelerometers located at the input and output nodes measure the respective acceleration. The first accelerometer is placed on the motorcycle chassis and the second accelerometer is placed on the handlebar adjacent to the throttle unit.

Figure 1(a) and 1(b) shows the experimental setup for the in laboratory and on the road vibration analysis. The measurement instruments include two accelerometers (Dytran 3055B2T) for the z and y axis on the rider right hand, a tachometer (OPTEL-THEVON 152 G7 5V GPK XSI), calibrator (B&K 4294), data acquisition software (LMS Test Express), data acquisition hardware (LMS Scadas Mobile) and a portable work station. The measurement is carried out on straight-flat asphalt road surface with a period of 20 seconds data acquisition time. Accelerometers are located on the rider right hand to measure the hand vibration. The tachometer is mounted on the engine chassis of the motorcycle to measure the speed of the engine. The sensors are connected to the LMS Scadas Mobile running on LMS Test Express and a portable computer for the data acquisition system.

The modal model of the suspended handlebar used in the structural dynamic modification (SDM) within the LMS Test Lab software is used for the evaluation of the effect of stiffness and damping values of the rubber mounts on the dynamic characteristic of the suspended handlebar. Figure 1 (a), shows four rubber mounts installed on the suspend the handlebar. The existing value of the stiffness and damping in the z-axis are $600 \text{kN} \text{m}^{-1}$ and $6 \text{kg} \text{s}^{-1}$ and for the y-axis are $150 \text{kN} \text{m}^{-1}$ and $6 \text{kg} \text{s}^{-1}$ respectively. The optimization search covers the 0% - 300% of existing stiffness and damping values with the minimization of FRF area performance index (V.E.T. Index).
3. Results and discussions
3.1. Modal analysis
3.1.1. Modal analysis of stock handlebar
Figure 2 shows the stock handlebar FRF stabilization curve in the y and z axis. The first five modes extracted below 200 Hz are at 31.92 Hz, 35.60 Hz, 45.12 Hz, 72.17 Hz and 152.62 Hz for the y-axis and four modes at 46.05 Hz, 56.11 Hz, 64.54 Hz and 156.70 Hz for the z-axis.

3.1.2. Modal analysis of suspended handlebar
Based on figure 3, for the z-axis, the six modes extracted from the FRF curve on the z-axis at 27.00 Hz, 38.90 Hz, 51.02 Hz, 69.13 Hz, 95.11 Hz and 121.60 Hz. All of the modes extracted is selected to form the modal model of the respective axes for the SDM.
3.2. Transmissibility measurement

Figure 4 shows the acceleration transmissibility ratio of the stock and suspended handlebar for the z-axis at the frequency range from 0 - 200 Hz. Based on figure 4, the z-axis transmissibility of the stock handlebar is in general higher than the suspended handlebar except at frequency of 25 Hz and 70 Hz. The highest transmissibility of the stock handlebar is 4.0 at 4 Hz while the suspended handlebar is 3.8 at 25 Hz. Both of the axes show an acceleration transmissibility reduction that dependent on the frequencies which most of the reductions are on the motorcycle typical cruising frequency range of 50 – 58 Hz or at the engine speed of 3000 – 3500 rpm. From this estimation, the suspended handlebar will reduce the vibration response induced on the rider during operating conditions.

3.3. Hand-arm vibration

Based on the biodynamic axes of hand model, the measurement on the accelerometers mounted on the rider hand are used. For the z-axis response in figure 5 (a), the stock handlebar vibration displays two cluster of peaks, for the lower speed range of 1500 – 2750 rpm the clustering frequencies is at 46.05 Hz which coincide with the first mode of the z-axis. At the speed range of 3000 – 4000 rpm, the peaks clustered at the frequency of 64.54 Hz which coincide with the third mode of the z-axis. This speed independent constant frequency response indicate that the vibration is resonance-related. While during interchanging of clustering peaks, during the speed of 2750 – 3000 rpm the peaks are significantly clustered at the second mode frequency of about 56.11 Hz. The speed dependent and frequency dependent nature of the peaks can be attribute to the engine unbalance vibration. It is clear, that the stock handlebar suffered from the large amplitude vibration of the natural frequencies. For the suspended handlebar response on the z-axis in figure 5 (b), the installation of suspended handle altered the dynamic characteristic of the handlebar. The peaks clustered around the 46.05 Hz, 56.11 Hz and 64.54 Hz frequencies. With the introduction of the rubber mounts in the suspended handlebar the peaks pattern from the speed range of 1500 – 4000 rpm still exist. However, the peaks are effectively reduced in vibration amplitude for the suspended handlebar case especially in the speed range 3000 – 3750 rpm.
which are significantly important as it covers the cruising speed of the motorcycle at the speed of 50 – 60 kmh\(^{-1}\). The data for the on the road test, verifies the effectiveness of the suspended handlebar in reducing hand arm vibration.

In order to see it more clearly, the difference in response of the stock and suspended handlebar at a single typical engine cruising speed is selected. Figure 6 shows the weighted FRF acceleration of the z-axis for the cruising engine speed of 3000 rpm at 60 kmh\(^{-1}\). The peak weighted acceleration of the stock handlebar is 1.33 m\(s^{-2}\) at 56.25 Hz and after the installation of suspended handlebar, the highest peak is 0.52 m\(s^{-2}\) at 52.50 Hz indicating a reduction of 61 %. For, the FRF area performance index is 25.54 m\(kgms^{-3}\) for the stock handle and 13.05 m\(kgms^{-3}\) for the suspended handle gives a vibration reduction of 49 %. It is shown that the y-axis is more prone to road-tire vibration compare to z-axis as the y-axis exhibit a higher or equal magnitude of vibration acceleration on the lower frequency spectrum compared to higher frequency spectrum.

![Figure 5.](image5.png)

(a) z-axis with stock handlebar  
(b) z-axis with suspended handlebar

**Figure 5.** Hand acceleration spectra waterfall graph (on the road z-axis)

![Figure 6.](image6.png)

**Figure 6.** Weighted FRF rms acceleration graph of the hand at engine speed of 3000 rpm. (z-axis)

Figure 7 shows the more detail hand-arm vibration values\( \delta_{H\&A} \) for the stock and suspended handlebar and its reduction percentage at engine cruising speed range of 3000 – 3500 rpm (60-75 kmh\(^{-1}\)). It is shown that the vibration values of the stock handlebar are higher than suspended handlebar within the speed range. The peak vibration value of the stock handlebar is 16.51 m\(s^{-2}\) at 3375 rpm and the suspended handlebar vibration values of 3.41 m\(s^{-2}\) with the reduction of 79 %. Based on the hand-arm vibration exposure, the existing stock handlebar has a limit of 11 and 44 minutes of exposure before reaching an exposure action value (EAV) and exposure limit value (ELV) respectively. While the
suspended handlebar has a 258 minutes and 1032 minutes of exposure period before exceeding the (EAV) and (ELV) respectively. The installation of suspended handlebar has reduced the hand-arm vibration exposure point per hour from 545 to 23 and dramatically increase the time required to reach the exposure limits (EAV) and (ELV) by 20 times.

![Figure 7. Hand-arm vibration acceleration values and percentage of reduction against cruising engine speed.](image)

3.4. Optimization of rubber mount properties

Referring to figure 3, from the modal analysis of the suspended handlebar, the validated modal model of both axes are used in the structural dynamic modification. Figure 8 shows the suspended handlebar optimized value of rms V.E.T. Index under a structural dynamic modification of rubber mount stiffness and damping properties. The baseline rms V.E.T. index calculated is $5.782 \text{ kgms}^{-3}$ at the total calculated stiffness and damping values at $150.0 \text{ kNm}^{-1}$ and $6.0 \text{ kgs}^{-1}$ in the y-axis and $600.0 \text{ kNm}^{-1}$ and $6.0 \text{ kgs}^{-1}$ in the z-axis. With the optimization of rms V.E.T. Index toward the lowest index value, the measured index is $0.164 \text{ kgms}^{-3}$ at the addition of stiffness and damping from baseline value of 300 % and 90% respectively. The total calculated stiffness and damping values of the optimized V.E.T. index is at $472.5 \text{ kNm}^{-1}$ and $11.4 \text{ kgs}^{-1}$ in the y-axis and $2400.0 \text{ kNm}^{-1}$ and $18.0 \text{ kgs}^{-1}$ in the z-axis.

![Figure 8. Optimization of suspended handlebar](image)
4. Conclusion
A suspended handle adaptor has been developed to attenuate the motorcycle handlebar vibration transmitted to the rider. The highest attenuation of the hand-arm weighted RMS acceleration is 79% based on the on-road test which gives a longer vibration exposure time by 20 times. Based on the optimization of rubber mount properties of the suspended handlebar in SDM, the lowest V.E.T. index calculated is 0.164 $k g m^{-1}$ from the baseline index of 5.782 $k g m^{-1}$. The total calculated stiffness and damping value is at 472.5 $k N m^{-1}$ and 11.4 $k g s^{-1}$ in the y-axis and 2400.0 $k N m^{-1}$ and 18.0 $k g s^{-1}$ in the z-axis.

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