RESEARCH ARTICLE

REVISED Whole body vibration and rider comfort determination of an electric two-wheeler test rig [version 5; peer review: 2 approved, 2 approved with reservations]

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Abstract

Background

Two-wheeled vehicles are the major mode of transportation in India. Such vehicles are exposed to excessive vibration on the road when compared to four-wheeled vehicles. However, the research on the reduction of whole body vibration in the case of two-wheelers is not explored in detail. The present study predicts rider comfort in the case of an electric two-wheeler as per ISO 2631-1, by obtaining the finding the weighted acceleration at the strategic locations of vibration at the test rig.

Methods

An electric two-wheeler test rig is used in the study. The values of acceleration from the test rig in running conditions are obtained by using NI LabVIEW 2019. The drive cycle of the electric vehicle (EV) test rig is controlled by Sync sols' EV lab software. Obtaining the weighted root mean square (RMS) acceleration from running the test setup, it is compared with the ISO 2631-1 standard to obtain the rider comfort.

Results

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Loading area, traction motor, base mount, and suspension were found to be the strategic points of vibration. Frequency weighted RMS acceleration of 0.3 to 0.4 m/s^2 obtained at these points are prone to cause discomfort for the rider. Vehicle speed, road profile, and duration of exposure were found to be important parameters affecting the rider's comfort. A maximum of 4.6 m/s^2 amplitude was observed. The loading area, which corresponds to a rider's seat in actual vehicle, is important and reduction of these vibrations make the ride comfortable for the rider. Suspension and base mount of the test rig are found to be uncomfortable observing the weighted RMS acceleration.

Conclusions

A suitable damping technique design is very much essential in reducing these vibrations and improve the rider comfort, as many more non-deterministic vibrations are prone to cause dis-comfort in case of actual on road riding conditions.

Keywords
Electric Two-wheeler, Rider comfort, Whole-body vibration, RMS Acceleration, Road profile

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REVISED **Amendments from Version 4**

In this version we have modified Figure 2 and equations as per the suggestions by the reviewer.

In the figure and equations, the symbols are made consistent in relation to unsprung and sprung masses in the model.

Any further responses from the reviewers can be found at the end of the article

Introduction

In India, the major mode of transportation is two-wheeled vehicles.[1] About 15 million two-wheeled vehicles were sold in India over the last 10 years on yearly basis.[2] Professionals like the food and goods delivery partners, low-wage employees, and post-delivery persons mainly use two-wheelers for their daily transportation.[3] Two-wheeled vehicles, owing to limited size and mass are prone to vibration when compared to four-wheeled vehicles.[4] Whole-body vibration (WBV) mainly affects these people who are in continuous exposure to noise and vibration throughout the day.[5,6] Truck drivers, drill operators, heavy machinery workers, and forklift drivers are the victims of these vibrations.[7] High risks of lower back pain, motion sickness, and digestive system problems have been reported due to WBV when exposed for a longer period.[8,9]

The whole body vibration of the vehicle is dangerous not only to the rider but also to the vehicle as well.[10] In a vehicle exposed to different terrain conditions, the driving scenario is subjected to vibration, and these are transmitted to the human body through the seat, handlebar, and footrest in the case of two-wheelers.[11] These vibrations transferred to the human body cause different health issues in long run.[12,13] Some researchers are working on reducing these vibrations to effectively increase rider comfort.[14–17]

A vehicle's comfort is influenced by many factors such as the seat design,[18] driving posture[19] and environmental factors,[20] road condition, and suspension system to name a few. In a two-wheeler, the rider's comfort plays a very important role, as the rider has continuous exposure to these influencing factors. Both the static and dynamic condition of the vehicle are important in predicting the rider's comfort.[21] Different kinds of shock absorbers,[22] and damping techniques[23] play a vital role in improving the rider's comfort. Two-wheelers especially in the Indian scenario are very much subjected to vibration due to the condition of roads even in the cities.[24] The comfort level is greatly influenced by potholes, humps, cracks, and riding speed, and some study work has assisted in recognizing the potholes for safe driving.[25]

The measurement of whole-body vibration in terms of human health and comfort, perception probabilities, and motion sickness occurrence is studied with the help of ISO 2631-1 standard.[26] It provides guidance on measurement techniques for periodic, random, and transient whole-body vibrations.[27] By getting the Frequency Response Function (FRF) at critical vibrational points, variable acceleration values at multiple spots were identified. The rider's comfort depends on these values of acceleration. The higher the value of acceleration lowers the rider's comfort. ISO 2631-1 standard provides different levels of comfort faced by riders depending on the acceleration values. Table 1 gives the detailed classification of the rider's comfort level as per ISO 2631-1.

The present study involves finding the strategic locations of vibration and evaluation of rider comfort on an electric two-wheeler (E2W) test rig. Different points at the test rig are evaluated for their acceleration values in different running conditions. The points (locations on the body of test rig) at which the amplitude of vibration is higher than other locations are considered strategic points of vibration. The vibration at the strategic points is high enough to cause discomfort to the

Table 1. Comfort level criteria.[26]

Acceleration (m/s^2)	Category
Less than 0.315	Not uncomfortable
0.315-0.63	A little uncomfortable
0.5-1	Fairly uncomfortable
0.8-1.6	Uncomfortable
1.25-2.5	Very uncomfortable
Greater than 2.5	Extremely uncomfortable

rider. The impact hammer test[28] is conducted using the PCB (Pico Coulomb) Piezotronics made impact hammer of sensitivity 10.1 mV/g and data acquisition by using NI LabVIEW.

Methods

Development of state space model

The electric two-wheeler test rig is modeled as a state space model for finding the state space equations as shown in equation 1 and 2. Performing the impact hammer test on the setup, the natural frequencies are obtained. The details of the work carried out are discussed in this section.

Test setup

The test setup is an electric vehicle two-wheeler test rig, which uses a 1.5 kW, brushless direct current (BLDC) traction motor powered by a 25AH $LiFePO_4$ battery. Figure 1 shows the photograph of different parts of the Electric two-wheeler (E2W) test rig (components sourced from Artis Technologies) and Table 2 gives the nomenclature.

Using the laboratory's setup, the E2W test rig is modeled as state space model.[29] However, to build a similar model, two considerations were made, which are briefly discussed here. The first thing to consider is the cylindrical steel roller of approximately 40 mm diameter and 200 mm in length beneath the test rig's wheel is used to simulate a real-life road surface. The roller used is a hard plastic material in this case, however, unlike the road and wheel, the roller causes a small vertical displacement to the wheel. As a consequence, the vertical displacement of the roller concerning the vertical displacement of sprung and un-sprung masses is estimated to be near zero or zero.[28,30] The second subject of consideration concerns the sprung and un-sprung masses. Sprung mass is the percentage of the vehicle's overall mass that is supported by the suspension. Un-sprung mass refers to the mass of the suspension, wheels, and other components that are directly connected to them. This implies that a vehicle's sprung mass is typically the vehicle's kerb weight, the weight of the driver, and in certain cases, the weight of the engine.[31] A state space model of the E2W test rig is shown in Figure 2.[32] The model nomenclature is indicated in Table 3. The acceleration values are measured by the PCB Piezotronics made accelerometers of 101.1 mV/g sensitivity and data acquisition is carried out through National Instrument's LabVIEW software. (MyOpenLab is an open source alternative that can carry out a similar function). Three trials were conducted and the average values are considered for analysis.

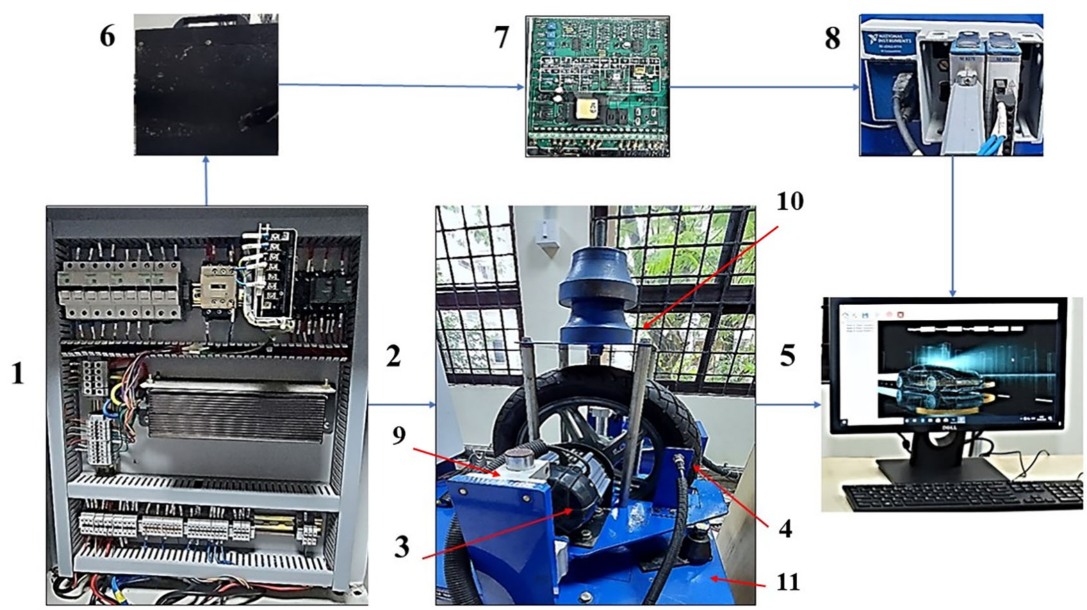

Figure 1. Electric two-wheeler test rig.

Table 2. **E2W test rig nomenclature.**

Number	Part name
1	Electric panel
2	Wheel and the loading area
3	Traction motor
4	RPM sensor
5	Desktop with Sync sols EV lab Software
6	25 Ah Battery
7	Battery Modulator
8	NI Data Acquisition system
9	Suspension
10	Loading area
11	Base mount

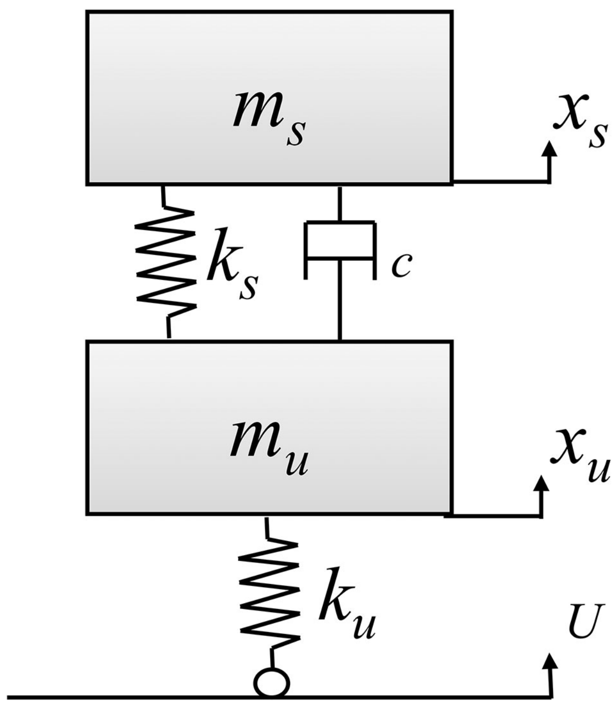

Figure 2. **Model of the E2W test rig.**

Table 3. **Test rig model nomenclature.**

Variables	Description
m_u	Un-sprung mass (tyre mass) – (kg)
m_s	Sprung mass (Mass of test rig - Tyre mass) – (kg)
x_u	Vertical displacement of m_u – (m)
x_s	Vertical displacement of m_s – (m)
k_u	Tyre stiffness – (N/m)
k_s	Spring stiffness of vehicle suspension – (N/m)
c	Damping coefficient of the vehicle suspension – (Ns/m)
U	Vertical displacement of the roller – (m)

The governing equations of the state space model derived are as indicated below in equations 1, 2 and 3, 4 respectively:

$$m_s\ddot{x}_s + c\,(\dot{x}_s - \dot{x}_u) + k_s\,(X_s - X_u) = 0 \tag{1}$$

$$M_u\ddot{x}_u + c\,(\dot{x}_u - \dot{x}_s) + k_s\,(X_u - X_s) + k_u(x_u - U) = 0 \tag{2}$$

$$X_s(s)\,\left[M_sS^2 + CS + K_s\right] = X_u(s)\,[CS + K_u] \tag{3}$$

$$X_u(s)\,\left[M_uS^2 + CS + K_s + K_u\right] = X_s(s)\,[CS + K_s] + X(s)\,[K_u] \tag{4}$$

Figure 2 shows the state space model of the E2W test rig and the corresponding notations as indicated in the figure. Here, the governing system equation of the test rig (1 & 2) are derived to get the Laplace equations (3 & 4).

Figure 3 shows the magnitude vs frequency plots of the impact hammer test conducted on the E2W test rig. The plot obtained from the NI LabVIEW, 2019[33] shows the natural frequency of the test rig as obtained at two strategic points on the test rig as shown in Figure 3. The peaks in the graphs indicated the natural frequency of the rig. The average of the natural frequency obtained is shown in Table 4.

Obtaining acceleration using LabVIEW

National Instruments' LabVIEW 2019 (64-bit) software is used to extract the acceleration values through accelerometers along with conversion of raw acceleration values into RMS acceleration. Some open software like 'MyOpenLab' or PyLab_Works can be used for data acquisition as well. Fast Fourier transform (FFT)[34] is used to obtain the root mean square (RMS) acceleration values at the strategic locations. Using LabVIEW, the RMS acceleration is obtained using spectral analysis provided in the software. The frequency response functions (FRF) are obtained from the software. The values are then converted to frequency weighted RMS acceleration as per ISO 2631-1 standard. The acceleration in z-axis is considered and 'wk' weighting factor is considered.

The test setup is tested under different loading conditions such as kerb load, 5 kg load, and 10 kg load. This type of loading makes a machine or a material get stiffer as the load increases.[35] PCB Piezotronics made accelerometers are mounted at four strategic locations of vibration as indicated in Figure 1; the loading area, traction motor, suspension and the base mount of the rig. RMS acceleration, at these strategic locations, is recorded using LabVIEW programming. These values are then sorted using MS Excel to find the peak values at each interval and graphs are plotted to show the RMS acceleration vs frequency characteristics as shown in Figure 5.

No load condition of the electric two-wheeler test rig is conducted without adding any payload. This condition reveals the strategic location of the test rig and allows identifying the major vibration amplitude regions. Adding payload of 5 kg and 10 kg the mechanical vibration characteristics of the test rig changes showing different vibration patterns. This pattern of vibrations is studied in order to obtain the dangerous frequencies and amplitudes. Strategic locations especially the loading area, corresponds to rider's seat in an actual two-wheeler and hence ISO 2631-1 standard is compared in this study.

Drive cycle

The drive cycle used for the study is shown in Figure 4. Different scenarios like idling, acceleration, steady speed, and deceleration are shown in the graph. The drive cycle runs each of these scenarios for a particular time duration. The cycle begins with a preparation speed-up period of 5 seconds, followed by 20 seconds of idling, 18 seconds of acceleration, and 2 seconds of steady speed. The cycle then decelerates for the next 11 seconds, a combination of acceleration and steady speed for the next 7 seconds, decelerates for the next 30 seconds, idles for the next 11 seconds, and ends with 3 seconds of halting. The values of acceleration are recorded at the strategic locations during this cycle.

Results and discussion

In this study, major strategic locations of vibrations in an electric two-wheeler test rig are found. The vibration response from the strategic locations indicates the rider's comfort through weighted RMS acceleration values. As compared to ISO 2631-1, the results obtained are discussed in detail in this section.

Observing, the weighted acceleration at the loading area as well as suspension as shown in Figures 5, 6 and 7 it is noted that, the acceleration response at the loading area is near to the uncomfortable acceleration as guided by ISO 2631-1

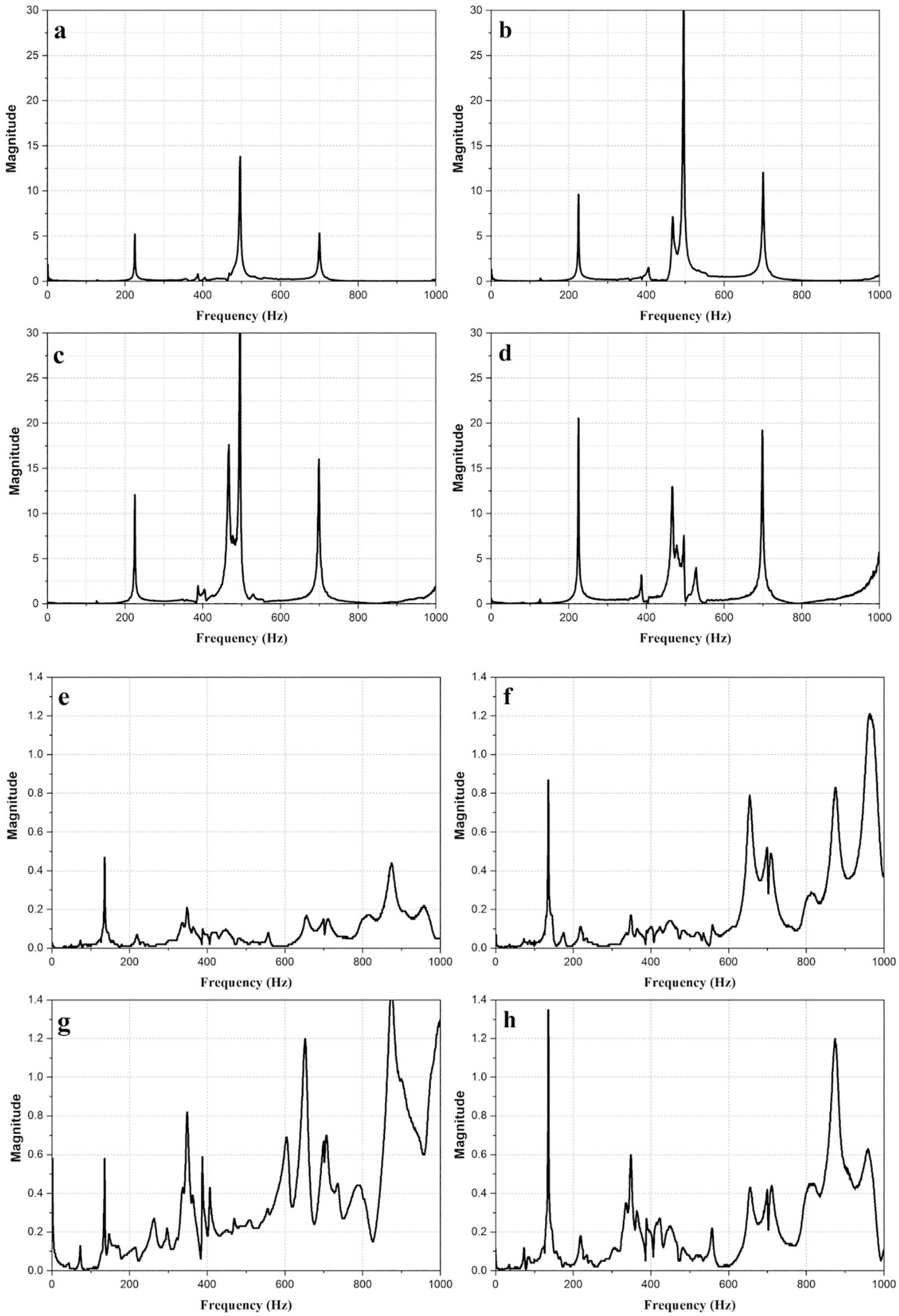

Figure 3. **Impact hammer test on E2W test rig (a,b,c,d - Loading area- left back, right back, left front, right front), (e,f,g,h – Base mount – left back, right back, left front, right front).**

Table 4. **Average of natural frequencies.**

Frequency (Hz)	Magnitude (g)
180.225	6.338
575.36	11.37
786.942	7.03

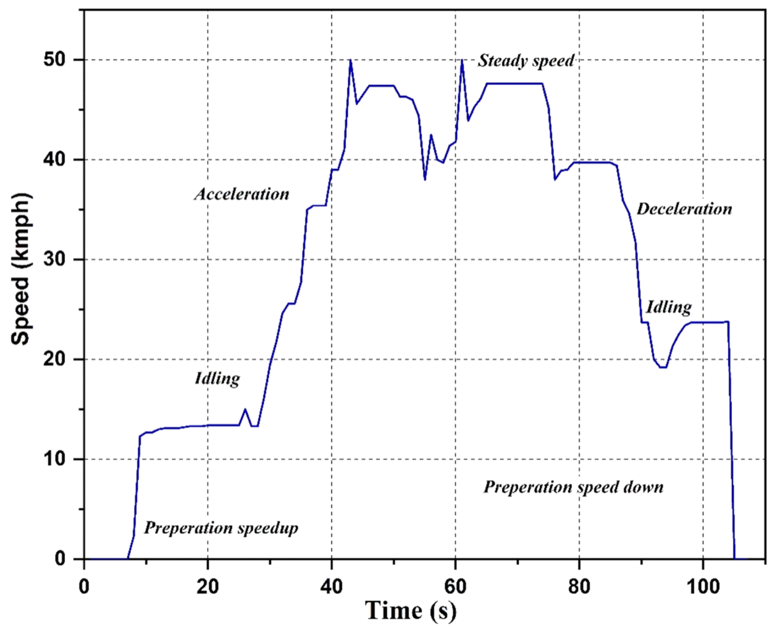

Figure 4. **Drive Cycle.**

standard as shown in Table 1. Upon loading of 5 kg the vibration amplitudes increased by about 5.8% and 2.2% at loading area and suspension respectively. This increase is observed due to the change in loading condition and stiffness as shown in the state space model. However, upon loading 10 kg the response measured indicates slightly lesser vibration characteristics showing about 4.3% and 3% at loading area and suspension respectively.

At the traction motor as well as base mount of the test rig it can be observed from Figures 5, 6 and 7 that, the vibration decreased upon increasing the load from no load to 5 kg and further to 10 kg. About 7.27% and 8.91% of weighted acceleration was decreased by the addition of 5 kg and about 11.1% and 18.93% decrement in weighted acceleration is observed when 10 kg loading is added to the system at traction motor and base mount of the rig respectively. This clearly signifies the mass damping phenomenon in the system when the loads are added.

With reference to Table 1, Figure 8 shows the weighted acceleration (calculated fom the Tom Irvine ISO 2631-1 MATLAB model) comparison at different strategic locations of vibrations in the electric two-wheeler test rig. Observing the rms acceleration at the loading area it shows ~0.29 m/s^2 of maximum RMS acceleration. This shows that this location is very close to the uncomfortable region with reference to ISO 2631-1 standard. However, at the traction motor, suspension, and base mount, the rms acceleration values indicate them to be under uncomfortable region. Here uncomfortable region indicates that, these vibrations are prone to cause dis-comfort for the rider when an actual two-wheeler is considered. Hence, these vibrations need to be addressed with proper damping systems to enhance the rider's comfort.

Another important criterion to be considered to evaluate the rider's comfort are the excitation frequencies. ISO 2631-1 standard focusses on the frequencies from 0.5 Hz to 80 Hz in evaluating the WBV and human comfort. In this regard, Figure 9 shows the excitation frequencies in the E2W test rig. These frequencies observed are well under the ISO criterion and it is observed to affect the rider's comfort. From the Figure 9 it can be seen that, Loading area which corresponds to the

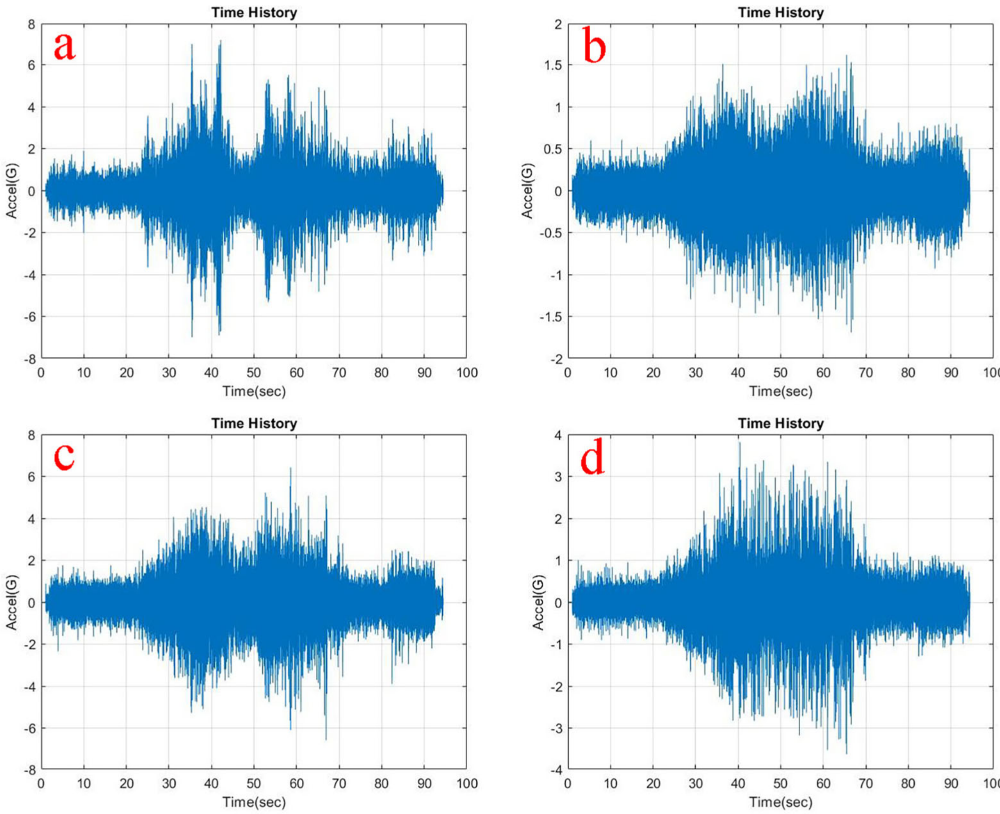

Figure 5. RMS Acceleration at the strategic locations (a) loading area, b) traction motor, c) suspension, d) base mount) at no load condition.

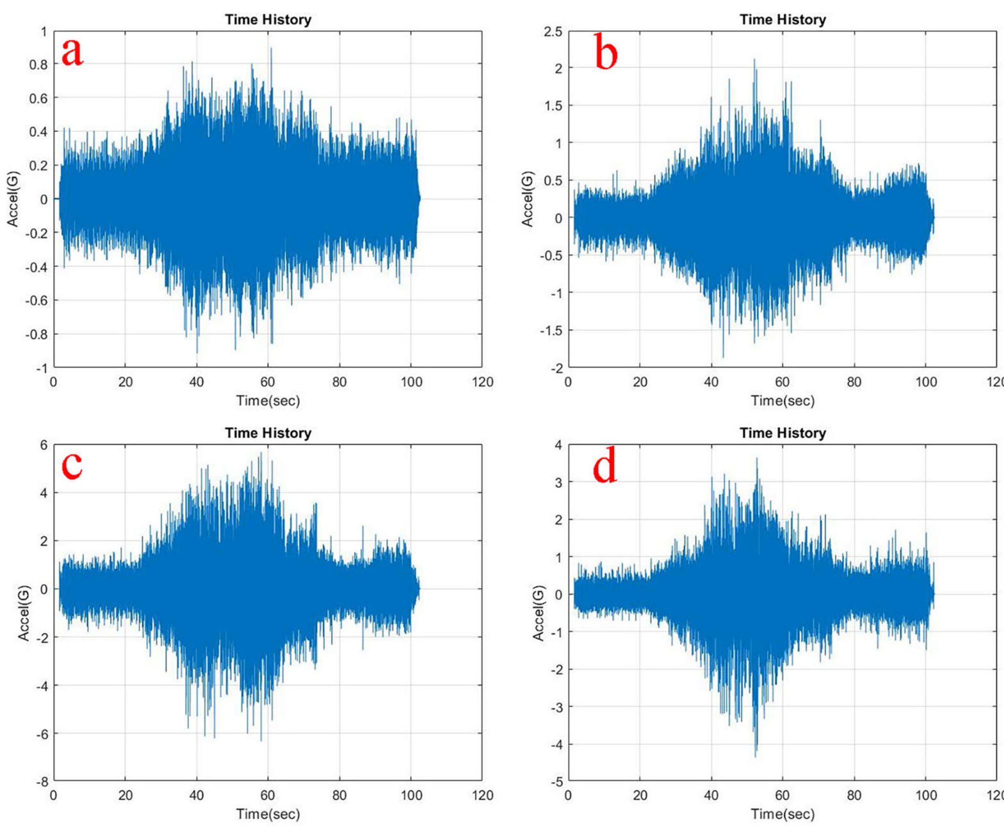

Figure 6. RMS accelerations at the strategic locations (a) loading area, b) traction motor, c) suspension, d) base mount) at 5 kg loading.

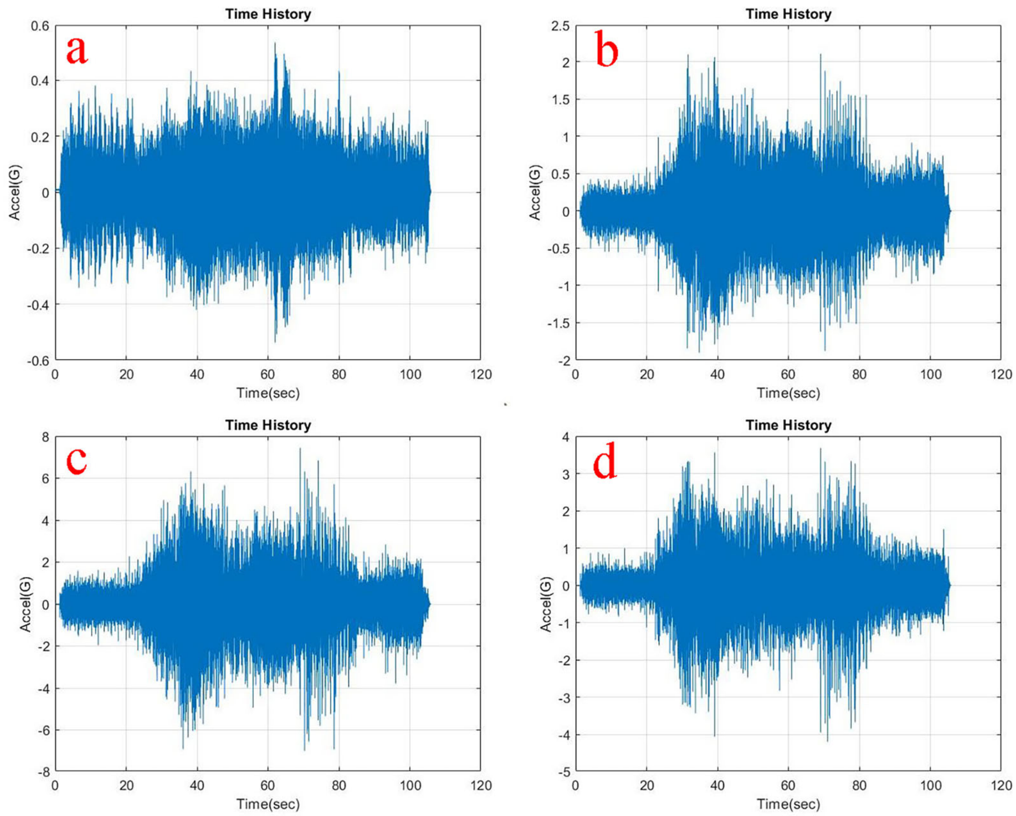

Figure 7. RMS accelerations at the strategic locations (a) loading area, b) traction motor, c) suspension, d) base mount) at 10 kg loading.

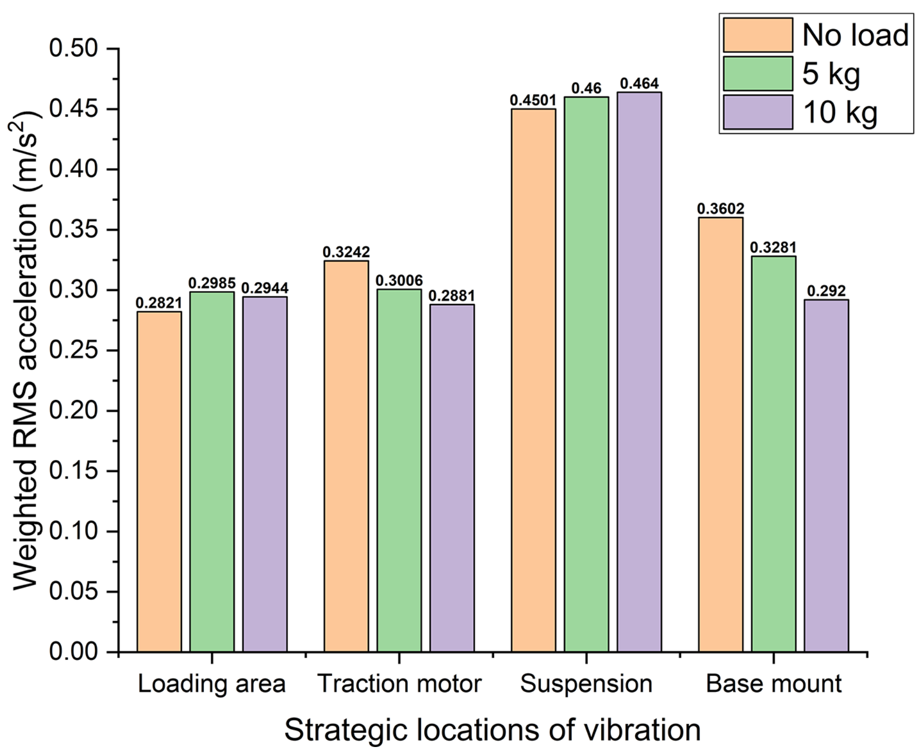

Figure 8. Comparison of weighted acceleration at strategic locations of the test rig.

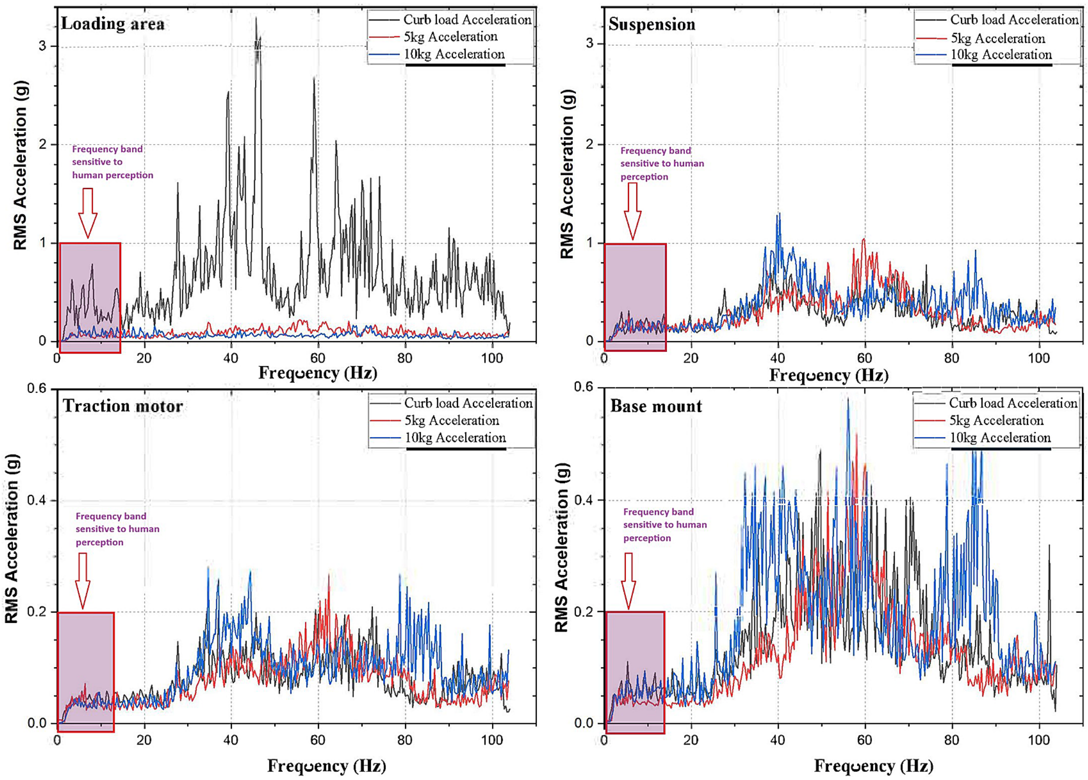

Figure 9. Exciting frequencies at the strategic locations.

seat of the actual vehicle has several exciting frequencies within the range of 0.5 Hz to 80 Hz and these are prone to cause dis-comfort for the rider.

Conclusions

A detailed experimental analysis of finding the strategic locations of vibration is discussed in this paper. The acceleration values play an important role in deciding the rider's comfort. Electric two-wheeler, even though a cost-effective mode of transportation, require further research in improving rider comfort. Observing the different strategic locations of vibration at the test rig the following conclusions are drawn from this study.

Observing different strategic locations i.e., loading area, traction motor, suspension, and base mount of the test rig, the vibrations generated at these key points affect the rider's comfort. Comparing the weighted acceleration values with the ISO 2631-1 standard, the vibrations generated are found to be at uncomfortable region at the key locations of the test rig. The addition of weights to the system showed a decrement in vibration levels which is due to the phenomenon of mass damping. Further, exciting frequencies at the test rig shows several frequency components that affect the rider's comfort. Hence, a suitable damping treatment is always essential to reduce these affects on the human body.

However, as the speed increases, the vibration intensity increased as well. This is due to the wheels running on the roller support, which simulates an actual road scenario. Hence, it can be concluded that in the actual driving scenario of a two-wheeler the vibration increases as the speed of the vehicle is increased. Further, the condition of the road is again an influencing factor, which increases the vibration intensity.

Overall study indicates that the electric two-wheeler is subjected to vibrations is an important area to be considered for further research work and this can be reduced by using suitable damping techniques at the strategic locations of vibrations.

Data availability

Figshare: data for paper submitted to f1000 research. https://doi.org/10.6084/m9.figshare.22092101.v1.[36]

This project contains the following underlying data:

- 5kg raw data fig 4.xlsx (RMS acceleration for 5kg loading)
- 10kg raw data fig 4.xlsx (RMS acceleration for 10kg loading)
- Down left back fig 3e.xlsx (Impact hammer test data at base mount at back side left)
- Down left front fig 3g.xlsx (Impact hammer test data at base mount at front side left).
- Down right back fig 3f.xlsx (Impact hammer test data at base mount at back side right).
- Down right front fig 3g.xlsx (Impact hammer test data at base mount at front side right).
- No load raw data fig 4.xlsx (RMS acceleration for No load condition).
- Raw Data for fig 5.lvm (RMS acceleration obtained at strategic locations).
- Top left back fig 3c.xlsx (Impact hammer test data at loading area at back side left).
- Top right back fig 3b.xlsx (Impact hammer test data at loading area at back side right).
- Top right front 3d.xlsx (Impact hammer test data at loading area at front side right).

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Reference Source

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Publisher Full Text

Open Peer Review

Current Peer Review Status: ✓ ? ✓ ?

Version 5

Reviewer Report 07 November 2024

https://doi.org/10.5256/f1000research.173971.r336542

?

Roberto Ventura
Università degli Studi di Brescia, Brescia, Italy
Benedetto Barabino
DICATAM, Universita degli Studi di Brescia (Ringgold ID: 9297), Brescia, Lombardy, Italy

The authors did not address our previous report and ignored all of our comments.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Micromobility, Transportation Safety, Risk Modelling.

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Version 3

Reviewer Report 01 August 2024

https://doi.org/10.5256/f1000research.160573.r273316

?

Roberto Ventura
Università degli Studi di Brescia, Brescia, Italy
Benedetto Barabino

DICATAM, Universita degli Studi di Brescia (Ringgold ID: 9297), Brescia, Lombardy, Italy

This study investigates the whole-body vibration of two-wheeled vehicles by performing some experimental trials on a two-wheeler test rig. Acceleration data are processed according to ISO 2631-1 standard to compute weighted RMS values. Hence, RMS values are compared with ISO 2631-1 thresholds to infer the expected comfort level faced by riders.
While the paper explores an interesting topic deserving attention, its contribution to the current state of the art lacks clarity. Moreover, some technical aspects must be refined.
Comment 1
Background
Although the riding comfort of two-wheeled vehicles is a well-researched topic, this aspect is surprisingly only marginally evident in the literature review provided. The authors seem to have overlooked several crucial previous studies, both theoretical and experimental in nature.
On the theoretical front, for instance, Cano Moreno et al. [Ref-1,5] conducted a comprehensive analytical assessment of the impact of e-scooter vibrations on driver comfort and health through simulations. Additionally [Ref-2] evaluated motorcycle comfort levels using a frequency-domain approach, considering human sensitivity, and highlighted the dependence of proposed comfort indices on suspension characteristics.
Turning to the experimental realm, [Ref-3,4] performed empirical studies comparing the comfort experienced by riders of e-bikes and e-kick scooters in terms of vibrational acceleration. These studies conducted real-world trials across various road surfaces and user demographics. Notably, they found that e-kick scooters generally induce higher vibrational magnitudes than e-bikes. Furthermore, factors such as pavement surface, sensor position, user gender, height, and travel speed emerged as critical determinants of vibrational magnitude for both vehicles.
It is strongly recommended that the authors enrich their literature review by incorporating these seminal studies along with other relevant contributions. Such inclusion would provide a more comprehensive understanding of the state-of-the-art research in this field and offer valuable insights for advancing their own work.

Comment 2
Contributions
It's crucial to highlight the unique contributions and distinctions of the current study from existing literature. This involves identifying gaps in the current research landscape that the study addresses. The authors should clearly outline how their work stands out from the current state of the art, whether through innovative methodologies or fresh perspectives. Justifying the necessity of the study is essential, demonstrating its significance in advancing knowledge or addressing critical issues. Additionally, any methodological innovations introduced should be succinctly described to underscore their relevance and potential impact.

Comment 3
Materials and methods
The authors should clarify the criteria used to select a load range between 5 kg and 10 kg. This load range may seem relatively light, particularly when compared to the average user weight of 60-80 kg. Additionally, the study only considers acceleration in the z-axis and the ISO 2631-1 "wk" weighting factor. This limitation is significant since real-world scenarios involve transversal accelerations caused by factors such as braking and turning manoeuvres. Consequently, concerns arise about the applicability of the test rig experiment results to real-world conditions. It would be beneficial for the authors to justify this choice, ensuring it aligns with realistic usage conditions

and enhances the credibility and relevance of the study's findings. Finally, it would be useful if the authors could provide an estimation of the parameters governing the analytical model of the test rig (i.e., M1, M2, K1, K2, C).

Comment 4
Discussion of the results
In a scientific paper, it is essential to discuss the results by comparing them with the findings of previous work to identify similarities and inconsistencies. For instance, is the observed positive correlation between speed and vibration intensity an expected outcome? Similarly, is the influence of road conditions an expected finding? To the best of my knowledge, it is. Please provide further discussion.

Comment 5
Conclusions
The conclusions provided in the manuscript partially lack elaboration on the research's theoretical and practical implications, limitations, and future research perspectives. It is essential to delve deeper into these aspects to provide a comprehensive understanding of the study's significance and potential contributions to the field.

References
1. Cano-Moreno J, Islán M, Blaya F, D'Amato R, et al.: E-scooter Vibration Impact on Driver Comfort and Health. *Journal of Vibration Engineering & Technologies*. 2021; **9** (6): 1023-1037 Publisher Full Text
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3. Boglietti S, Ghirardi A, Zanoni C, Ventura R, et al.: First experimental comparison between e-kick scooters and e-bike's vibrational dynamics. *Transportation Research Procedia*. 2022; **62**: 743-751 Publisher Full Text
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5. Cano-Moreno, J. D., Marcos, M. I., Haro, F. B., D'Amato, R., A. Juanes, J., & Heras, E. S: Methodology for the study of the influence of e-scooter vibrations on human health and comfort. In Proceedings of the Seventh International Conference on Technological Ecosystems for Enhancing Multiculturality. *Research gate*. Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My primary research expertise includes the safety of infrastructures subjected to heavy vehicle transit, risk analyses in the transportation field, and the dynamics of micromobility vehicles.

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Reviewer Report 28 May 2024

https://doi.org/10.5256/f1000research.160573.r231721

Bui Van Cuong
Automotive and Power Machinery Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam

I appreciate the research contribution of the author team. However, the study has several limitations and only partially addresses each aspect. Here are some suggestions for improvement:

1) The inconsistency in capitalization in Table 3 and Figure 2 should be rectified.
2) Authors should use symbols like "m_s" and "m_u" for Sprung mass and Unsprung mass, respectively.
3) Specific parameters are missing in Table 3.
4) The method for determining the Root-Mean-Square (RMS) value of acceleration in Figure 8 needs clarification. Which equation?
5) The frequency range used is not appropriate for ISO 2631-1 evaluation. It is crucial to analyze the low-frequency range from 1-15Hz, particularly the frequency band sensitive to human perception, which lies between 4-8Hz. This adjustment would ensure a more accurate assessment of vibration effects on human comfort.
6) Equations 1 to 4 on page 6 are presented but not simulated. To enhance content quality, numerical simulations should be conducted alongside experiments.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research interests encompass vehicle dynamics and control, optimal design and control methodologies, as well as active and semi-active control strategies for suspension system. I also specialize in multi-objective optimization techniques, including Genetic Algorithms (GA) and Particle Swarm Optimization (PSO).

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 07 Jun 2024

Satish Shenoy B

We are very grateful for the reviewer's comments and all the necessary changes have been incorporated in the manuscript and highlighted.

Reviewer: Bui Van Cuong, Automotive and Power Machinery Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam.

Comments:

1. The inconsistency in capitalization in Table 3 and Figure 2 should be rectified.

Answer: The inconsistency in capitalization has been rectified and updated in the paper.

2. Authors should use symbols like "ms" and "mu" for Sprung mass and Unsprung mass, respectively.

Answer: Currently m1 and m2 is used for sprung mass and Unsprung mass. However, this will be taken care of further in the research papers.

3. Specific parameters are missing in Table 3.

Answer: Table 3 has been updated accordingly.

4. The method for determining the Root-Mean-Square (RMS) value of acceleration in Figure 8 needs clarification. Which equation?

Answer: The method of obtaining RMS acceleration is explained in "Obtaining acceleration using LabVIEW" section of the paper. Here, the RMS value is found through LabVIEW software as mentioned, and not through equations.

5. The frequency range used is not appropriate for ISO 2631-1 evaluation. It is crucial to analyze the low-frequency range from 1-15Hz, particularly the frequency band sensitive to human perception, which lies between 4-8Hz. This adjustment would ensure a more accurate assessment of vibration effects on human comfort.

Answer: Low-frequency zone is highlighted in the figure and updated in Figure 9. However, as ISO 2631-1 states the assessment of vibration in the range of 0.5 Hz – 80 Hz, this figure is adopted in the paper. Further, in the research, this frequency region will be considered.

6. Equations 1 to 4 on page 6 are presented but not simulated. To enhance content quality, numerical simulations should be conducted alongside experiments.

Answer: This would be taken as a future scope of the paper and will be done as per suggestions.

Thank you

Competing Interests: No Competing interests.

Reviewer Report 30 January 2024

https://doi.org/10.5256/f1000research.160573.r236174

Peter Múčka
Slovak Academy of Sciences, Bratislava, Slovakia

Manuscript was partially improved. I consider the scientific level or contribution of the results to be still limited. The article is more of a measurement report than a scientific article. The influence of the mass change on the vibration of the quarter-car model is well known.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Vibration, vehicle dynamics, signal processing

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Reviewer Report 03 October 2023

https://doi.org/10.5256/f1000research.155303.r209188

Peter Múčka
Slovak Academy of Sciences, Bratislava, Slovakia

Manuscript was partially improved but several comments were ignored.

- The results do not offer any substantial new results in area of two-wheeled vehicle vibration.

- Reviewer did not consider this paper to be the contribution to the topic of two-wheeled vehicles comfort.
- All presented results or dependences are known (sprung mass increase influence on vibration).
- The comparison with ISO 2631-1 reaction levels is inappropriate because the ISO 2631-1 uses frequency-weighted acceleration.
- Typical natural frequencies of suspended quarter-car model are about 1 Hz for sprung mass and 10 Hz for unsprung mass.
- The important frequency range in ISO 2631-1 is up to 80 Hz.
- The article lacks the discussion of natural frequencies of the test rig and its influence on tested vehicle vibration with the published literature.

Specific comments:

Page 4
"The electric two-wheeler test rig is modeled as a state space model for finding its natural frequencies."
COMMENT: Natural frequencies of measuring system were identified experimentally by impact hammer. The connection between quarter-car model (Fig. 2) parameters and identified natural frequencies was not presented.

Page 7 – Fig. 3
COMMENT: Add the dimension to the Magnitude.

Page 8
"Hence, comparing these values with ISO 2631 as given in table 1, the comfort category has moved to comfortable region from extremely uncomfortable region after loading." ...
"As compared to ISO 2631, the results obtained are discussed in detail in this section."
COMMENT: As it was stated in first review, it is not appropriate to compare the frequency-weighted specified in ISO 2631-1 and unweighted acceleration values.

Page 9 – Fig. 6
COMMENT: Using 6 decimal points for frequency is superfluous.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Vibration, vehicle dynamics, signal processing

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 23 Dec 2023

Satish Shenoy B

Rebuttal to Reviewer comments
We are very grateful for the reviewer's comments and all the necessary changes have been incorporated in the manuscript.

General comments:
1. Manuscript was partially improved but several comments were ignored.

Answer: Manuscript is updated with all the comments addressed.

2. The results do not offer any substantial new results in area of two-wheeled vehicle vibration.

Answer: The results have been improved by adding frequency weighted acceleration. Finding this acceleration and comparing the results with ISO 2631-1 standard the rider's comfort is accessed and this is a value addition to the field.

3. Reviewer did not consider this paper to be the contribution to the topic of two-wheeled vehicles comfort.

Answer: Kindly find the new manuscript update in which a detailed explanation is provided.

4. All presented results or dependences are known (sprung mass increase influence on vibration).

Answer: The study is mainly focused on finding the strategic locations of vibrations which affect the rider's comfort. These points are found to mitigate these issues in future. The sprung and unsprung mass are indicated as to find the state space equations.

5. The comparison with ISO 2631-1 reaction levels is inappropriate because the ISO 2631-1 uses frequency-weighted acceleration

Answer: Frequency weighted acceleration is considered and updated with appropriate results and discussion.

6. Typical natural frequencies of suspended quarter-car model are about 1 Hz for sprung mass and 10 Hz for unsprung mass.

Answer: Here, the impact hammer test reveals the natural frequency of the entire electric two-wheeler test rig.

7. The important frequency range in ISO 2631-1 is up to 80 Hz.Answer: Yes, ISO 2631-1 suggests that frequency range of 0.5-80 Hz. However, these frequencies affecting the human body are an ongoing work and this paper doesn't include the same. This paper deals with understanding the rider's comfort level in accordance with the weighted acceleration comparison with ISO standards. However, the natural frequency study is beyond the scope of this paper.

8. The article lacks the discussion of natural frequencies of the test rig and its influence on tested vehicle vibration with the published literature.

Answer: The article has been updated with discussion on the peak frequencies affecting the rider's comfort. This study is mainly focused on finding rider's comfort and hence only the frequencies under the range of 0.5 Hz to 80 Hz is considered as per ISO 2631-1.

Specific comments:

1. Fig 4 "The electric two-wheeler test rig is modeled as a state space model for finding its natural frequencies."COMMENT: Natural frequencies of measuring system were identified experimentally by impact hammer. The connection between quarter-car model (Fig. 2) parameters and identified natural frequencies was not presented.

Answer: The sentence has been modified and updated.

2. Page 7 – Fig. 3COMMENT: Add the dimension to the Magnitude.

Answer: The magnitude in the y-axis represents the impact of the hammer on the machine and it is dimensionless.

3. Page 8 "Hence, comparing these values with ISO 2631 as given in table 1, the comfort category has moved to comfortable region from extremely uncomfortable region after loading." …"As compared to ISO 2631, the results obtained are discussed in detail in this section."COMMENT: As it was stated in first review, it is not appropriate to compare the frequency-weighted specified in ISO 2631-1 and unweighted acceleration values.

Answer: The updated paper includes weighted acceleration comparison with ISO 2631-1, and I hope now it adds value to the comparison.

4. Page 9 – Fig. 6COMMENT: Using 6 decimal points for frequency is superfluous.

Answer: It has been modified and updated.

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 16 August 2023

https://doi.org/10.5256/f1000research.143915.r187825

Le Van Quynh
Automotive and Power Machinery Engineering, Thai Nguyen University of Technology, Thai Nguyen City, Vietnam

Thank you for your work and the paper submitted. There is a lot of work presented and I would suggest some revisions to improve the quality of the paper

- Most of the analysis results, the authors only reconstructed considering the value analysis on the time domain based on ISO 2631-1 standard, but did not analyze the frequency domain, especially the low frequency domain. Therefore, the goal of smooth analysis is not vehicle ride comfort. I advise the authors to correct and add to clarify.
- Page 4: The author shows the measuring positions in Fig.1.
- Page 5: Eq.(1)- E(4) have not been found to be related to the experimental results, please review?
- Page 8: the y axis representation of Fig.5 is the acceleration values, not RMS acceleration values, please review?

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Vibration Analysis; Nonlinear Dynamic Structural; Vibration Modal

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 29 Aug 2023

Satish Shenoy B

We are very grateful for the reviewer's comments and all the necessary changes have been incorporated in the manuscript.

Please note all the comments are addressed in the paper and highlighted for reference.

2. Le Van Quynh, Automotive and Power Machinery Engineering, Thai Nguyen University of Technology, Thai Nguyen City, Vietnam
General comments:

- **Most of the analysis results, the authors only reconstructed considering the value analysis on the time domain based on ISO 2631-1 standard, but did not analyze the frequency domain, especially the low frequency domain. Therefore, the goal of smooth analysis is not vehicle ride comfort. I advise the authors to correct and add to clarify.**

Answer: The graphs and plots showing frequency domain have been added to the paper (Figure 5) and explained.

- **Page 4: The author shows the measuring positions in Fig.1.**

Answer: All the positions along with strategic locations have been updated in the figure.

- **Page 5: Eq.(1)- E(4) have not been found to be related to the experimental results, please review?**

Answer: Here the equations 1 & 2 are the governing system equations and later derived Laplace equations (3 & 4) represent the state space equations. The detail explanation is again added to the manuscript.

- **Page 8: the y axis representation of Fig.5 is the acceleration values, not RMS acceleration values, please review?**

Answer: RMS acceleration have been indicated and it is updated in version 2 of the paper.

Competing Interests: No

Reviewer Report 24 July 2023

https://doi.org/10.5256/f1000research.143915.r187826

Peter Múčka
Slovak Academy of Sciences, Bratislava, Slovakia

The work is not clearly and accurately presented. It cites the current literature.

The academic merit of the work is low.

The novelty of the work is limited. This is the report from vibration measurement.

Details of methods and analysis provided do not allow replication by others. The interpretation of results is confused (the measured values are not comparable in principle with ISO 2631-1 comfort reaction levels).

In my opinion the work does not offer the novel or important results.

General comments:

1. ISO 2631-1 does not specify impact hammer test approach. Please clarify.

2. Page 3 – Methods
COMMENT: State-space representation is a mathematical model of a physical system related by first-order (not involving second derivatives) differential equations. The used quarter-car model (Fig. 2) for two-wheeler test rig is described by differential equations involving second derivative. Clarify.

3. Authors measured the acceleration at two-wheeled test rig. It is not clear why the quarter-car model (Fig. 2), equations of motions (1-4) and Table 3 Test rig model nomenclature are used in the paper. I did not see any results connected with them.

4. Page 7 "Obtaining acceleration using LabVIEW"

COMMENT: This approach should be connected and explained with definitions in ISO 2631-1. Where is the measuring point? ISO 2631-1 specified the likely reactions of passengers in public transport. Where is passenger in your case?

5. Page 8 “These values are then compared with the ISO 2631-1 standard to further analyze the rider comfort.”
COMMENT: ISO 2631-1 is specified for standing, sitting and recumbent persons. ISO 2631 used the frequency-weighted acceleration. Clarify.

6. Page 8 – Comparison of measured acceleration values at the test rig with comfort level criteria based on frequency-weighted acceleration measured at sitting, standing or recumbent persons is not correct.

7. The results are not compared with observations and results of other authors. What is the impact of such results?

Specific comments:

Page 3 – “By getting the Frequency Response Function (FRF) at critical vibrational points, variable acceleration values at multiple spots were identified”
COMMENT: ISO 2631-1 did not specify this approach for acceleration identification. Clarify.

Page 3. “Table 1 gives the detailed classification of the rider’s comfort level as per ISO 2631-1.”
COMMENT: Specify how acceleration was estimated in line with ISO 2631-1: 1997.
Annex C.2.3 Comfort reactions to vibration environments in ISO 2631-1 specified magnitudes of overall vibration total values.

Page 5 – Eq. (2)
COMMENT: In Eq. (2) the variable x is used for kinematic excitation (vertical excitation of the rolller) but the Fig. 2 used the variable U.

Page 5, Table 2
COMMENT: C (Ns/m) is not damping ratio but damping coefficient.
Is this ok? “M1 Un-sprung mass (tyre mass) – (kg)”.
I assume, the first dof (X1) ist he roller mass (undamped) vibration and the second dof (X2) is tyre mass (damped) vibration. Please clarify.

Page 6, Figure 3
COMMENT: The Scheme of Impact hammer test on E2W test rig (cases a) to h) may be visualized. It is not clear what is “loading area” and what is “base mount”.

Page 7
"The values of acceleration are recorded at the strategic locations during this cycle.“
COMMENT: Where are these strategic locations? Clarify.

Page 7
COMMENT: Add the scheme of location of PCB Piezotronics accelerometers.

Page 7
"Table 4. Average of natural frequencies."
COMMENT: Natural frequencies of what system? Match the natural frequencies to the particular parts of analysed mechanical system.

Is the work clearly and accurately presented and does it cite the current literature?
No

Is the study design appropriate and is the work technically sound?
No

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Vibration, vehicle dynamics, signal processing

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 29 Aug 2023
Satish Shenoy B

We are very grateful for the reviewer's comments and all the necessary changes have been incorporated in the manuscript.

Please note all the comments are addressed in the paper and highlighted for reference.

1. **Peter Múčka, Slovak Academy of Sciences, Bratislava, Slovakia**

General comments:
1. ISO 2631-1 does not specify impact hammer test approach. Please clarify.
Answer: Impact hammer test was conducted in order to check if any operating frequencies co-inside with the natural frequency of the system. Accordingly, one of the natural frequencies (180Hz) was found to near to the natural frequency of the system and the relation has been mentioned and updated in the conclusions.

2. Page 3 – Methods
COMMENT: State-space representation is a mathematical model of a physical system related by first-order (not involving second derivatives) differential equations. The used quarter-car model (Fig. 2) for two-wheeler test rig is described by differential equations involving second derivative. Clarify.
Answer: Here the equations 1 & 2 are the governing system equations and later derived Laplace equations (3 & 4) represent the state space equations. The detail explanation is again added and updated to the manuscript.

3. Authors measured the acceleration at two-wheeled test rig. It is not clear why the quarter-car model (Fig. 2), equations of motions (1-4) and Table 3 Test rig model nomenclature are used in the paper. I did not see any results connected with them.
Answer: The equations 1 to 4 are derived to show the system mathematically and this is basic study conducted on the test rig. The research has continued considering an actual vehicle and converting the ICE vehicle to Electric as well. Understanding the quarter car model of the test rig is important in understanding the dynamics of the system.

4. Page 7 "Obtaining acceleration using LabVIEW"
COMMENT: This approach should be connected and explained with definitions in ISO 2631-1.
Where is the measuring point? ISO 2631-1 specified the likely reactions of passengers in public transport. Where is passenger in your case?
Answer: Strategic locations have been indicated and have been updated in the version 2 of the paper. However, ISO 2631 standard is compared in this paper against the RMS acceleration obtained at the strategic locations. As these strategic locations especially the loading area corresponds to the rider's seat in an actual two-wheeler, this standard has been used. Further, this study is continued in an actual two-wheeler considering an actual rider and road interactions. Which is the future scope of the this paper.

5. Page 8 "These values are then compared with the ISO 2631-1 standard to further analyze the rider comfort."
COMMENT: ISO 2631-1 is specified for standing, sitting and recumbent persons. ISO 2631 used the frequency-weighted acceleration. Clarify.
Answer: Here ISO 2631 is compared with the RMS acceleration obtained at the strategic locations of vibration. As these strategic locations especially the loading area corresponds to the rider's seat in an actual two-wheeler, this standard has been used.

6. Page 8 – Comparison of measured acceleration values at the test rig with comfort level criteria based on frequency-weighted acceleration measured at sitting, standing or recumbent persons is not correct.
Answer: Frequency weightings not considered in this paper. This paper only compares the RMS acceleration to determine the peak amplitudes in the test rig. Frequency weightings and calculations of Vibration dose value is the future scope of this paper.

7. The results are not compared with observations and results of other authors. What is the impact of such results?

Answer: We have not come across such results from literatures. These results taken from accelerometers in an electric two-wheeler test rig and these results are unique.

Specific comments:

Page 3 – "By getting the Frequency Response Function (FRF) at critical vibrational points, variable acceleration values at multiple spots were identified" COMMENT: ISO 2631-1 did not specify this approach for acceleration identification. Clarify.
Answer: Conducting FRF is a process conducted using NI's LabVIEW software. This is conducted in order to convert the raw acceleration obtained to RMS acceleration at the strategic locations. Obtaining RMS acceleration, later these values are compared with ISO 2631 as mentioned in the standard. ISO 2631 specifies comfort categories based on RMS acceleration, and only this part of the standard is being compared with the results obtained.

Page 3. "Table 1 gives the detailed classification of the rider's comfort level as per ISO 2631-1." COMMENT: Specify how acceleration was estimated in line with ISO 2631-1: 1997.
Annex C.2.3 Comfort reactions to vibration environments in ISO 2631-1 specified magnitudes of overall vibration total values.
Answer: These have been added in the version 2 adding RMS accelerations which signifies the overall vibration total values as specified by the standard.

Page 5 – Eq. (2) COMMENT: In Eq. (2) the variable x is used for kinematic excitation (vertical excitation of the rolller) but the Fig. 2 used the variable U.
Answer: These variables are identified and rectified at both the locations. The roller excitation is indicated as U.

Page 5, Table 2 COMMENT: C (Ns/m) is not damping ratio but damping coefficient.
Is this ok? "M1 Un-sprung mass (tyre mass) – (kg)".
I assume, the first dof (X1) is the roller mass (undamped) vibration and the second dof (X2) is tyre mass (damped) vibration. Please clarify.
Answer: The variable name is identified and rectified. C is damping coefficient. Here X1 is the vertical displacement of mass M1 and X2 is the vertical displacement of Mass M2.

Page 6, Figure 3 COMMENT: The Scheme of Impact hammer test on E2W test rig (cases a) to h) may be visualized. It is not clear what is "loading area" and what is "base mount".
Answer: The strategic locations i.e. loading area, traction motor, suspension and base mount are updated in figure 1 in version 2 of the paper.

Page 7 "The values of acceleration are recorded at the strategic locations during this cycle."
COMMENT: Where are these strategic locations? Clarify.
Answer: The strategic locations are as shown in figure 1 (loading area, traction motor, suspension and base mount).

Page 7 COMMENT: Add the scheme of location of PCB Piezotronics accelerometers.
Answer: Scheme of location of PCB Piezotronics accelerometers are added to the paper and highlighted for reference.

Page 7 "Table 4. Average of natural frequencies."
COMMENT: Natural frequencies of what system? Match the natural frequencies to the particular parts of analysed mechanical system.
Answer: Here the natural frequencies shown are of the entire electric two-wheeler test rig. The frequency is matched with particular part in version 2 of the paper.

Competing Interests: No