

Experimental Investigation of the Fluidic Seat of a Two-wheeler for Enhanced Vibration Damping

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Abstract

Exposure to vibration is a major problem for two-wheeler riders in India. Conventional polyurethane foam seats exhibit poor damping, leading to discomfort and musculoskeletal risks. This study experimentally investigates the effectiveness of incorporating fluid cavities into a PU foam seat to enhance vibration damping. Four types of viscous fluids, namely silicone oil, castor oil, hydraulic oil and mineral oil, were filled within a TPU bladder, which is then fixed within the pelvic region of a PU foam seat. Vibration analysis is performed using a tri-axial ADXL345 accelerometer with an Arduino-based DAS operating at a sampling rate of 200 Hz, in accordance with ISO 2631 standards. The experiment is performed on rumble strip and speed bump road profiles at a constant speed of 20 km/h. The effectiveness of the proposed seat is quantified using Root-Mean-Square (RMS) acceleration values. The experimental analysis shows that fluid integration effectively improves the overall performance of the seat compared with a standard PU foam seat. Silicone oil shows superior performance with 25.91% and 21.32% reduction in vibration exposure on rumble strips and speed bumps, respectively. Castor oil also shows improved performance, with reductions of 18.54% and 16.34% in vibration, making it environmentally friendly. The proposed ergonomic seat can effectively reduce vibration exposure, thereby improving comfort for two-wheeler riders. Additionally, the proposed seat is cost-effective, practical and can be implemented within a two-wheeler seat.

Keywords: Fluidic Damping, Polyurethane Foam, Silicone Oil, Two-wheeler Seat, Vibration Damping.

Introduction

The popularity of motorcycles as a commuting tool is particularly evident in developing countries, where they are seen as economically viable and fuel-efficient. Additionally, motorcycles can easily move through congested traffic. However, due to their low mass and limited suspension capabilities, a significant amount of vibration is transferred to the motorcyclist (1). Factors such as road irregularities, which include potholes, rumble strips and speed bumps, contribute to a high exposure to vibration. Prolonged exposure to these vibrations can negatively impact rider health and comfort over time. Thus, vibration isolation between the motorcyclist and the seat is a critical focus point in motorcycle ergonomics (1, 2). Among various alternatives, seat design modifications are considered a simple, cost-effective way to reduce vibration without affecting the motorcycle suspension system.

Vibration exposure in two-wheeler riders is a significant ergonomic and health issue, especially in developing countries where motorcycles are the

main mode of transportation. Prolonged exposure to these vibrations can cause musculoskeletal disorders, fatigue and discomfort among two-wheeler riders (2, 3). The ISO 2631 standard provides guidelines for evaluating vibration using acceleration measurements and frequency-weighting techniques (3). Past studies indicated that the seat design of a motorcycle plays a major role in the transmission of vibration to two-wheeler riders (4). However, the conventional PU foam used for motorcycle seats, though comfortable, lacks damping ability during transients and high-frequency excitations (5). Polyurethane foams are commonly used in vehicle seats because of their low density, long lifespan and comfort (6). However, their ability to damp vibrations depends on their density, stiffness and viscoelastic properties (7). Previous studies have found that higher-density foams can support loads but also increase vibration transmissibility (8). In addition, polyurethane foam microstructure plays a major role in energy dissipation. However, a

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recently conducted study on foam-based isolation systems indicates that foam cannot be used to dampen vibrations in dynamic systems (9). The use of fluids in damping systems has been found quite promising because they offer high damping capabilities (10). Silicone oil, hydraulic oil and bio-based oils have high viscosity and high thermal stability; therefore, these fluids can be used in damping systems (11). Previous research on liquid-based isolation systems has shown that they exhibit improved damping due to viscous shear effects (12). It has also been found in previous studies on hydraulic dampers with non-Newtonian fluids that these systems exhibit improved damping performance in mechanical systems (13, 14). Magnetorheological fluids have also been studied for adaptive vibration-damping systems due to their viscosity (15). However, these systems are generally very costly and complex (16). As a result, passive viscous fluids, such as silicone oil, remain preferred for motorcycle seats due to their simplicity, cost-effectiveness and long-term reliability (17). Vibration measurement is a critical process in evaluating motorcycle comfort. Recent advances in micro-electromechanical systems have led to cost-effective vibration measurement systems using accelerometers such as the ADXL345 (18, 19). Frequency-weighted RMS acceleration measurements have been widely used to evaluate the effects of vibration on humans, as recommended by ISO 2631 (20). The use of data-acquisition systems such as Arduino has also been instrumental in enabling vibration measurements in real-world settings (21). Environmental sustainability has also led to numerous studies on bio-based fluids for motorcycle dampers. Vegetable oils, such as castor oil, have shown promising properties in terms of viscosity, biodegradability and environmental sustainability

compared to conventional fluids, such as mineral oils (22). The use of vegetable oils in motorcycle dampers is a step in the right direction in promoting environmental sustainability in engineering (23). Recent advances in motorcycle seat ergonomics have introduced innovations, such as incorporating modern materials into motorcycle dampers, to improve comfort during long rides. Hybrid foam materials, bio-based fluids and advanced materials, such as auxetic materials, have shown improved comfort during motorcycle riding (24). This indicates the possibility of incorporating fluid-based dampers in motorcycle seats.

Despite these developments, research on fluid-integrated two-wheeler seats is still limited. Comparison of various viscous fluid types under practical conditions is still very limited. Also, very little attention is given to developing economic solutions to reduce motorcycle vibrations in developing countries.

The present study addresses the above issues through an experimental assessment of a fluid-integrated polyurethane foam seat for vibration damping in two-wheelers. This research contributes to the development of practical, affordable two-wheeler seat designs that improve vibration reduction.

Methodology

The present investigation aims to evaluate the vibration-damping performance of a fluid-integrated two-wheeler seat under real riding conditions. The study follows ISO 2631-1 guidelines for vibration assessment and compares a baseline polyurethane (PU) foam seat with four fluid-modified configurations. The methodology consists of seat modification and fluid integration, fluid characterisation, instrumentation, controlled road testing and vibration analysis.

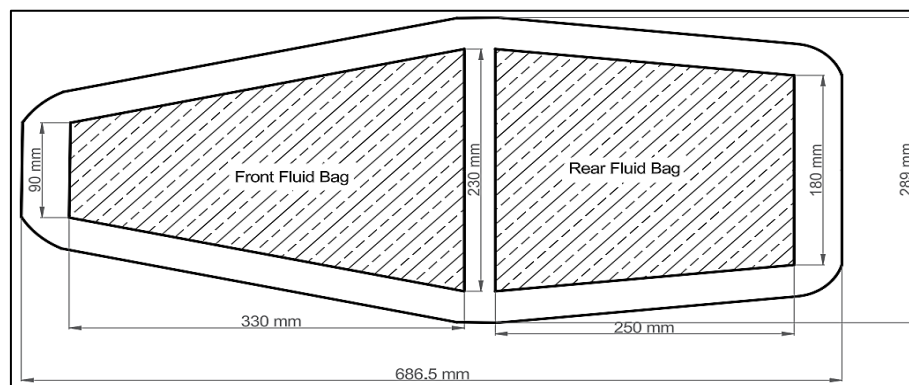


Figure 1: Fluid Bag Dimensions

Seat Modification and Fluid Integration

A commercially available single-layer PU foam two-wheeler seat was chosen as the baseline configuration. The seat was sectioned to accommodate a fluidic damping component. The pelvic support area was provided with a cavity. This area is the primary load-carrying area. The fluidic component was inserted between the two foam layers. Figure 1 illustrates the geometry and placement of the TPU bladder within the PU foam seat. The TPU bladder has an average thickness of 15 mm and each bladder was filled with 500 ml of test fluid. This volume was chosen to provide

sufficient fluid shear deformation, maintain the seat's structural integrity and minimise changes in stiffness and ergonomics. The seat was reassembled using industrial-grade adhesive and the original seat cover was restored to maintain geometrical integrity. Figure 2 shows the step-by-step process of seat modification, including foam sectioning, cavity formation, fluid bag insertion and reassembly. It also presents the experimental setup used for vibration measurement. This process ensures consistent integration of the fluidic component without significantly altering the original seat geometry.

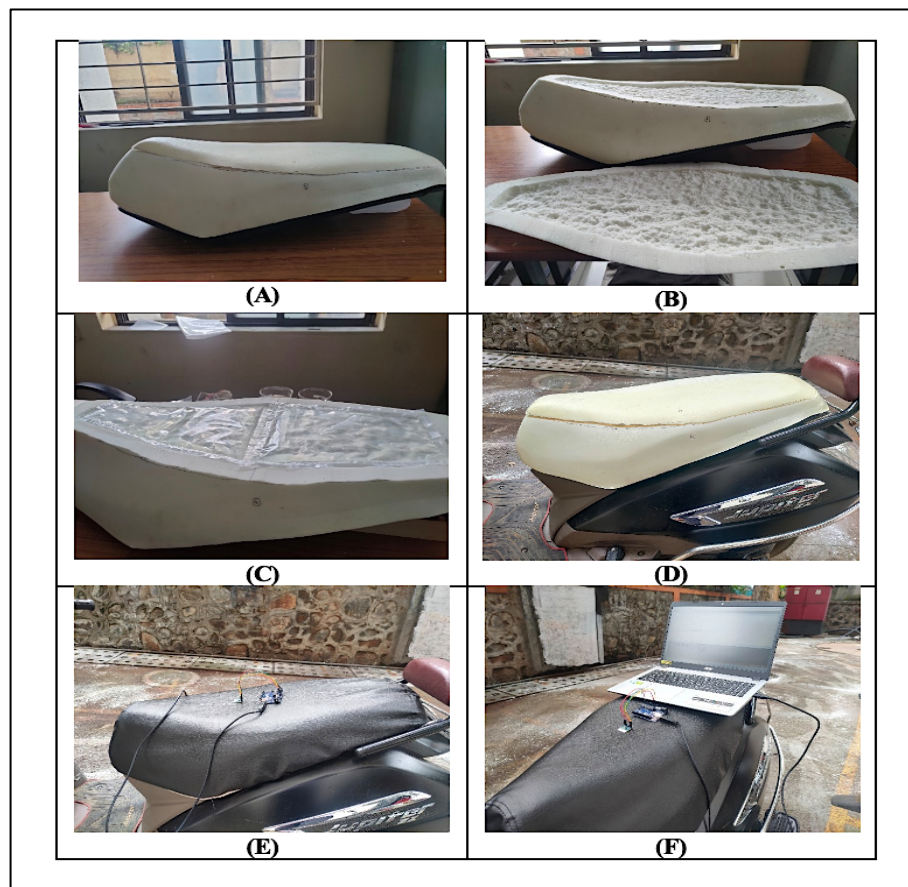


Figure 2: Fluidic Seat Manufacturing: (A) Sectioning of the Foam Seat, (B) Making Cavities in the Foam Seat, (C) Fluid Bag Installation in the Foam Seat, (D) Reassembling of Foam Seat, (E) Seat Cover Mounting, (F) Data Acquisition Through Sensors

Fluid Selection and Preparation

Figure 3 presents the different viscous fluids used in the study, namely silicone oil (Figure 3A), castor oil (Figure 3B), mineral oil (Figure 3C) and hydraulic oil (Figure 3D). The viscous fluids used in the study were selected based on their rheological properties, availability and ability to dampen passive vibration. Viscous fluids can dissipate vibrational energy through shear deformation

under dynamic loading conditions and their damping capacity increases with increasing viscosity. Silicone oil was selected for its high viscosity (700 cP) and thermal stability, which are important properties for a viscous damping fluid. Castor oil was selected for its high viscosity (650 cP) and biodegradability, which offer better environmental benefits than the other options. Hydraulic oil was selected for its common use as a

viscous fluid with a moderate viscosity of 100 cP. On the other hand, mineral oil was selected for its low cost and 50 cP viscosity, allowing the study of the damping ability of the selected fluids with

varying rheological properties. The selected viscous fluids were used in the same proportion by pouring them into a TPU bladder.

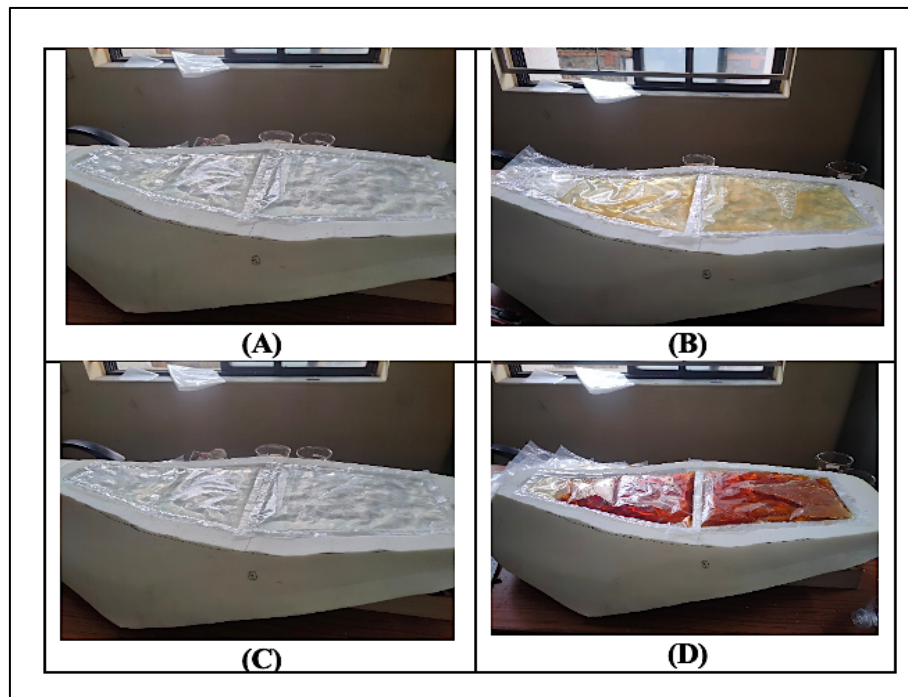


Figure 3: Fluid Bag Preparation: (A)Silicone Oil, (B) Castor Oil, (C)Mineral Oil, (D) Hydraulic Oil

Instrumentation and Data Acquisition

The vibrations were measured using a triaxial accelerometer, the ADXL345. Before the experiments, the ADXL345 sensor was calibrated to ensure accurate measurements. The sensor was calibrated by placing it on a stable, flat surface to obtain baseline acceleration values along each axis, which were used to correct offset errors. The sensor has a measurement range of $\pm 6g$. The sensor is sufficiently sensitive to obtain the required measurements for investigating human exposure to whole-body vibrations. The Arduino board was used to obtain sensor measurements at

a sampling frequency of 200 Hz. This is sufficient to obtain the required measurements within the frequency range of human exposure to vibrations, as defined by ISO 2631. The results of the experiments show that the Z-axis experiences the highest vibration compared to the X- and Y-axes. Figure 4 shows the complete experimental setup, including the placement of the triaxial accelerometer at the rider-seat interface. This configuration enables accurate measurement of vibration transmitted to the rider, particularly along the vertical (Z) axis, which is most critical for comfort analysis.

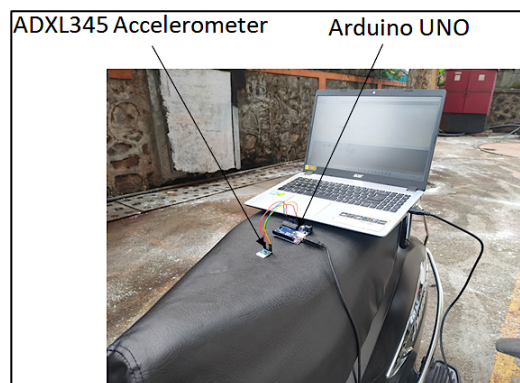


Figure 4: Experimental Setup

Road Testing

The modified two-wheeler was tested on two road profiles. Figure 5 illustrates the two road conditions used for testing, namely rumble strips (Figure 5A) and speed bumps (Figure 5B). These profiles represent common real-world excitations encountered by two-wheeler riders and are used to evaluate the seat's dynamic response under different vibration conditions. The experiments were carried out on the road at a constant speed of

20 km/h. The constant velocity was maintained to ensure uniform excitation of all seat configurations and to compare the seats' responses. Also, it is the normal speed of the two-wheeler on the road when encountering rumble strips or speed bumps in an urban environment. The tests were carried out for each fluid configuration, including the unmodified PU foam seat. Acceleration data was collected in real time using the Arduino and transmitted to a laptop via serial communication for further analysis.



Figure 5: Road Profile Used for Vibration Testing: (A) Rumble Strip Road Profile, (B) Speed Bump Road Profile

Data Processing and Analysis

In the present study, the primary parameter for evaluating vibration was the root-mean-square (RMS) acceleration, which has been widely employed in Whole Body Vibrations (WBV) studies and is supported by the ISO 2631 evaluation method. The study aimed to evaluate the comparative vibration reduction capacity of various seat configurations. The raw data collected

by the accelerometer's Z-axis was used to calculate the RMS acceleration. The Root Mean Square acceleration was calculated using equation [1]. Where a_i is the instantaneous acceleration value and N is the total number of samples. The calculated acceleration data were used to compare the damping performance of each fluid configuration. The percentage reduction in vibration was calculated using equation [2].

$$\text{RMS} = \sqrt{\frac{1}{N} \sum_{i=1}^N a_i^2} \quad [1]$$

$$\% \text{ Reduction} = \frac{a_{\text{PU}} - a_{\text{fluid}}}{a_{\text{PU}}} \times 100 \quad [2]$$

Where a_{PU} is the RMS acceleration of the baseline seat and a_{fluid} is the RMS acceleration of the fluid-modified seat.

Figure 6 provides a schematic representation of the vibration transmission path and damping mechanism of the proposed fluid-integrated seat. The diagram illustrates how vibrations from the road are attenuated by viscous shear within the fluid-filled TPU bladder, reducing vibration at the rider interface. The upward arrows show the direction of vibration transmission and

measurement of transmitted vibration. The vibrations caused by the road are transferred to the motorcycle frame and then to the seat structure. The fluid-integrated TPU bladder within the PU foam seat structure dampens vibrations through viscous shear, reducing the rider's perceived vibration.

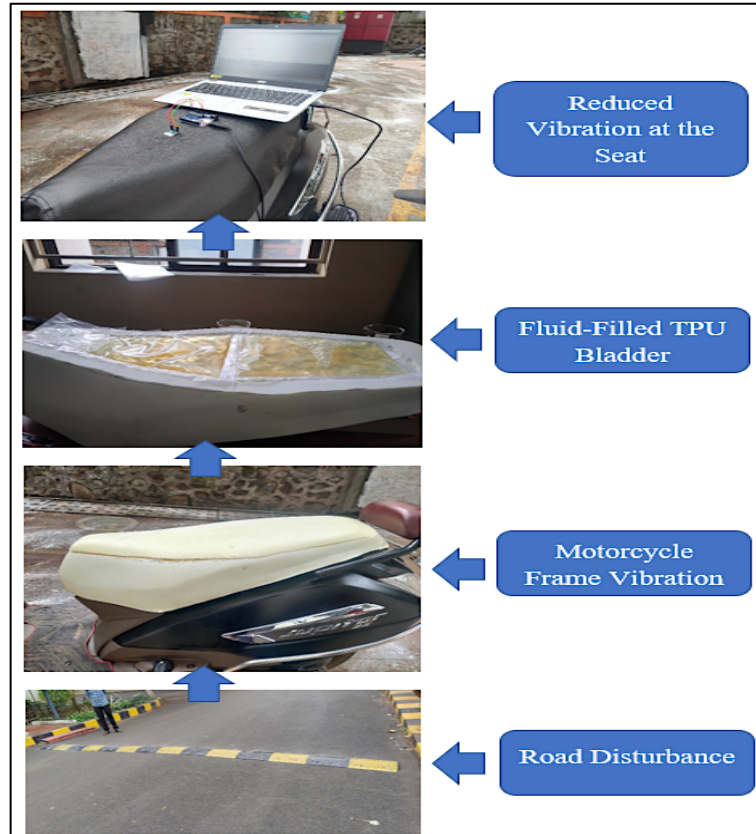


Figure 6: Schematic Representation of the Damping Mechanism of the Proposed Fluid-integrated Seat

Results

Rumble Strip Road Profile

The vibration response of the modified two-wheeler seat was analysed for the given seat configurations subjected to rumble strip excitation, which is considered representative of high-frequency disturbances commonly encountered during routine riding in urban areas. The time-domain acceleration response curves for all seat configurations show significant differences in

vibration response characteristics. Figure 7 shows the acceleration response of the conventional PU foam seat under rumble strip excitation. The higher vibration amplitude indicates poor damping, serving as a baseline for comparison with fluid-integrated seat configurations. Figure 8 presents the acceleration response of different fluid-filled seat configurations under rumble strip excitation. The reduced amplitude and smoother response curves demonstrate the effectiveness of fluid integration in attenuating vibration.

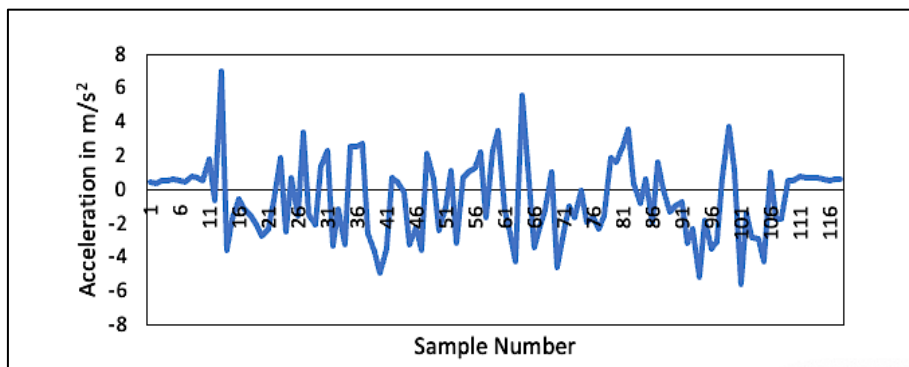


Figure 7: Acceleration Data in m/s^2 of Regular Foam on Rumble Strip at 20 km/hr

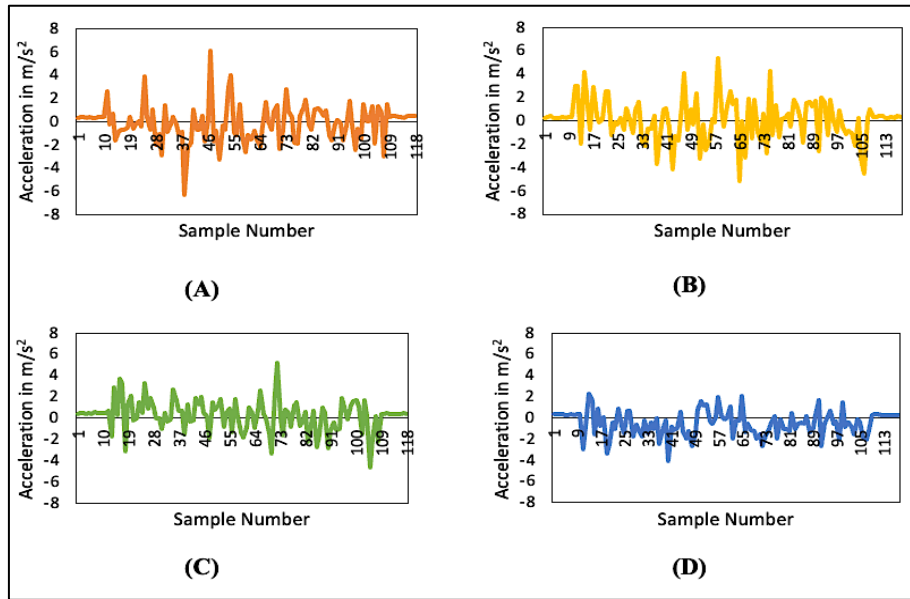


Figure 8: Acceleration Data in m/s^2 of Different Fluids on the Rumble Strip at 20 km/hr: (A) Mineral Oil, (B) Hydraulic Oil, (C) Silicone Oil, (D) Castor Oil

The RMS acceleration results in Figure 9 indicate improved damping capability for the seats with fluid-filled cavities. Among all seat configurations, the conventional PU foam seat exhibited the highest RMS acceleration of $2.3167 m/s^2$, indicating the greatest vibration transmission to the rider. Among the modified seat configurations, the silicone-oil seat exhibited the lowest RMS

acceleration of $1.7163 m/s^2$, corresponding to a 25.91% reduction in vibration compared to the conventional seat. Castor oil also demonstrated good damping, with an RMS acceleration of $1.887 m/s^2$, corresponding to a 18.54% reduction in vibration. Hydraulic and mineral oils exhibited damping, with reductions of 13.15% and 8.83% in vibration, respectively.

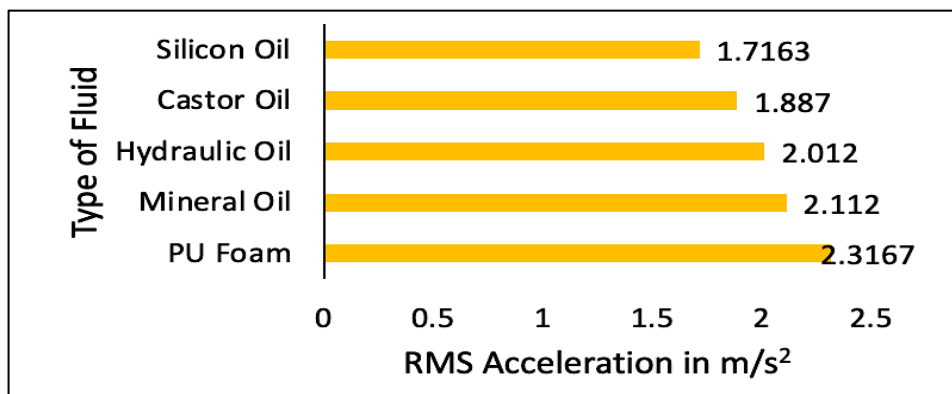


Figure 9: RMS Acceleration Values for Each Seat Configuration on the Rumble Strip

It was observed that silicone oil's damping potential was due to its high viscosity, incompressibility and high thermal stability, leading to greater viscous shear energy dissipation within the fluid bladder. Similarly, castor oil

showed good damping performance due to its high viscosity and good rheological properties. However, the relatively lower damping potential of hydraulic and mineral oils was due to their low viscosity and limited energy dissipation.

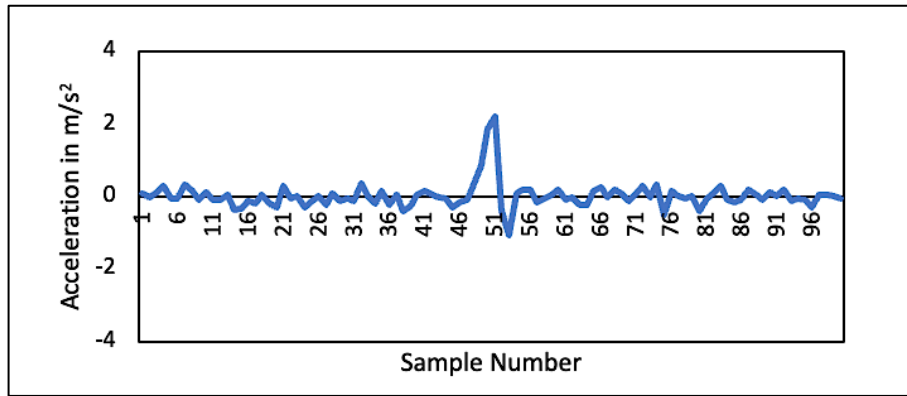


Figure 10: Acceleration Data in m/s² of Regular Foam on Speedbump at 20 km/hr

Speed Bump Road Profile

Figure 10 shows the acceleration response of the conventional PU foam seat when subjected to a speed bump. It was observed that the system's response to the speed-bump road profile was

similar to the rider's experience during the actual crossing of the bump. The acceleration response profile of the baseline PU foam seat showed a sharp peak due to the wheel's impact with the speed bump, followed by rapid damping.

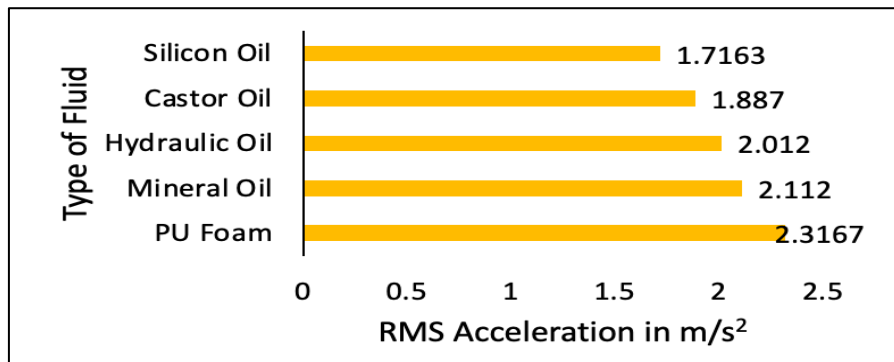


Figure 11: RMS Acceleration Values for Each Seat Configuration for the Speed Bump

Figure 11 presents the RMS acceleration comparison for different seat configurations under speed bump excitation. It was observed that fluid-integrated seat configurations exhibited lower peak values and a smoother damping response, indicating greater shock-absorption potential. Among the fluid-integrated seat configurations, silicone oil had the highest damping potential, resulting in a 21.32% reduction in RMS acceleration relative to the baseline seat configuration. Castor oil had a damping potential of 16.34%, whereas the damping potentials of the hydraulic oil and the mineral oil were approximately 11.25% and 7.72%, respectively.

Discussion

This study primarily evaluates vibration attenuation at the rider-seat interface. While reduced vibration exposure is generally associated with improved riding comfort, detailed ergonomic evaluations, such as pressure distribution, rider

posture analysis and subjective comfort assessments, were beyond the scope of this study. The present study evaluates the vibration attenuation at the rider-seat interface using a fluid-integrated polyurethane foam seat. The results show that the inclusion of viscous fluid cavities in the seat significantly reduces vibration transmission compared to the conventional PU foam seat for both rumble strip and speed bump excitations. This result is in line with recent studies on liquid-filled and fluid-based vibration isolation systems, which show improved vibration isolation capabilities due to enhanced energy dissipation via fluid shear (15, 17). The superior damping capabilities of silicone oil, as observed in the present study, can be attributed to its relatively high viscosity, low compressibility and thermal stability, which increase shear resistance within the fluid cavity. Similar results were observed in the recent studies on vibration isolation systems, where silicone oil was found to show improved

dynamic properties and reduced transmissibility due to its viscoelastic behaviour (25, 26). This confirms the dominant role of shear deformation in the vibration attenuation in the fluid-based damping system. Castor oil was also observed to exhibit relatively higher damping capabilities, almost on a par with those of silicone oil, though slightly lower. This can be attributed to the relatively higher viscosity and bio-based properties of the castor oil. Recent studies on sustainable materials have shown that they are effective damping agents and are environmentally friendly, making them a viable option for damping fluids in various applications (27). Hydraulic oil and mineral oil, however, showed relatively lower damping capabilities, as compared to the other oils. This can be attributed to the relatively lower viscosity of these oils, which results in lower shear resistance in the fluid, thereby reducing damping capabilities. Similar results were observed in recent studies on vibration isolation systems, where damping performance is largely determined by the viscosity of the fluids used (28). Furthermore, recent trends in two-wheeler vibration control have also considered advanced damping techniques, such as magnetorheological and adaptive damping, which could improve rider comfort by reducing vibration at contact points (29). However, such techniques are also very complex and expensive. Therefore, the passive fluid-integrated seat concept proposed in this study offers a more practical and cost-effective solution. The use of the low-cost ADXL345 accelerometer and the Arduino-based data acquisition system proved effective in the experiment. Similar data-acquisition techniques using MEMS technology have also been effectively employed in recent vibration analysis studies (30). The 200 Hz sampling frequency was found to be effective in this experiment, as it was considered effective in the ISO 2631 standard for the range of human vibration exposure.

It is also worth noting that although reducing vibration exposure is likely to improve the rider's comfort, the study did not evaluate pressure distribution or analyse the rider's posture. Therefore, the comfort improvement can be considered only from a vibration analysis perspective. Furthermore, the experiment was conducted at a constant speed of 20 km/h, with road conditions that may not be representative of

all riding conditions. The findings of this study indicate that the fluid-integrated seat concept could be a more practical and cost-effective solution for reducing vibration in two-wheelers, using high-viscosity fluids such as silicone oil and castor oil.

Conclusion

In this study, an experimental attempt has been made to assess the effectiveness of integrating fluid cavities into a conventional polyurethane foam seat for reducing vibrations of two-wheelers under actual riding conditions. The results of this study clearly indicate that integrating fluids into a conventional polyurethane foam seat is highly effective for reducing vibration levels at the rider seat interface during both rumble strips and speed bump excitations, as per ISO 2631 guidelines. In this study, silicone oil was identified as having the highest damping performance among the oils tested, due to its high viscosity and viscous shear energy dissipation characteristics. The novelty of this study lies in developing an innovative, cost-effective fluid-integrated seat design to reduce vibration levels during actual riding conditions for two-wheelers without affecting the existing suspension system. The results of this study demonstrate the effectiveness of passive fluid-based damping and its potential to replace expensive, sophisticated active/semi-active suspension systems. The use of bio-based fluids, such as castor oil, also exhibits cost-effective, eco-friendly solutions for vibration reduction. From an application perspective, the proposed fluid-integrated seat design has the potential to enhance motorcyclists' comfort and reduce the risk of health problems from vibration-induced fatigue, especially in developing nations where motorcycles are commonly used for commuting. Though this study has shown promising results for integrating fluids into conventional polyurethane foam seats to reduce vibration levels during two-wheeler riding, it has some limitations. The operating conditions of this study were limited to a single operating speed and specific road conditions. The assessment of this study was limited to vibration measurements. The results of this study were not obtained through ergonomic and biomechanical analyses. Further research could be conducted to evaluate the effectiveness of the proposed system under different operating

speeds and road conditions. In addition, further research could be conducted to evaluate the effectiveness of the proposed system through ergonomic and biomechanical analyses.

Abbreviations

None.

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Author Contributions

Vishwanath Mali: conceptualization, experimental investigation, data analysis, manuscript preparation, Ajit Bhosale: conceptualization, experimental investigation, data analysis, manuscript preparation. All authors have read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

The authors declare that no generative AI tools were used in the writing of the manuscript.

Ethics Approval

This study does not involve human participants or animals requiring ethical approval.

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