International Journal on Emerging Technologies **8**(2): 40-42(2017)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

A Review of Whole-Body Vibration Exposure and Seat Suspension Control Strategies in Agricultural Tractors

Harbhinder Singh
University Institute of Engineering and Technology, Panjab University, Chandigarh, India.

(Corresponding author: Harbhinder Singh)
(Received 05 October, 2017 accepted 26 November, 2017)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT : Whole-body vibration (WBV) is a significant occupational hazard for agricultural tractor operators, particularly during prolonged field operations. Continuous exposure to vibration adversely affects operator comfort, productivity, and long-term musculoskeletal health. This review critically examines published literature on WBV characteristics in agricultural tractors, vibration measurement standards, health implications, and vibration mitigation strategies with special emphasis on seat suspension systems and intelligent control approaches. A structured literature selection methodology was adopted to analyze experimental investigations, analytical modeling techniques, and modern semi-active control strategies. The review highlights that conventional passive suspensions are insufficient under varying field conditions, whereas intelligent semi-active systems, especially fuzzy logic–based controllers, demonstrate superior vibration attenuation. Key research gaps and future directions for improving tractor ride comfort and operator safety are identified.

Keywords: Whole-body vibration, Agricultural tractors; Seat suspension, Intelligent control, Fuzzy logic, ISO 2631, Ride comfort.

I. INTRODUCTION

Whole-body vibration (WBV) remains one of the most critical occupational health challenges faced by agricultural tractor operators. Tractors frequently operate on uneven terrain and typically lack primary suspension systems, resulting in direct transmission of ground-induced vibrations to the operator through the chassis and seat. Prolonged exposure to WBV has been linked to lower back pain, spinal degeneration, fatigue, and reduced operational efficiency [1-3]. Numerous experimental and epidemiological studies have confirmed that vibration levels experienced during common agricultural operations often exceed comfort and health limits recommended by international standards.

II. METHODOLOGY FOR LITERATURE SELECTION

This review follows a structured literature selection methodology to ensure comprehensive and unbiased coverage. Peer-reviewed journal articles and conference papers were collected from major scientific databases including Scopus, Web of Science, IEEE Xplore, Science Direct, and SpringerLink. The review primarily considers literature published between 1990 and 2014, with emphasis on recent advances in intelligent and semi-active seat suspension systems [4].

Search queries included combinations of keywords such as whole-body vibration, agricultural tractor vibration, seat suspension, ISO 2631, ride comfort, fuzzy logic control, neural networks, adaptive control, and semi-active suspension. Inclusion criteria comprised experimental WBV studies in tractors, analytical and numerical modeling of tractor–seat systems, and research proposing vibration mitigation strategies [5-8]. Studies unrelated to agricultural machinery or lacking quantitative validation were excluded.

III. WHOLE-BODY VIBRATION IN AGRICULTURAL TRACTORS

Experimental studies consistently report that WBV levels in agricultural tractors are influenced by tractor type, engine power, tyre configuration, soil condition, implement attachment, and operating speed. Vertical vibration generally dominates under transport conditions, whereas longitudinal and lateral components become significant during tillage operations. Considerable variation exists in reported vibration levels due to differences in experimental setups, sensor placement, and measurement duration [9].

Most studies measure vibration at the seat pan using tri-axial accelerometers in accordance with ISO 2631. However, some investigations place sensors on the axle, chassis, or seat base, leading to differences in reported transmissibility values. These inconsistencies highlight the need for standardized experimental protocols for meaningful comparison of WBV studies.

IV. VIBRATION MEASUREMENT STANDARDS AND HEALTH IMPLICATIONS

The ISO 2631-1 standard is widely used for evaluating WBV exposure and assessing its effects on human comfort and health. Frequency-weighted root mean square (RMS) acceleration values are commonly compared against comfort boundaries and health guidance caution zones. Numerous studies report that tractor operators are exposed to vibration levels within or above the ISO 2631 health guidance caution zone (0.5–1.15 m/s²).

Long-term exposure to such vibration levels has been strongly associated with musculoskeletal disorders, particularly lower back pain and lumbar spine degeneration. Epidemiological studies indicate that operators exposed to RMS acceleration levels exceeding 0.8 m/s² for extended daily durations exhibit significantly higher prevalence of chronic spinal disorders.

V. SEAT SUSPENSION SYSTEMS FOR VIBRATION MITIGATION

Since most agricultural tractors lack chassis suspension, the seat suspension system plays a critical role in isolating vibration transmitted to the operator. Conventional passive seat suspensions employ fixed stiffness and damping parameters, which limits their effectiveness under varying operating conditions. These systems are generally effective only over a narrow frequency range and often fail during severe field excitations.

Semi-active seat suspensions, which allow real-time modulation of damping characteristics with low energy requirements, have emerged as a practical alternative. Experimental and simulation studies demonstrate that semi-active systems outperform passive suspensions in terms of vibration attenuation and ride comfort [10].

VI. INTELLIGENT CONTROL STRATEGIES FOR SEAT SUSPENSION

Intelligent control techniques have been widely applied to semi-active seat suspension systems to address nonlinearity and uncertainty in agricultural operating conditions. Fuzzy logic control is particularly popular due to its robustness and ease of implementation. Studies report that fuzzy-controlled suspensions achieve 20–45% reductions in frequency-weighted RMS acceleration compared to passive systems, with notable improvements in the critical 4–8 Hz frequency range.

Alternative intelligent approaches such as neural networks, adaptive control, and sliding mode control have also been explored. Neural network controllers offer strong adaptability but require extensive training data [11-13] Adaptive control strategies dynamically adjust system parameters but may face stability challenges. Sliding mode control provides high robustness but can introduce chattering effects. Hybrid control strategies combining fuzzy logic with other approaches have demonstrated enhanced performance but increase system complexity.

VII. MODELING AND SIMULATION APPROACHES

Dynamic modeling of tractor–seat systems is commonly used to predict vibration behavior and evaluate control strategies. Multi-degree-of-freedom models incorporating tractor body dynamics, tyre properties, implement-induced excitations, and seat suspension parameters are widely reported. Validation using experimental data improves model reliability and supports systematic comparison of control techniques [14-17].

VIII. RESEARCH GAPS AND FUTURE DIRECTIONS

Despite significant progress, several research gaps remain. These include long-term field validation of intelligent seat suspension systems, integration of driver posture and anthropometric variability into control design, real-time adaptation to changing soil and implement conditions, and comprehensive cost–benefit analyses for commercial adoption. Addressing these gaps is essential for translating advanced control strategies into practical agricultural applications.

IX. CONCLUSION

This review confirms that WBV remains a serious concern for agricultural tractor operators. Conventional passive seat suspensions are inadequate under variable field conditions. Intelligent semi-active seat suspensions, particularly those employing fuzzy logic control, demonstrate substantial potential for reducing vibration exposure and improving ride comfort. Future research should focus on long-term field validation and cost-effective implementation of intelligent suspension technologies.

REFERENCES

[1]. Ahmadian, M. and Vahdati, N. (2006). Transient dynamics of semi-active suspensions with hybrid control. *Journal of Intelligent Material Systems and Structures*, **17**(2), pp.145-153.

[2]. Ahn, K. K. (2014). Active pneumatic vibration isolation system using negative stiffness structures for a vehicle seat. *Journal of Sound and Vibration,* **333,** pp. 1245–1268.

[3]. Alfadhli, A., Darling, J. and Andrew, J. H. (2015). "The control of an active seat suspension using an optimized fuzzy logic controller based on preview information from a full vehicle model. *Journal of Vibrations*, pp. 1-21.

[4]. Al-Holou, N., Joo, D. S. and Shaout, A. (1996). The development of fuzzy logic based controller for semi-active suspension system. *Proceedings of the 37th Midwest Symposium on Circuits and Systems,* pp. 1373-1376.

[5]. Alleyne, A. and Hedrick, J. K. (1995). Non-linear adaptive control of active suspensions. I*EEE Trans. Control Syst. Technol.,* **3**(1), pp. 94–101.

[6]. Assadsangabi, B., Eghtesad, M., Daneshmand, F. and Vahdati, N. (2009). Hybrid sliding mode control of semi-active suspension systems. *Smart Materials Structures,* **18**(12).

[7]. Ballo, I. (2007). Comparison of the properties of active and semi-active suspension, *Vehicle System Dynamics,* **45,** 11, pp. 1065-1073.

[8]. Bani-Hani, K. A., Mashal, A. and Sheban, M. A. (2006). Semi-active neuro-control for base-isolation system using magnetorheological (MR) dampers. *Earthquake Engineering & Structural Dynamics,* **35,** pp. 1119–1144.

[9]. Barr, A. and Ray, J. (1996). Control of an active suspension using fuzzy logic. *Proceedings of the Fifth IEEE International Conference on Fuzzy Systems,* **1**, pp. 42-48.

[10]. Blundell, M. (1999). The modelling and simulation of vehicle handling part 3: tire modelling. *Journal of Multi-body Dynamics,* **214**(1), pp 1-32.

[11]. Boileau, P. E. and Rakheja, S. (1990). Vibration attenuation performance of suspension seats for off road forestry vehicles. *International Journal of Industrial Ergonomics,* **5**, pp. 275-291.

[12]. Bo, L. and Fan, Y. (2004). Design and simulation analysis of LQG controller of active suspension. *Transactions of The Chinese Society of Agricultural Machinery,* **1**, pp.45-49.

[13]. Burton, A., Truscott, A. and Wellstead, P. (1995). Analysis, modelling and control of an advanced automotive self-levelling suspension system. *IEEE Proceedings-Control Theory*, **142** (2), pp. 129-139.

[14]. Chalasani, R. (1986). Ride performance potential of active suspension systems-part I: simplified analysis based on a quarter-car model. *Proceedings of 1986 ASME Winter Annual Meeting, Los Angeles, CA*.

[15]. Chalasani, R. (1986). Ride performance potential of active suspension systens-Part II: comprehensive analysis based on a full-car model. *ASME Symposium on Simulation and Control of Ground Vehicles and Transportation Systems,* **80** (2), pp. 187-204.

[16]. Chang, C. C. and Roschke, P. (1998). Neural network modeling of a magnetorheological damper. *Journal of Intelligent Material Systems and Structures,* **9**, pp755–764.

[17]. Chang, C. C. and Zhou, L. (2002). Neural network emulation of inverse dynamics for a magnetorheological damper. *Journal of Structural Engineering,* **128**(2), pp 231–239.