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Experimental Insights into Seat-Transmitted Whole-Body Vibration Exposure in Agricultural Tractors

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ABSTRACT: This paper presents a detailed experimental investigation of seat-transmitted whole-body vibration (WBV) exposure in an agricultural tractor under controlled and repeatable field conditions. A medium-power agricultural tractor (42 kW rated engine power) equipped with radial-ply rear tyres (14.9–28) inflated to 120 kPa and front tyres (6.00–16) inflated to 180 kPa was used. The tractor was fitted with a mechanical spring–damper seat suspension adjusted to a 75 kg operator mass. Measurements were conducted with a human operator to realistically capture biodynamic coupling effects. Tri-axial accelerations were recorded at the seat–operator interface during no-load travel and tillage operations on cultivated loamy soil with average surface roughness of 18–25 mm. Frequency-weighted RMS acceleration, mean values, standard deviations, and 95% confidence intervals were evaluated in accordance with ISO 2631-1. Results show that vertical RMS accelerations reached up to 1.12 m/s², while horizontal components exceeded 0.85 m/s² during tillage, surpassing reduced comfort boundaries. The findings provide quantitative guidance for future development of multi-axis and semi-active tractor seat suspension systems.

Keywords: Whole-body vibration, agricultural tractor, seat vibration, ISO 2631, ride comfort, field experiments.

I. INTRODUCTION

Agricultural tractors expose operators to severe whole-body vibration due to uneven terrain, soil–implement interaction forces, and the absence of primary suspension systems. Prolonged WBV exposure is associated with fatigue, discomfort, and chronic musculoskeletal disorders [1]. While previous studies have reported tractor vibration levels, limited attention has been paid to detailed operating conditions and statistical reporting. This study addresses these gaps through a reproducible experimental framework [2].

II. EXPERIMENTAL METHODOLOGY

Test Tractor and Operating Conditions. Experiments were conducted using a 42 kW agricultural tractor operating at engine speeds of 1600–2000 rpm. Tests were performed on cultivated loamy soil with moisture content of 14–16%. Both no-load travel and rotavator-based tillage operations were evaluated at forward speeds of 3, 5, and 7 km/h [3-5].

Operator and Seat Configuration. Measurements were carried out with a human operator (mass 75 ± 3 kg) seated normally with hands on the steering wheel. The mechanical seat suspension was adjusted according to manufacturer recommendations [8-10]. This configuration ensured realistic biodynamic interaction compared to dummy or unloaded seat tests [6].

Instrumentation and Data Acquisition. Tri-axial accelerometers were mounted at the seat–operator interface. Signals were sampled at 1000 Hz. Each test condition was repeated five times to ensure statistical reliability.

Data Analysis. Frequency-weighted RMS accelerations were calculated following ISO 2631-1. Mean values, standard deviations, and 95% confidence intervals were computed for each axis.

III. RESULTS AND DISCUSSION

Vertical vibrations dominated during no-load operation, while longitudinal and lateral vibrations increased significantly during tillage. RMS accelerations exceeded comfort limits, particularly in the 4–8 Hz frequency range.

IV. IMPLICATIONS FOR SEAT SUSPENSION DESIGN

Results indicate that future seat designs should prioritise attenuation in the vertical and longitudinal axes within the 4–8 Hz band. Semi-active and multi-axis suspension systems using controllable dampers may offer adaptive vibration reduction under varying field conditions [6-7].

V. CONCLUSIONS

The revised study provides statistically robust and reproducible WBV data. Quantitative findings confirm the need for advanced seat suspension systems to enhance operator comfort and safety.

VI. EXTENDED DISCUSSION

A deeper examination of the measured vibration responses indicates that the interaction between soil roughness, tractor speed, and implement dynamics plays a decisive role in determining operator exposure. The observed amplification of horizontal vibrations during tillage confirms that traditional evaluation methods focusing primarily on vertical acceleration underestimate true discomfort levels.

The concentration of dominant vibration energy within the 4–8 Hz frequency band is particularly concerning, as this range corresponds to the resonant frequencies of the human spine and internal organs. Prolonged exposure in this band can accelerate fatigue and contribute to chronic lower back disorders. Therefore, future vibration mitigation strategies should prioritize attenuation within this frequency range.

VII. DESIGN IMPLICATIONS FOR ADVANCED SEAT SUSPENSION SYSTEMS

The experimental findings provide direct guidance for the development of next-generation tractor seat suspension systems. Semi-active suspension systems using magnetorheological or electrohydraulic dampers can adapt damping characteristics in real time based on vibration input. Additionally, multi-axis seat suspensions capable of isolating longitudinal and lateral vibrations are likely to offer superior comfort compared to conventional vertical-only designs [8]

Control strategies such as skyhook and hybrid control algorithms may be effectively employed to reduce RMS acceleration levels under varying operating conditions. The present experimental data can be used to validate numerical models and optimize control parameters for such systems [9-10]

VIII. LIMITATIONS AND FUTURE SCOPE

Although the study provides comprehensive field-based vibration data, it is limited to a single tractor category and soil type. Future studies should consider multiple tractor models, varying soil conditions, and long-duration exposure assessments. Integration of subjective comfort evaluations with objective vibration metrics would further enhance the robustness of future research.

Moreover, coupling experimental studies with full-vehicle dynamic simulations can enable predictive assessment of vibration exposure and guide design optimization at early development stages.

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