Transport and Telecommunication, 2025, volume 26, no. 2, 175-184
Transport and Telecommunication Institute, Lauvas 2, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2025-0014

EXPERIMENTAL STUDY OF THE EFFECT OF TIRE PRESSURE AND CAB HEIGHT OF A TRACTOR-TRAILER DRIVER ON DRIVING COMFORT

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The work concerns the study of the influence of the driver's cabin and tire pressure settings on the driving comfort in a semi-trailer tractor, assessed by analyzing vibrations at the base of the driver's seat during the transport of mining spoil. The following configurations were considered: a tractor with nominal cabin height and tire pressure settings, a raised cabin, and increased tire pressure. Driving comfort was assessed based on the difference between the maximum and minimum vertical acceleration and the determined RMS (Root Mean Square) and PSD (Power Spectral Density) indicators. From the ride comfort perspective, the lowest RMS values were for the vehicle with correctly set suspension and tire pressure. PSD analysis indicated the dominance of vibrations with a frequency of 1-3 Hz, which have a large impact on travel comfort.

Keywords: Driver’s comfort, dynamics loads, tire pressure settings, tractor-trailer

1. Introduction

Driving comfort in trucks in the transportation, construction, mining, quarrying, and agricultural industries plays a key role in both driver health and operator-driver efficiency. The construction and mining transport sectors are the industries with the highest percentage of workers exposed to vibrations in the European Union. Truck drivers often perform tasks on a variety of uneven surfaces and are therefore exposed to whole-body vibration daily, resulting in a high incidence of musculoskeletal disorders, especially lower back pain. Back pain is the most common cause of work-related disability for drivers and continues to be the leading cause of morbidity and loss of productivity among this group of workers (Johnson *et al.*, 2018). Health problems may result from the value of the resonant frequencies of these body parts (lumbar spine 8-12 Hz) (Dębowski, 2021). The resonant frequencies of the body parts of a seated person during vertical vibration depend on the anatomical structure and biomechanics of the body. The frequency of vertical vibration of the human body below about 0,5 Hz can cause symptoms of motion sickness, sweating, nausea, or vomiting (Griffin, 1990). During vibrations with frequencies below about 2 Hz, most body parts move vertically according to the forcing. Human eyes can follow objects moving with the body, or compensate for the movement and look at stationary objects. Free hand movements can be disrupted causing some interference with hand positioning activities. The first resonance occurs at about 5 Hz but interference with simple hand activities (such as writing or holding items) can occur in the 4-5 Hz range. Blurring of objects can occur at vibration frequencies of 15-60 Hz, which is related to the resonant frequency of the eye in the head, as well as the complex dynamic response of the body between the seat and the head.

In the context of changing vehicle design solutions affecting safety and comfort, driver comfort research is timely and crucial for future design and operating configurations. In highly automated vehicles, interiors often differ from those of traditional vehicles. New design solutions for tires, vehicle suspension, and cabin, as well as possible changes in parameters in the process of operation, mean that new standards are required for the entire vibration isolation system of the vehicle: tires, vehicle suspension, cabin suspension, and seat suspension taking into account individualized anthropometric parameters of the driver, especially since the driver in the process of operation can change key parameters, i.e. stiffness and damping of tires and height of the driver's cabin setting. Merely increasing only the driver's body weight while keeping other parameters unchanged can limit adverse health effects (de la Hoz-Torres *et al.*, 2022). Anthropometric characteristics are considered the main basis for the design of seat dimensions and determine the contact forces between the human body and the seat, which affect the biomechanics of seat-human interaction (Hiemstra-van Mastrigt *et al.*, 2017). Ride duration plays an important role in terms of ride comfort (Drost *et al.*, 2017).

In highly automated vehicles, passengers can assume various seating positions, including semi-reclining, and the entire vehicle vibration isolation system must provide an adequate level of protection against vibrations during operation regardless of the position occupied in the cabin and the type and condition of the road surface.

The elastic-damping properties of a vehicle's tires can be both design parameters, defined by the vehicle manufacturer, and operational parameters, where the driver can change them within a limited range. Tire pressure is a key factor in driver comfort. Proper tire pressures ensure optimal vibration damping and vehicle stability. Tires dampen vibrations, which reduces the driver's perception of vibration. Excessive tire deformation can lead to greater energy loss, which affects driving economy, tire overheating and the risk of tire damage, deterioration of steering and steering precision, and this can negatively affect the driver's psychological comfort. In turn, too much tire pressure results in reduced vibration damping, as tires are more rigid, which increases the transmission of vibrations and shocks from the road surface to the cabin. The new design of cellular-structure unpressurized tires features higher radial stiffness and higher radial hysteresis compared to pneumatic tires, which affects vibration damping and road surface contact area (Drost *et al*., 2020). The cellular structure of non-pneumatic tires generates higher unit pressures in the road contact area. Optimization of tire cell structure masses and characteristics is aimed at reducing the vertical acceleration of the driver's seat and the dynamic load on the wheels (Belhorma *et al.*, 2022).

In a vehicle without a suspension system, all of the energy from the wheel would be transferred to the frame as the vehicle moves, which could result in a loss of contact between the wheel and the road surface. The comfort of the vehicle is related to the dissipation of energy generated through shocks on the road without causing excessive vibration in the vehicle (Sharma *et al.*, 2016). The optimal suspension design of heavy vehicles, allows the vehicle to maintain increased lateral tilt stability (Cao *et al.*, 2007). The traction properties of any vehicle can be improved by keeping the body vibration frequency low during typical operation (Jain *et al.*, 2007). Typical body vibration frequencies for a passenger car are 1-1,5 Hz, while for a truck they are 2-2,5 Hz.

Proper cab height adjustment affects both the sensation of vibration and the driver's ergonomics, visibility, and vehicle stability. The optimal cab setting depends on the characteristics of the route and the driver's preferences. Modern tractor-trailers often offer adjustable cab suspension heights, allowing the driver to adjust conditions to suit current needs.

Seat suspensions are widely used to reduce the dynamic loads acting on people in trucks, including buses and semi-trailer trucks (Kim *et al.*, 2018a). However, current standard seats in most passenger cars rely on the seat cushion design to dampen vibrations without any suspension system under the seat cushion and have limited effectiveness in dampening vibrations (Griffin, 1990). Automakers can improve seat design to reduce driver discomfort by combining a soft seat cushion through the suspension system with the cabin to minimize vibration and a hard backrest for protection during accidents (Lantoine *et al.*, 2021). Passive air suspension seats are the current industry standard, but new technologies, such as electromagnetic active vibration reduction seats, offer potentially significant improvements in reducing dynamic loads acting on the human body (Davies *et al.*, 2022). In addition, a seat with active suspension reduces vertical vibration exposure by up to 50% compared to passive seats (Johnson *et al.*, 2018). A seat with motion-enabled suspension can reduce vibration exposure and the associated strain on the neck and lower back muscles in agricultural vehicle operators (Kim *et al.*, 2018b). The height of the seat relative to the floor and the seat back tilt can be universal, while the seat tilt, height, and thickness of the lumbar support require variety to accommodate different body types (Wang *et al.*, 2023). The seat material itself plays a key role in damping vibrations and improving driving comfort, which is important in vehicle comfort (Wu *et al.*, 1999). Optimal parameters of the body position behind the steering wheel, including an elbow angle of 100° and a steering column tilt of about 50°, minimize stress on the muscles of the hands (Kuta *et al.*, 2019).

Designing comfortable seats requires a customized approach because ergonomic criteria, while important, do not always meet users' comfort expectations (Kolich *et al.*, 2003). Inadequate seat support leads to abnormal postures and thus increased physical strain, compounding driver fatigue. Research findings underscore the importance of designing seats that support correct posture and minimize dynamic loads (Michida *et al.*, 2001). A trend can be observed that vehicles with low vibration levels are rated much better by passengers of both individualized vehicles and public transport passengers (Bakinowski *et al.*, 2022; Belhorma *et al.*, 2022).

Experimental testing of vehicles is the basis for the modernization and development of motor vehicle design (Więckowski, 2024, Pusty *et al.*, 2024), while the rapid development of motorization has come with the development of computer, computational, and measurement techniques. Computer techniques led to the development of computer simulations and models of traffic dynamics as early as the 1960s with varying levels of model complexity. These models evolved from simple flat models with a small number of degrees of freedom to more complex spatial models. In the paper (Ahn *et al.*, 2023), a flat half-vehicle suspension model presented as a linear system with 4 degrees of freedom consisting of a cab connected to the tractor body connected to the front and rear suspension systems of the vehicle was subjected to impacts coming from the road surface via the tire. Mathematical models are constantly being developed and used today to improve vehicle design. However, experimental research is the basis for building mathematical computational models and is commonly used to evaluate vehicle ride comfort (Zehsaz *et al.*, 2011; Lozia, 2022; Yang *et al.*, 2009).

2. Purpose of the work

The purpose of this study is to analyze the effect of changes in tire pressure and the height of the driver's cab on the driver's comfort in a tractor-trailer loaded with a semi-trailer of mining spoils. This objective will be realized in experimental studies of real objects by measuring the vibrations of the vehicle cab, measured at the base of the driver's seat.

3. Object of study and description of the road

The object of the study was a truck tractor coupled to a semi-trailer loaded to the authorized total weight with 20000 kg of mining spoils. The roads on which the acceleration values were measured are shown in Figures 1 and 2, and the location of the acceleration sensor at the base of the driver's seat is shown in Figure 3.

Figure 1. View of the surface of roads on which acceleration values were measured - straight

Figure 2. View of the surface of roads on which acceleration values were measured - bridge

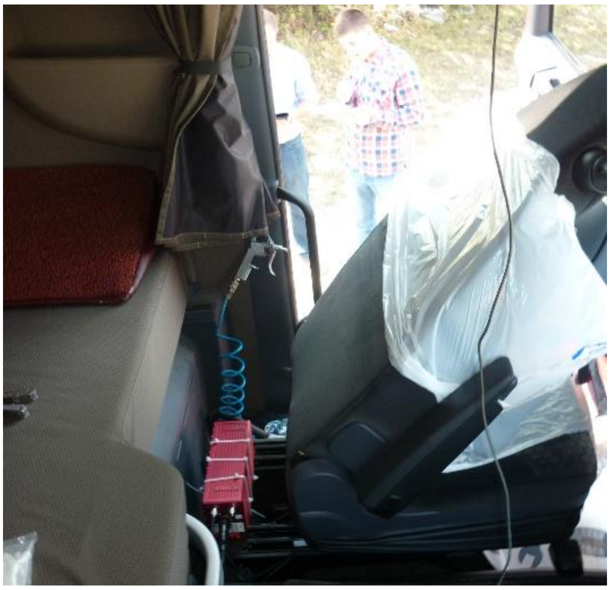


Figure 3. View of the location of the acceleration sensor at the base of the driver's seat

4. Scope of the study

The scope of the study included measuring the vibration of the driver's cabin at the base of the seat while driving on selected road sections. Test configurations adopted:

- configuration 1 - tractor with driver's cab nominally, tire pressure nominally;
- configuration 2 - tractor with driver's cab raised, tire pressure nominally;
- configuration 3 - tractor with driver's cab raised, tire pressure increased.

The height of the cab setting was nominally: 330 mm at the front, 55 mm at the rear, raised: 350 mm at the front, and 60 mm at the rear. The tire pressure of the front wheels was nominally: 0,72 MPa, raised by 0,91 MPa. The tests were conducted in Mietków in Lower Silesia Province, Poland, on a road while transporting mining spoils. The road had an asphalt surface with transverse irregularities and no visible cavities. The following survey sections were marked on the road: a straight line, on which it was traveled at a speed of about 55 km/h; a bridge with a length of about 380 m, over which it traveled at a speed of approx. 40 km/h.

5. Time domain results

The results of the recorded measurements of the components of the acceleration vector in three mutually perpendicular directions (AcX, AcY, AcZ) are shown in Figure 4a-f. These are the components of the acceleration values in the time domain. Registration of the above-described waveforms was carried out in a reference system rigidly connected to the OXTS RT3002 measuring device, at its mounting point, and the sampling frequency was 100 Hz.

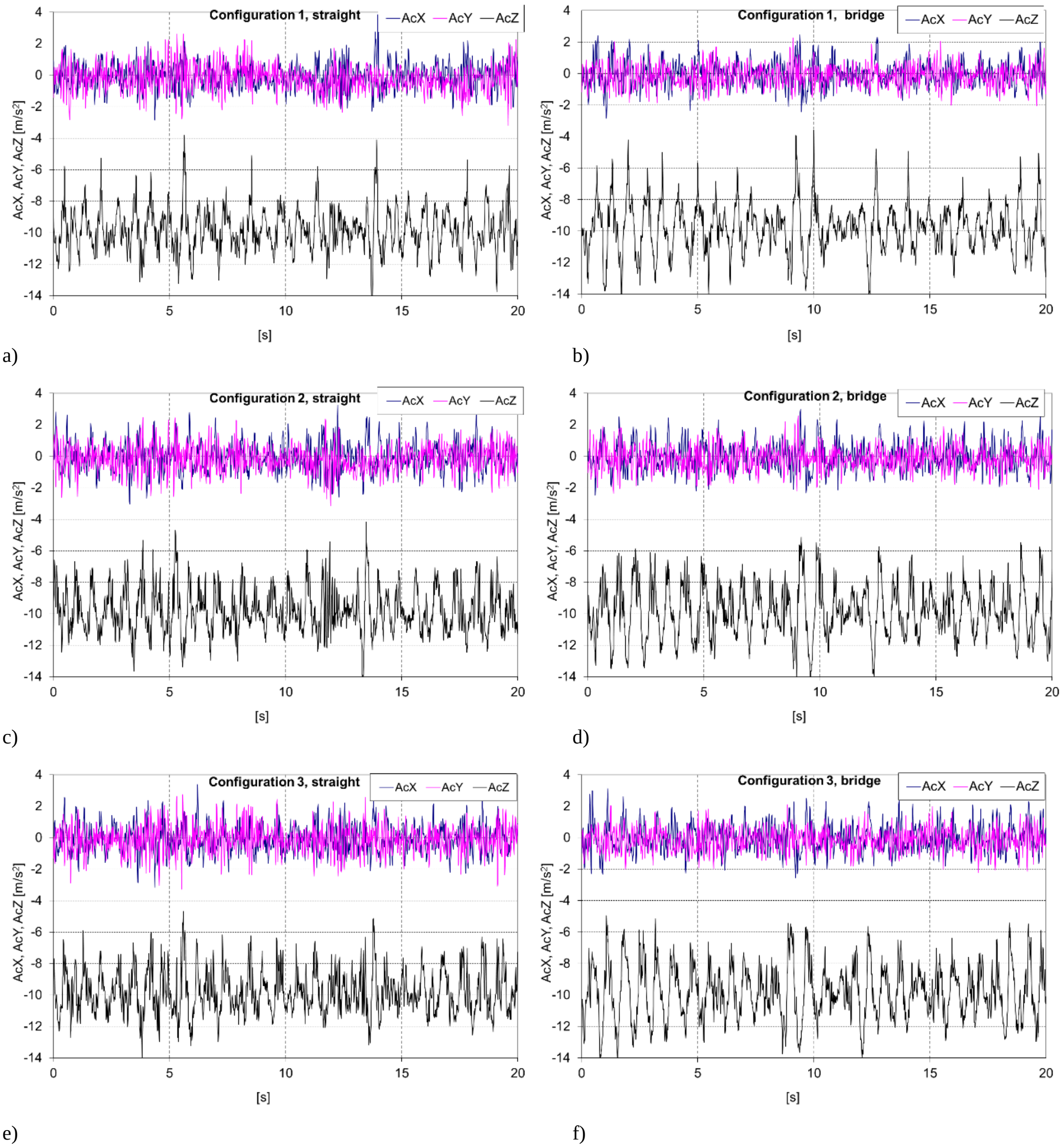


Figure 4. Results of measurements of the components of the acceleration vector in three mutually perpendicular directions; a) configuration 1 – straight, b) configuration 1 – bridge, c) configuration 2 – straight, d) configuration 2 – bridge, e) configuration 3 – straight, f) configuration 3 – bridge

To evaluate driving comfort, the difference in the maximum values of the vertical component of the acceleration value (Ac) was chosen as a comparative quantity:

$$Ac = AcZ_{max} - AcZ_{min}, \tag{1}$$

where: AcZ_{max} – maximum value of the vertical component of acceleration [m/s^2], AcZ_{min} – minimum value of the vertical component of acceleration [m/s^2].

Table 1. Test results in AcZ_{max}, AcZ_{min}, and calculations Ac

Measuring section	Configuration 1			Configuration 2			Configuration 3		
	AcZ_{min}	AcZ_{max}	Ac	AcZ_{min}	AcZ_{max}	Ac	AcZ_{min}	AcZ_{max}	Ac
straight	-14,74	-3,81	10,67	-14,41	-4,17	10,24	-14,00	-4,67	9,32
bridge	-16,10	-1,83	14,26	-16,32	-1,93	14,38	-16,15	-1,31	14,84

Ac values are small on a straight road, ranging from 9,32 m/s^2, (configuration 3) to 10,93 m/s^2 (configuration 1). Smaller differences in Ac values indicate higher ride comfort. The best comfort occurs in configuration 3.

When crossing the bridge, the highest Ac values occur in configuration 3 (14,84 m/s^2), suggesting the lowest ride comfort. The smallest difference is in configuration 1 (14,26 m/s^2). When driving on a straight section, configuration 2 was the least favorable, from the point of view of driving comfort, while configuration 3 was the least favorable when crossing a bridge.

In the next step, Root Mean Square (RMS) values were determined, which are appropriate for analyzing acceleration signals because they reflect the effective energy of vibrations, are robust to phase variation, and allow for a standardized comparison of different signals. In vibration and mechanics, RMS is a key tool for evaluating vibration levels and their potential impact on mechanical systems (Engel, 2001; Griffin, 1990). RMS was determined from the following relationship:

$$RMS = \sqrt{\frac{1}{T}\int_0^T AcZ^2(t)dt}, \quad (2)$$

where: T – duration of the acceleration signal AcZ.

Table 2. The results of calculating the value of RMS

Measuring section	RMS [m/s^2]		
	Configuration 1	Configuration 2	Configuration 3
straight	11,13	11,18	11,16
bridge	11,46	11,63	11,6

The determined RMS values on a straight section are very similar in all configurations, with differences of only 0,05 m/s². This indicates the stability of traffic dynamics on a straight section of the road regardless of the configuration considered. The lowest RMS value occurs in configuration 1 (11,13 m/s²), while the highest RMS occurs in configuration 2 (11,18 m/s²), thus indicating the highest dynamics in this configuration.

Raising the driver's cab with the driver's cab in a situation of increased tire pressure resulted in a slight decrease in RMS values (configurations 2 and 3). The determined RMS values on the bridge are higher than on the straight section for each configuration, indicating more dynamic traffic conditions in this type of section. The lowest RMS occurs in configuration 1 (11,46 m/s^2), and the highest RMS occurs in configuration 2 (11,63 m/s^2), indicating the highest dynamics. RMS differences on the bridge between configurations are 0,17 m/s^2, which is noticeably higher than on the straight section (0,05 m/s^2). This indicates a greater variation in dynamics across configurations on the bridge. Configuration 2 on both sections has the highest dynamics, which may be related to certain traffic parameters in this configuration.

Time-domain analysis led to the following conclusions:

- a greater effect on the adverse transmission of vibrations to the seat base is caused by raising the cab than by increasing the tire pressure;
- the lowest RMS values from the point of view of driving comfort occurred in configuration 1, for a vehicle with properly adjusted suspension and tire pressure.

Based on the RMS values of the recorded accelerations, it can be concluded that the level of discomfort when driving on a straight road and when crossing a bridge is only at the level of minor discomfort according to BS 6841 (BSI, 1987) and ISO 2631-1 (1997).

6. Frequency domain research

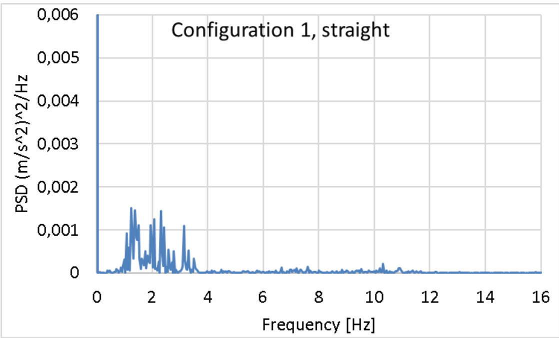
Analyzing acceleration waveforms in the frequency domain will indicate which frequencies are present, and which are relevant to resonance and its effects on the human body or the vehicle. About the vehicle, high frequencies can indicate problems such as excessive wear, mechanical damage, or seizure of cabin suspension components. Therefore, the results of measuring the time signal AxZ(t) were used to determine the amplitude spectrum |X[k]|, as a module of the composite values returned by the FFT (Fast Fourier Transform) to determine the PSD (Power Spectral Density) from relation (3).

$$PSD[k] = \frac{|X[k]|^2}{\Delta f}, \tag{3}$$

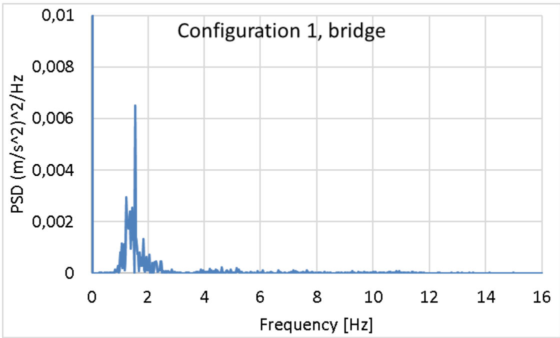
where:
$|X[k]|^2$ – square of the modulus of the amplitude spectrum for the frequency k,
N – number of time domain signal samples available for analysis,
Δf – frequency resolution (distance between points in the frequency spectrum).

$$\Delta f = \frac{1}{T}. \tag{4}$$

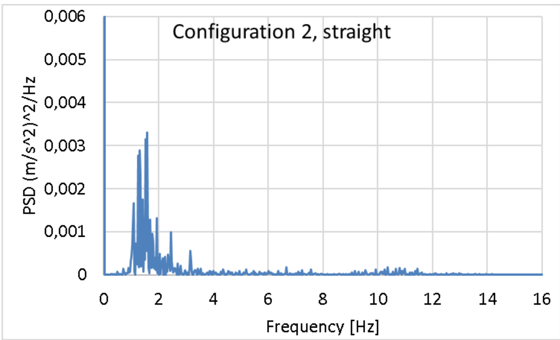
The results of PSD calculations are shown in Figure 5. Based on the analysis performed in the frequency domain, it is possible to determine in which frequency range there is an impact of vibrations on the base of the driver's seat. For further analysis, the frequency range of 0,02-16 Hz was selected, which can cause a negative impact on driving comfort under the analyzed conditions.



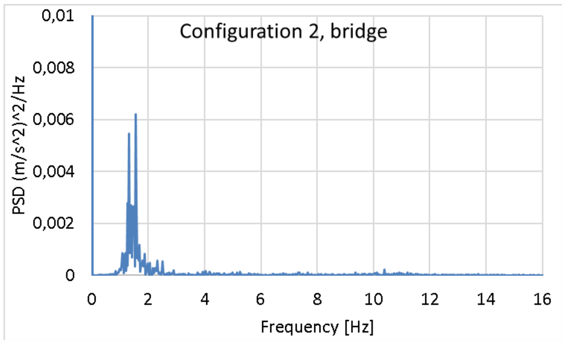
a)



b)



c)



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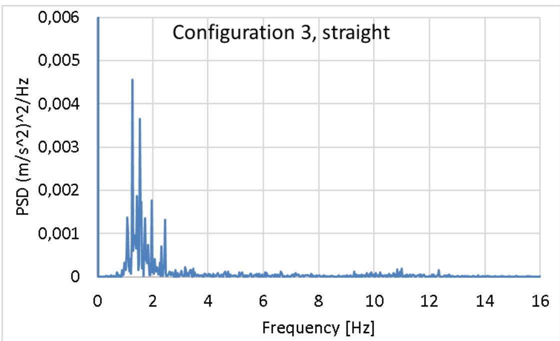
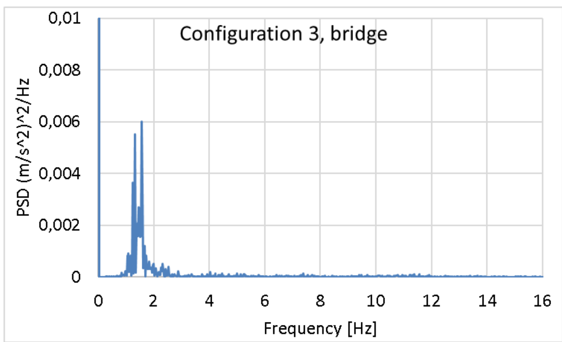


e)



f)

Figure 5. PSD calculation results; a), c), e) straight, b), d), f) bridge

During straight-line travel, for a vehicle with a cab and nominal tire pressures (configuration 1), the PSD values are the lowest in the analyzed frequency range and do not exceed 0,0016 $(m/s^2)^2/Hz$. The dominant PSD values are in the frequency range of 1-3,8 Hz. Increasing the height of the cabin increases the maximum PSD values to 0,0035 $(m/s^2)^2/Hz$ and the practical disappearance of vibrations with frequencies higher than 3 Hz. Increasing tire pressure and raising the cab results in an increase in PSD values to 0,0046 $(m/s^2)^2/Hz$ and the disappearance of vibrations with frequencies greater than 2,5 Hz.

When crossing the bridge, the most favorable PSD values from the point of view of comfort occur for the correct cab height and tire pressure values. Increasing the cab height resulted in two dominant frequencies of 1,3 and 1,6 Hz, and they also occur for increased tire pressure (configuration 3), although the maximum value is slightly lower than in configuration 2. In general, vibrations with frequencies above 3 Hz are not transmitted to the seat base.

7. Conclusions

The paper presents a problem related to the study of the influence of the driver's cab setting and tire pressure on driving comfort in a tractor-trailer loaded with a semi-trailer with mining spoils. The impact of vibrations was evaluated by analyzing the recorded signals of the vertical component of the acceleration vector at the base of the driver's seat. The methodology of road experimental research is presented, and methods for analyzing the studied phenomena in the time and frequency domain are used.

Analysis of traffic dynamics on road sections and the bridge in different configurations of a semitrailer tractor loaded with a semi-trailer with mining spoils shows significant differences in driving comfort, as measured by Ac accelerations and dynamic parameters such as RMS and PSD.

Ac values were higher on the bridge, suggesting a less comfortable ride. The Ac value was particularly high in configuration 3 (14,84 m/s^2), while the smallest difference was observed in configuration 1 (14,26 m/s^2). In contrast, configuration 2 was the least comfortable on a straight stretch of road, while configuration 3 was the least comfortable on a bridge.

Time-domain analysis showed that raising the cab had a greater effect on the adverse transmission of vibrations to the seat base than increasing tire pressure. The lowest RMS values, indicating the highest comfort, occurred in configuration 1, which had the suspension and tire pressure correctly adjusted.

In terms of PSD spectrum analysis, on a straight stretch of road, the most favourable PSD values occurred in configuration 1, with nominal pressure and cab height in line with the standard. Raising the cab and increasing the tire pressure introduced additional vibrations, especially above 2,5 Hz, which increased the PSD values to 0,0046 $(m/s^2)^2/Hz$.

When crossing the bridge, the best PSD values from a comfort standpoint occurred in configuration 1, where both cab height and tire pressure were nominal. Increasing cab height, particularly in configuration 3, resulted in two dominant ones in the 1,3-1,6 Hz frequency range. In contrast, increasing the tire pressure in configuration 2 resulted in the appearance of additional vibrations in the same range, but with smaller maximum values.

The conclusions of the analysis show that configuration 1 provides the best driving comfort both on a straight stretch of road and during a bridge crossing. Increasing the height of the cab increases the transmission of vibrations, which decreases comfort, and raising the tire pressure has less impact on the dynamics of the impact on the driver's seat base. The PSD analysis indicates the dominance of vibrations with a frequency of 1-3 Hz, which have the greatest impact on the comfort of a mining truck tractor.

References

1. Ahn, D.-V., Kim, K., Oh, J., Seo, J., Lee, J. W., and Park, Y.-J. (2023) Optimal control of semi-active suspension for agricultural tractors using linear quadratic Gaussian control. *Sensors*, 23(14), 6474. https://doi.org/10.3390/s23146474.
2. Bakinowski, Ł., and Firlik, B. (2022) Influence of the type of place occupied by a tram passenger on the ride comfort. *Archives of Transport*, 62(2), 49–58. https://doi.org/10.5604/01.3001.0015.9176.
3. Belhorma, M., and Bouchikhi, A. S. (2022) Multi-objective optimisation of the electric wheelchair ride comfort and road holding based on Jourdain’s principle model and genetic algorithm. *Acta Mechanica et Automatica*, 16(1), 58–69. https://doi.org/10.2478/ama-2022-0008.
4. BSI. (1987) *BS 6841 - Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.* British Standard Institution. https://doi.org/10.3403/00171912U.

5. Cao, D., Rakheja, S., and Su, C.-Y. (2007) *Optimal damping design of heavy vehicle with interconnected hydro-pneumatic suspension*. SAE Technical Paper 2007-01-0584. https://doi.org/10.4271/2007-01-0584.
6. Davies, H. W., Wang, F., Du, B. B., Viventi, R., and Johnson, P. W. (2022) Exposure to whole-body vibration in commercial heavy-truck driving in on- and off-road conditions: Effect of seat choice. *Annals of Work Exposures and Health*, 66(1), 69–78. https://doi.org/10.1093/annweh/wxab078.
7. de la Hoz-Torres, M. L., Aguilar, A. J., Ruiz, D. P., and Martínez-Aires, M. D. (2022) Whole body vibration exposure transmitted to drivers of heavy equipment vehicles: A comparative case according to the short- and long-term exposure assessment methodologies defined in ISO 2631-1 and ISO 2631-5. *International Journal of Environmental Research and Public Health*, 19(9), 5206. https://doi.org/10.3390/ijerph19095206.
8. Dębowski, A. (2021) *Torsional vibration and its damping in the motorbike steering system*. Warsaw: Publishing House of the Military University of Technology, 157 (in Polish).
9. Drost, J. P., Shafer, M. D., and Bush, T. R. (2020) Comfortable leg splay of mid-sized males in automotive seats. *Applied Ergonomics*, 85, 103062. https://doi.org/10.1016/j.apergo.2020.103062.
10. Engel, Z. (2001) *Environmental protection against vibration and noise*. Warsaw: Scientific Publishers PWN.
11. Griffin, M. J. (1990) Vibration and Human Responses. *Handbook of human vibration, Academic Press,* 1-25. https://doi.org/10.1016/B978-0-12-303040-5.50005-2.
12. Hiemstra-van Mastrigt, S., Groenesteijn, L., Vink, P., and Kuijt-Evers, L. F. M. (2017) Predicting passenger seat comfort and discomfort on the basis of human, context and seat characteristics: A literature review. *Ergonomics*, 60(7), 889–911. https://doi.org/10.1080/00140139.2016.1233356.
13. ISO 2631–1. (1997) *Mechanical vibration and shock. Evaluation of human exposure to whole-body vibration. Part 1*. General Requirements, International Organization for Standardization.
14. Jackowski, J., Żmuda, M., and Wieczorek, M. (2023) Comparative analysis of small size non-pneumatic tires and pneumatic tires - radial stiffness and hysteresis, selected parameters of the contact patch. *Eksploatacja i Niezawodność – Maintenance and Reliability*, 25(3). https://doi.org/10.17531/ein/167362.
15. Jain, P. (2007) *Design and analysis of a tractor-trailer cabin suspension*. SAE Technical Paper 2007-26-047. https://doi.org/10.4271/2007-26-047.
16. Johnson, P. W., Zigman, M., Ibbotson, J., Dennerlein, J. T., and Kim, J. H. (2018) A randomized controlled trial of a truck seat intervention: Part 1—Assessment of whole body vibration exposures. *Annals of Work Exposures and Health*, 62(8), 990–999. https://doi.org/10.1093/annweh/wxy062.
17. Kim, J. H., Dennerlein, J. T., and Johnson, P. W. (2018b) The effect of a multi-axis suspension on whole body vibration exposures and physical stress in the neck and low back in agricultural tractor applications. *Applied Ergonomics*, 68, 80–89. https://doi.org/10.1016/j.apergo.2017.10.021.
18. Kim, J. H., Marin, L. S., and Dennerlein, J. T. (2018a) Evaluation of commercially available seat suspensions to reduce whole body vibration exposures in mining heavy equipment vehicle operators. *Applied Ergonomics*, 71, 78–86. https://doi.org/10.1016/j.apergo.2018.04.003.
19. Kolich, M. (2003) Automobile seat comfort: occupant preferences vs. anthropometric accommodation. *Applied Ergonomics*, 34(2), 177–184. https://doi.org/10.1016/S0003-6870(02)00142-4.
20. Kuta, Ł., Stopa, R., Szyjewicz, D., and Komarnicki, P. (2019) Determination of comfortable position for tractor driver's hands based on dynamic load. *International Journal of Industrial Ergonomics*, 74, 102866. https://doi.org/10.1016/j.ergon.2019.102866.
21. Lantoine, P., Lecocq, M., Bougard, C., Dousset, E., Marqueste, T., Bourdin, C., Allègre, J.-M., Bauvineau, L., and Mesure, S. (2021) Car seat impact on driver's sitting behavior and perceived discomfort during prolonged real driving on varied road types. *PLOS ONE*, 16(11), e0259934. https://doi.org/10.1371/journal.pone.0259934.
22. Lozia, Z. (2022) Application of modelling and simulation in durability tests of vehicles and their components. *Energies*, 15(24), 9398. https://doi.org/10.3390/en15249398.
23. Michida, N., Okiyama, H., Nishikawa, K., and Nouzawa, T. (2001). *A study of drivers' fatigue mechanisms during long hour driving.* (SAE Technical Paper 2001-01-0381). https://doi.org/10.4271/2001-01-0381.
24. Pusty, T., Mieteń, M., Pilich, J., Simiński, P., Kupicz, W., Lewiński, R., Mysłowski, J. (2024) Research on the possibility of carrying out convoy driving missions using vehicles with varying degrees of autonomy. *Archives of Transport*, 72(4), 7-21. https://doi.org/10.61089/aot2024.xdtvm095.
25. Sharma S. K., Pare V., Chouksey M., and Rawal B.R. (2016) Numerical studies using full car model for combined primary and cabin suspension. *Procedia Technology,* 23, 171-178. doi:10.1016/j.protcy.2016.03.014.

26. Wang, J., Zhi, J.-Y., Zhang, X.-W., Wei, F., and Zhang, L.-L. (2023) A method of aircraft seat dimension design for long-term use by passengers with different body types. *International Journal of Industrial Ergonomics*, 98, 103520. https://doi.org/10.1016/j.ergon.2023.103520.
27. Więckowski, D. (2024) *Experimental testing on motor vehicles*. Warsaw: Publishing House of the Warsaw University of Technology (in Polish).
28. Wu, X., Rakheja, S., and Boileau, P.-É. (1999) Distribution of human–seat interface pressure on a soft automotive seat under vertical vibration. *International Journal of Industrial Ergonomics*, 24(5), 545–557. https://doi.org/10.1016/S0169-8141(98)00058-4.
29. Yang, Y., Ren, W., Chen, L., Jiang, M., and Yang, Y. (2009) Study on ride comfort of tractor with tandem suspension based on multi-body system dynamics. *Applied Mathematical Modelling*, 33(1), 11–33. https://doi.org/10.1016/j.apm.2007.10.011.
30. Zehsaz, M., Sadeghi, M. H., Ettefagh, M. M., and Shams, F. (2011) Tractor cabin's passive suspension parameters optimization via experimental and numerical methods. *Journal of Terramechanics*, 48(6), 439–450. https://doi.org/10.1016/j.jterra.2011.09.005.