Experimental comparison of smooth movement of an agricultural tractor with balancer suspension and torsion bar suspension

I P Troyanovskaya¹,², V V Krasnokutsky¹ and M A Rusanov¹,²

¹ South Ural State University, 76, Lenin Avenue, Chelyabinsk 454080, Russia
² South Ural State Agrarian University, 13, Gagarina street, Troitsk 457100, Russia
e-mail: tripav63@mail.ru

Abstract. One of the reasons for the increased fatigue of tracked agricultural tractor operators is vibration. Reducing overall vibration is possible due to a change in suspension. All agricultural tracked tractors are equipped with an elastic balancing suspension, as a rule. Kharkov Tractor Plant has released an experimental batch of tractors with torsion bar suspension. The aim of this study was to determine the effect of the type of suspension on the smooth movement of the tractor. The experiment considered the real modes of operation of the tractor: plowing the ground in first and fourth gears, as well as the transport mode of movement. As a result of the tests, it was determined that the tractor with torsion suspension provides better ride comfort in transport mode. The torsion bar suspension has an advantage in the frequency range of 0.5–4 Hz, while the balancer suspension has an advantage in the high frequency range of 4–12 Hz when plowing the ground. The level of vibration acceleration of the floor of the tractor cab does not depend on the type of suspension in the frequency range above 12 Hz.

1. Introduction
Vibration acts on the driver of an arbitrary vehicle while driving [1-5]. It has a harmful effect on his body. The long-term effect of vibration leads to the destruction of the musculoskeletal system, functional disorders of the vessels, nervous system and vestibular apparatus [6-9]. Vibration issues are most relevant for agricultural tractor units [10-15].

Reducing vibration improves the working conditions of machine operators, reduces their fatigue and occupational morbidity. One of the ways to reduce the vibrational tension of tractors is to change its suspension [16-20].

Most agricultural tracked tractors have an elastic balance suspension [21]. Kharkov Tractor Plant released an experimental batch of crawler tractors HTZ-181 with torsion bar suspension. There was a need to evaluate the impact of the new torsion bar suspension on the vibration of the driver.

2. Research goal
The research goal is to determine the effect of the type of suspension of a caterpillar tractor on the ride when working as part of an arable unit.

3. Objects and methods of experimental research
Two KhTZ-181 caterpillar tractors were taken as objects of experimental research (Figure 1):
• serial tractor with balancer suspension,
• experimental tractor with torsion bar suspension.

![Figure 1. The KhTZ-181 tractor manufactured by the Kharkov Tractor Plant (a) with balancer suspension and (b) torsion bar suspension](image)

The experiment was conducted in the farm "Veselo-Podolyanskoe" Semenov district of Poltava region of Ukraine. Caterpillar tractors plowed the ground in first (speed 6.5 km / h) and fourth (speed 10 km / h) gears. The vertical components of the acceleration were measured on the cab floor at the place of attachment of the driver's seat during operation (Figure 2) [22-24].

![Figure 2. Location of vibration measurements on the floor of the tractor cab](image)

Vibration registration was carried out using vibration measuring equipment manufactured in Denmark (Figure 3), consisting of: piezoelectric vibration transducer, signal amplifier, registrar, narrowband analyzer and real-time recorder.

![Figure 3. Registration equipment of the company "Bruhl & Kjær"](image)
The equipment was selected according to the requirements of GOST 12.4.012-83 [25-27]. The signals of the vibration transducer were synchronously recorded by a magnetic recorder with a sampling interval of 0.0039 seconds. This corresponded to 1024 measurements in 4 seconds. The total recording time in each experiment was at least 50 seconds.

4. Processing of the experiment
The spectral composition of vibrational accelerations was determined after testing by distributing the mean square acceleration of the elementary harmonics of the oscillations over frequencies in the range from 0.2 to 100 Hz. Vibration acceleration values were averaged every 0.25 Hz.

\[
\ddot{a}(f) = \frac{1}{T} \int_{T_0}^{T} \ddot{a}_{Nf}(t)\,dt,
\]

where \(a_{Nf}(t)\) is the measured vibration acceleration in time \(t\) in the frequency band with medium non-geometric frequencies \(f\), m/s².

The logarithmic levels of vibration acceleration of elementary harmonics were calculated:

\[
l_a = 20 \log \left( \frac{\ddot{a}}{a_0} \right),
\]

where \(a_0 = 3 \cdot 10^{-4}\) m/s² is the reference (zero) value of the mean square value of the vibration acceleration.

5. Research results
The experimental results are presented in the form of envelopes of linear spectra of the logarithmic levels of the vertical components of vibration acceleration of the floor of the KhTZ-181 tractor.

Figure 4 shows the vibration acceleration of the floor of the tractor cab when plowing in first gear. The frequency range of 0.5–4 Hz has the acceleration of a tractor with a torsion bar suspension 2–7 dB lower than that of a tractor with a balancer suspension. The range of 4–12 Hz has vibration acceleration of a tractor with a torsion bar suspension 2–7 dB higher than that of a tractor with a balancer suspension.

Figure 5 shows the vibration acceleration of the floor of the tractor cab when plowing in fourth gear. The vibration acceleration of the cab floor of both tractors has approximately the same values in the range often of 0.5–1 Hz and 9–20 Hz. The range often 1–5 Hz has vibration acceleration lower for a tractor with torsion bar suspension. The range often 6–9 Hz has vibration acceleration lower for a tractor with a balanced suspension.

![Figure 4. Logarithmic levels of vertical vibration acceleration of the tractor cab floor during plowing at a speed of 6.5 km / h](image-url)
Figure 5. Logarithmic levels of vertical vibration acceleration of the tractor cab floor during plowing at a speed of 10 km/h

Figure 6 shows the vibration acceleration of the floor of the tractor cab in transport mode along the field road. The speed in movement was 10 km/h. The acceleration of vibration of the cab floor in the entire frequency range is 5–10 dB less for a tractor with torsion bar suspension. This indicates that the torsion bar suspension improves tractor performance. Acceleration peaks are in the frequency range 17–19 Hz. They show the transition of the rink from one track link to another.

### 6. Conclusion

The vibration acceleration of the floor of the tractor cab with torsion bar suspension is 5–10 dB less than that of a tractor with a balancer suspension in transport mode over the entire frequency range. XTZ-181 tractor with torsion bar suspension provides the best ride smoothness in transport mode.

Torsion bar suspension reduces the level of low-frequency vibration acceleration of the cab floor by 2–7 dB in the frequency range of 0.5–4 Hz with plowing. Balanced suspension has an advantage in the high frequency range of 4–12 Hz.

The level of vibration acceleration of the floor of the tractor cab does not depend on the type of suspension in the frequency range above 12 Hz.
References

[1] Cutini M, Costa C and Bisaglia C 2016 Development of a simplified method for evaluating agricultural tractor’s operator whole body vibration. Journal of Terramechanics 63 23-32.
[2] Singh A, Singh LP, Singh S and Singh H 2019 Whole-body vibration exposure among tractor drivers. International Journal of Vehicle Performance 5(3) 286–299042
[3] Shismuchi M 1970 Basic Study on the Vibration of the Tractor Used in Forestry Works (I) Vibration of the Crawler-type Tractor. The Journal of the Japanese Forestry Society 54(12) 399-407
[4] Gorshkov YG, Starunova IN, Kalugin AA and Troyanovskaya IP 2019 Investigation of the Slope Angle Influence on the Loading Imbalance of the Wheeled Vehicle Sides and the Change in the Center of Gravity Vector Direction. Journal of Physics: Conference Series 1177 012005
[5] Ahmadi I 2013 Performance assessment of a tractor driver whole body vibration measuring system. World Applied Sciences Journal. 21(11) 1583-6
[6] Ahmadi I 2013 Health hazard assessment of tractor driver whole-body vibration utilizing the ISO 2631 standard. Agriculturae Conspectus Scientificus 78(1) 71-8
[7] Porter JM and Gyi DE 2002 The prevalence of musculoskeletal troubles among car drivers. Occupational Medicine 52(1) 4–12
[8] Jiao K, Li Z, Chen M, Wang C and Qi S 2004 Effect of different vibration frequencies on heart rate variability and driving fatigue in healthy drivers. International Archives of Occupational and Environmental Health 77(3) 205-12
[9] Ljungberg JK and Neely G 2007 Stress, subjective experience and cognitive performance during exposure to noise and vibration. Journal of Environmental Psychology 27(1) 44-54
[10] Gao Z, Xu L, Li Y, Wang Y and Sun P 2017 Vibration measure and analysis of crawler-type rice and wheat combine harvester in field harvesting condition. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 33(20) 48-55
[11] Cvetanovic B and Zlatkovic D 2013 Evaluation of whole-body vibration risk in agricultural tractor drivers. Bulgarian Journal of Agricultural Science 19(5) 1155-60
[12] Peretti A, Deivecchio S, Bonomini F, Di Bisceglie AP and Colosio C 2013 Vibration on agricultural tractors. Giornale Italiano di Medicina del Lavoro ed Ergonomia 35(4) 297-302
[13] Cutini M, Brambilla M and Bisaglia C 2019 Assessment of a ride comfort number for agricultural tractors: A simplified approach. Biosystems Engineering 185 35-44
[14] Singh A, Nawayseh N, Singh LP, Singh S and Singh H 2018 Whole body vibration exposure during rotary soil tillage operation: The relative importance of tractor velocity, draft and soil tillage depth. International Journal of Automotive and Mechanical Engineering 15(4) 5927-40
[15] Dominoni S, Gobbi M, Mastinu G and Previati G 2013 Experimental assessment of the ride comfort of farm tractors. Proceedings of the ASME Design Engineering Technic Conference 1 V001T01A013
[16] Abdel-Hady S and Abouel-Seoud 2019 Control of driver whole-body vibration ride comfort in agricultural tractor. Agricultural Engineering International: CIGR Journal 21(2) 40-51
[17] Zhang X, Sun D, Song Y and Yan B 2012 Analysis on vibration reduction characteristics of viscoelastic suspension system based on nonlinear behavior. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 28(9) 47-51
[18] Kim JH, Dennerlein JT and Johnson PW 2018 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 80-9
[19] Zehsaz M, Sadeghi MH, Ettefagh MM and Shams F 2011 Tractor cabin’s passive suspension parameters optimization via experimental and numerical methods. Journal of Terramechanics 48(6) 439-50
[20] Deprez K, Moshou D, Anthonis J, De Baerdemaecker J and Ramon H 2005 Improvement of vibrational comfort on agricultural vehicles by passive and semi-active cabin suspensions. Computers and Electronics in Agriculture. 49(3) 431-440
[21] Schick FA 1968 Crawler Tractors (SAE Technical Papers)
[22] Xu L, Li Y, Sun P and Pang J 2014 Vibration measurement and analysis of tracked-whole feeding rice combine harvester. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering*. 30(8) 49-55

[23] Servadio P, Marsili A and Belfiore NP 2007 Analysis of driving seat vibrations in high forward speed tractors. *Biosystems Engineering* 97(2) 171-80

[24] Wang F, Cao X, Guo W, Ma G and He C 2007 Research on vibration strength and frequency structure of main driver seat of the wheat combine. *Nongye Jixie Xuebao/Transactions of the Chinese Society of Agricultural Machinery*. 38(4) 62-5

[25] GOST ISO 10816–1–97. *Mechanical Vibration. Evaluation of Machine Vibration by Measurements on Non-Rotating parts. Part 1. General Guidelines* (Moskow)

[26] De la Hoz-Torres ML, Aguilar-Aguilera AJ, Martínez-Aires MD and Ruiz DP 2019 A comparison of ISO 2631-5:2004 and ISO 2631-5:2018 standards for whole-body vibrations exposure: A case study. *Studies in Systems, Decision and Control* 202 711-19

[27] Nelson CM and Brereton PF 2005 The European vibration directive. *Industrial Health* 43(3) 472-9