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EXPERIMENTAL STUDY OF THE INFLUENCE OF WHEELBASE AND TRACK WIDTH PARAMETERS ON THE VERTICAL VIBRATIONS AND CONTROLLABILITY OF A UNIVERSAL PLOWING TRACTOR WITH A TRANSFORMED TRACKING SYSTEM

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Abstract. *Vertical oscillations of universal row-crop tractors affect operational reliability, structural strength and the quality of agrotechnical operations. This study evaluates the influence of running-system parameters (wheelbase, track width and ground clearance) on the vertical oscillations, handling and stability of the experimental TTZ 1033M tractor with a transformable running system. Oscillations were measured with ADXL345 accelerometers mounted on the front and rear axles at track widths of 1200–2400 mm and ground clearances of 650–870 mm, with short and long wheelbases, at several travel speeds and tyre pressures. The front wheels showed smaller and nearly synchronous vertical oscillations, whereas the rear wheels, which are rigidly connected to the frame, oscillated more strongly and differed noticeably from each other. Increasing ground clearance increased vertical oscillations, while increasing wheelbase reduced them; track width mainly affected the difference between the oscillations of the left and right rear wheels. A short wheelbase is recommended for inter-row operations and a long wheelbase for transport work.*

Аннотация. *Вертикальные колебания универсально-пропашных тракторов влияют на эксплуатационную надёжность, прочность конструкции и качество выполнения агротехнических операций. В работе оценивается влияние параметров ходовой системы (колёсной базы, колеи и агротехнического клиренса) на вертикальные колебания, управляемость и устойчивость опытного образца трактора ТТЗ 1033М с трансформируемой ходовой системой. Колебания измеряли акселерометрами ADXL345, установленными на переднем и заднем мостах, при колее 1200–2400 мм и клиренсе 650–870 мм, при короткой и длинной базе, при различных скоростях движения и давлении в шинах. Передние колёса имели меньшие и практически синхронные вертикальные колебания, тогда как задние колёса, жёстко связанные с остовом, колебались сильнее и заметно различались между собой. Увеличение клиренса повышало вертикальные колебания, а увеличение базы снижало их; колея в основном влияла на разницу колебаний левого и правого задних колёс. Для работы на междурядьях рекомендуется короткая база, для транспортных работ – длинная.*

Annotatsiya. *Universal qator oralig‘i traktorlarining vertikal tebranishlari ekspluatatsion ishonchlilikka, konstruksiya mustahkamligiga va agrotexnik ishlar sifatiga ta’sir qiladi. Ushbu ishda yurish tizimi parametrlarining (g‘ildirak bazasi, g‘ildirak izi va agrotexnik klirens) transformatsiyalanuvchi yurish tizimli TTZ 1033M tajriba traktorining vertikal tebranishlari, boshqaruvchanligi va turg‘unligiga ta’siri baholandi. Tebranishlar old va orqa ko‘priklarga o‘rnatilgan ADXL345 akselerometrlari yordamida, 1200–2400 mm g‘ildirak izi va 650–870 mm klirensda, qisqa va uzun bazada, turli harakat tezliklari va shinalardagi bosimlarda o‘lchandi. Old g‘ildiraklarning vertikal tebranishlari kichikroq va deyarli sinxron bo‘lgan, ramaga qattiq biriktirilgan orqa g‘ildiraklar esa kuchliroq tebranib, bir-biridan sezilarli farq qilgan. Klirensning ortishi vertikal tebranishlarni oshirgan, bazaning ortishi esa kamaytirgan; g‘ildirak izi asosan orqa chap va o‘ng g‘ildiraklar tebranishlari orasidagi farqqa ta’sir qilgan. Qator oralariga ishlov berishda qisqa baza, transport ishlarida esa uzun baza tavsiya etiladi.*

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Keywords: *universal row-crop tractor; vertical oscillations; wheelbase; track width; ground clearance; accelerometer; stability; handling.*

Ключевые слова: *универсально-пропашной трактор; вертикальные колебания; колёсная база; колея; агротехнический клиренс; акселерометр; устойчивость; управляемость.*

Kalit so‘zlar: *universal qator oralig‘i traktori; vertikal tebranishlar; g‘ildirak bazasi; g‘ildirak izi; agrotexnik klirens; akselerometr; turg‘unlik; boshqaruvchanlik.*

Introduction

Vertical oscillations of universal row-crop tractors directly affect operational reliability, structural strength and the agrotechnical quality indicators of the work performed. When a tractor travels over an uneven field surface, dynamic loads are transmitted to the frame and body through the running system. In this process the front and rear wheels operate in an interrelated mode. The front wheel is the first to encounter soil irregularities and generates the primary dynamic impulse, whereas the rear wheel, under the action of inertial forces and traction load, contributes to the overall oscillatory regime of the machine[1,1,2]. Therefore, testing and analysis of dynamic processes should be carried out not separately for each axle, but by considering the front and rear axles as a single dynamic system.

In this study, the influence of the running-system parameters (wheelbase, track width and agrotechnical ground clearance) on the handling and stability of the experimental universal row-crop tractor TTZ 1033M is assessed on the basis of field and laboratory-field test methods and the results of laboratory-field tests of the TTZ 1033M tractor.

Materials and methods

The tests included vibration measurements at different track widths (1200–2400 mm) and ground clearances (650–870 mm) with short and long wheelbases. Oscillations of the experimental tractor were measured with an ADXL345 accelerometer (Fig. 1), a three-axis micro-electromechanical sensor with 13-bit resolution and an extended measurement range of up to ±16 g. The output data are formed as 16-bit two’s-complement values and are transmitted via the SPI and I2C digital interfaces.

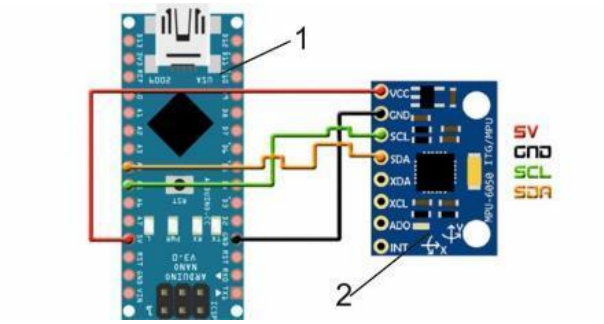


Fig. 1. Wiring diagram of the microcontroller with the accelerometer: 1 – Arduino Nano microcontroller; 2 – ADXL345 accelerometer

During testing, accelerometers were mounted on the front and rear axles of the experimental tractor (Fig. 2).

The ADXL345 accelerometer is widely used in mobile devices and is designed to measure both static acceleration caused by gravity (for determining the tilt angle) and dynamic acceleration arising from motion or shock [140, pp. 1265–1275; 141, pp. 22–35; 142, pp. 2344–2351; 143, pp. 5501–5510; 144, pp. 4953–4962]. The high resolution of the device ($4 \cdot 10^{-3}$ g/LSB) makes it possible to detect changes in the tilt angle of less than 1.0°. The low-power mode allows efficient power management of the measuring system.

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The tests were carried out on a hard surface at tractor speeds of 0.69, 2.74 and 4.99 m/s, tyre pressures of 1.2, 1.7 and 2.2 MPa, and an obstacle height of 30 mm. The experimental results are given in Appendix 17. The locations of the measurement points on the experimental tractor are shown in Fig. 2.

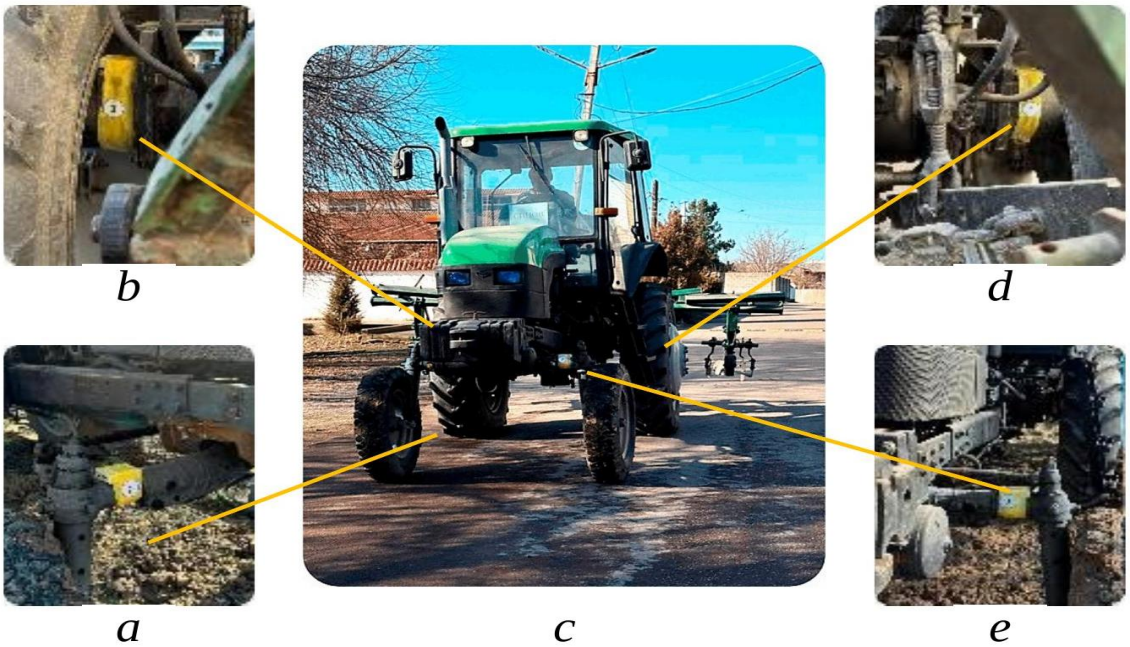


Fig. 2. Locations of the measurement points on the experimental tractor: (a, b) accelerometers mounted on the front axle; (c) experimental tractor; (d, e) accelerometers mounted on the rear axle

Results and discussion

Tractor handling is a complex characteristic that depends on the parameters of the steering system, the tyres and the tyre–ground interaction, as well as on the chassis geometry: wheelbase, track width and ground clearance. The TTZ 1033M test documentation contains the results of a series of measurements of wheel deflections and oscillation amplitudes at different speeds and tyre pressures; these data serve as the starting point for analysing how changes in wheelbase, track width and ground clearance affect the handling of the tractor.

Laboratory-field tests of the TTZ 1033M were carried out on a level asphalt road, using position sensors to record the deflections of the front and rear wheels. The test section was 100 m long (a 60 m measuring section; the remaining 40 m comprised 20 m each for acceleration/entry and exit). The test speeds were 2.25, 5.75 and 10.25 km/h and the tyre pressures were 0.12, 0.17 and 0.22 MPa; each test was repeated three times (Fig. 3).

The study of the influence of ground clearance, wheelbase and track width on vertical oscillations showed that, for all investigated values of these parameters, the magnitude of vertical oscillations of the front wheels is smaller than that of the rear wheels, and the front wheels oscillate practically in synchrony, whereas the vertical oscillations of the rear wheels differ noticeably from each other. This can be explained as follows.

As is known, the front wheels are connected to the tractor frame through a front axle that is hinged to the frame by a single pivot located at the middle of the axle. As a result, the tractor mass carried by the front wheels is redistributed practically evenly.

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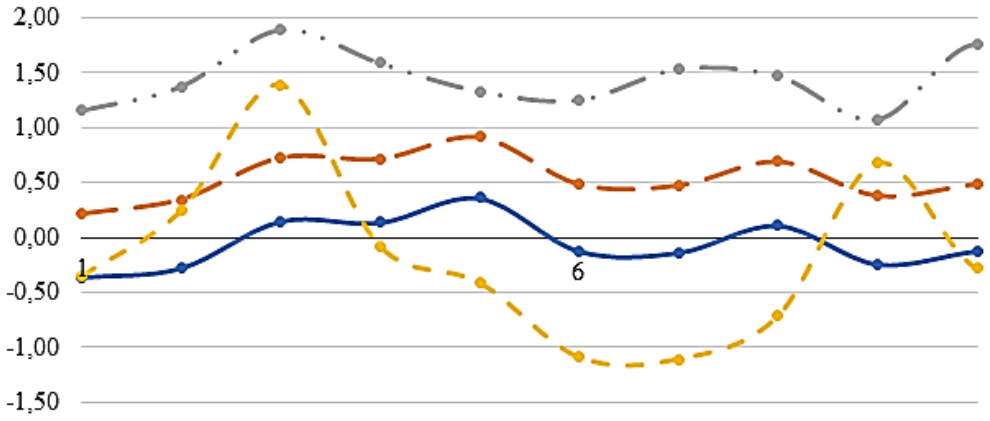


Fig. 3. Vertical oscillations of the TTZ 1033M tractor at maximum ground clearance, minimum wheelbase and maximum track width

In addition, part of the vertical loads acting on the front wheels is absorbed by the deflection of the front axle relative to the tractor frame owing to the hinged attachment; consequently, the load is redistributed between the front wheels, which brings their vertical oscillations closer to each other. The rear wheels are rigidly connected to the tractor frame through the rear axle, which precludes load redistribution between them. In addition, the asymmetric arrangement of components relative to the axle centreline leads to uneven loading, which affects the character of their vertical oscillations.

The study also showed that increasing ground clearance is accompanied by an increase in vertical oscillations, whereas increasing wheelbase, conversely, reduces them. Unlike clearance and wheelbase, a change in track width has a significant effect on the difference between the oscillation magnitudes of the rear wheels: as track width increases, the difference between the vertical oscillations of the rear wheels grows, and as it decreases, the difference falls.

The results on deviation from the rectilinear path and on lateral drift showed that the front wheels deviate considerably more than the rear ones (in some measurements the front wheels deviated by up to 31.18 mm in certain modes). The deviations of the rear wheels are generally smaller (up to about 2–3 mm), which indicates better stability of the rear axle. This is typical of designs in which the steered axle is more sensitive; increasing the wheelbase L generally reduces the relative amplitude of longitudinal and lateral yawing of the front axle with respect to the rear one (Fig. 4).

The study of the effect of tyre inflation pressure showed that increasing the pressure reduced the oscillation amplitude, especially at high speeds. At a tyre pressure of 0.22 MPa the lateral drift was minimal. This is important when interpreting the influence of ground clearance: with increased clearance and a high centre of mass, a combination with low tyre pressure impairs stability.

The study of motion along a sinusoidal path showed that the tractor followed a small-amplitude sinusoid (5 cm) more accurately; at larger amplitudes (15 cm), strong deviations (up to 20–25 mm) were observed. A wider track should help to reduce lateral drift when following a given path owing to better lateral stability.

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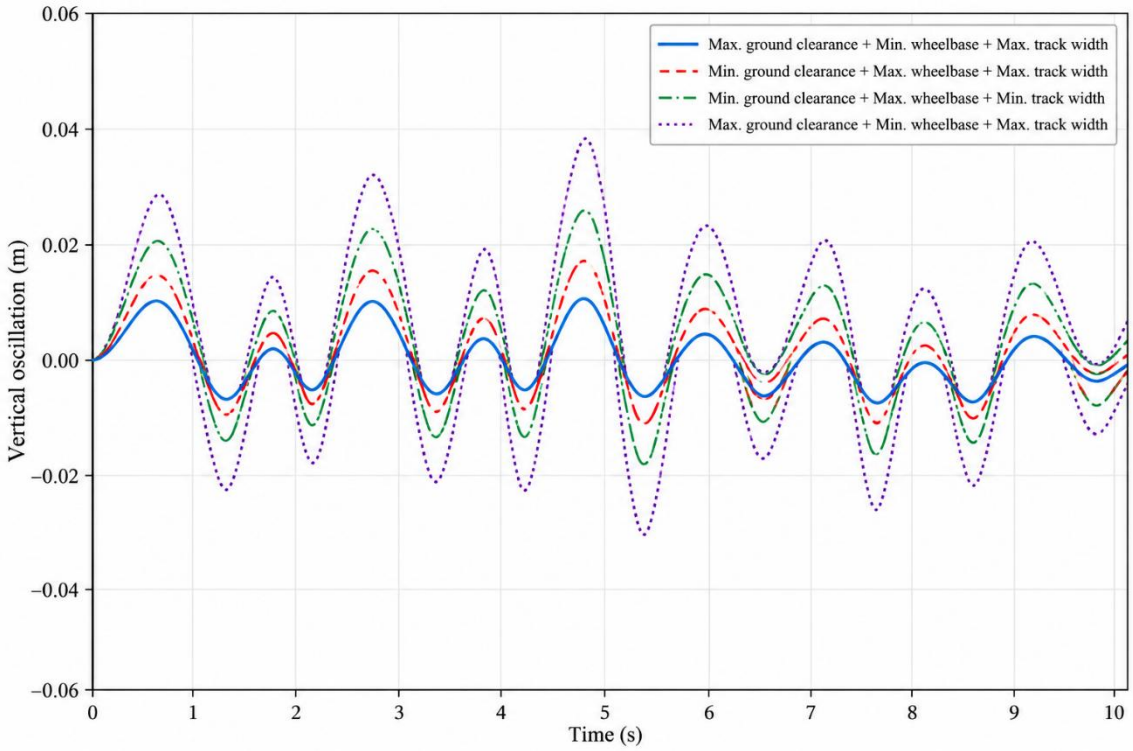


Fig. 3. Vertical oscillations of the TTZ 1033M tractor in various driving system positions

Thus, the measurements obtained in the course of the study confirm the general theoretical relationships: increasing the wheelbase and track width improves stability and path-following accuracy, whereas increasing ground clearance (all other things being equal) raises the centre of gravity and may impair lateral stability, especially at high speeds and low tyre pressure.

Conclusions

The experimental results established that reducing the tractor's support base reduces the magnitude of horizontal oscillations while simultaneously increasing the magnitude of vertical oscillations. To increase the soil tillage accuracy of the tractor by reducing horizontal vibrations, the tractor base should be reduced when passing between crop rows, while in transport operations, the base should be as long as possible to reduce vertical vibrations while preventing the tractor from overturning.

Conflict of interest: The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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