

Operational tests of a small-sized farm multi-purpose vehicle

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Abstract. The paper deals with the issue of expanding the scope of application of small-sized farm multi-purpose vehicles in the production process. The authors focus on the risks associated with the use of this type of machines. The authors prove that application of small-sized farm multi-purpose vehicles is feasible in agricultural production. To increase the interest of agricultural producers in small-sized farm vehicles it is necessary to develop a system of reliable assessment and verification of their actual consumer properties. For this purpose, the authors have studied the existing normative and technical documentation related to the functioning of this type of machines, varieties of small-sized vehicles and electrically driven trackless vehicles. Based on the available documents, they arranged a list of necessary tests to fully evaluate the main consumer properties. The test set consisted of nine procedures, including both static and dynamic tests. The paper provides data on the developed and manufactured experimental sample of electric cargo tricycle used on farms. The tricycle served as an example for the cycle of tests carried out according to the developed list. The paper summarizes the results obtained. Particular attention is paid to longitudinal and lateral sliding and tipping stability tests, center of mass position and traction tests, as well as dynamic tests to determine speed and braking performance, the mileage on a single battery charge, and vibration loading when operating under various road and climatic conditions.

1 Introduction

At present, there is a worldwide trend to increase the farm productivity and the yield of crops grown, while simultaneously reducing the cost of production. This goal is achieved mainly through the use of resource-saving technical means and technologies [1], ensuring rational use of natural resources. Continuously improved technical solutions and the use of new approaches lead to tangible agrotechnical results in the shortest possible time. In this regard, the study and improvement of new methods of operating machinery, as well as timely renewal of the machine and tractor fleet, especially in terms of mobile energy means is an urgent task [2], as well as the development and introduction of advanced models of machinery, taking into account global trends in the industry.

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In recent years, the number of three-wheeled motorized vehicles used all over the world has increased significantly [3]. As of 2021, nearly 3.5 million tricycles and motorbikes were used in the Philippines [4]. In China, they are produced in tens of thousands annually for urban and agricultural use [5]. The influence of three-wheeled motorized vehicles has become significant, mainly because of their versatility of use and convenience. According to a survey conducted in African countries [6], 40% of the respondents indicated that the tricycle was the only available transport vehicle due to the small size of roads. In several African countries, the main reason is convenience and ease of operation and relatively high speed of travelling at minimal cost. The use of tricycles has enabled agricultural producers to increase the cargo flow of farm produce [7].

However, there are some disadvantages of using tricycles. Firstly, it is a relatively high rate of road accidents involving tricycles [8]. Secondly, tricycle types with the internal combustion engine cause air pollution (about 67% of the total volume of public transport emissions at their mass use) and are one of the most inefficient consumers of petrol fuel [9].

In Russia, tricycles are gaining popularity with delivery services, in particular, food delivery, and for transporting small loads. For example, the company Yandex Lavka operates more than one and a half thousand electric vehicles only in the city of Moscow, among which tricycles account for 25%.

In the CIS countries, agricultural producers have also begun to use cargo motor and electric tricycles, especially on hilly terrains, where the passability of tractors is limited in terms of operational safety [10].

In general, for agricultural purposes, the use of a small-sized electric multi-purpose vehicle based on a tricycle is quite reasonable [2]. Such vehicles can find application in various technological operations, especially in transport operations for the delivery of planting material, fertilizers, various chemical inputs, as well as tools and compact power units for powering external consumers in field conditions.

The cost of freight transport is likely to decrease up to 3 times, while the mobility of employees may be further increased [2].

Nevertheless, there are many doubts among agricultural producers about the possibility of using machines based on tricycles in real agricultural production [11].

This fact leads to the need to improve the design of tricycles and adapt them to soil and climatic conditions of agricultural production. This is possible through the designing and subsequent implementation of a full range of tests affecting both structural and traction-dynamic qualities [12], as well as the machine stability.

This paper presents an experimental study to evaluate the dynamic loading and running smoothness of the machine, as well as the transverse stability of an agricultural cargo vehicle with an electric drive up to 3 kW.

The purpose of the study is to describe operational tests of a small-sized multi-purpose vehicle with an electromechanical drive to work out the design and its further use as a base chassis for the superstructure of various agricultural machines and equipment capable of working in heavy soils with stony inclusions.

2 Materials and methods

Theoretically, the research employs open-access literature sources, related to small-size transport vehicles and units with the electromechanical drive. The authors used open databases of patent documentation, information available from scientific and popular science editions, and thematic Internet resources. Practically, the research rests on the existing domestic and foreign experience of designing and testing small-sized units with the electric drive, including actual experience of the experimental work carried out at the department “Tractors and Automobiles” of Russian State Agricultural Academy – Moscow Timiryazev

Agricultural Academy in collaboration with key educational, scientific and production organizations of the Russian Federation.

The methodology of theoretical study implied its collection, processing, systematization, generalization and filtration in terms of application and testing of small-sized electric multi-purpose cargo vehicles, as well as the analysis of relevant development trends.

Experimental data were obtained through instrumental assessment of physical properties of the tested objects during the partial simulation of real operating conditions. Similar methods were applied to the bench equipment.

Separate data were collected and processed with the help of primary transducers and a complex of high-precision measuring equipment, including means of registration, collection, processing, and storage of data.

A sample vehicle for experimental research was represented by domestic electric cargo tricycle (ECT) with a brushless electric motor featuring a power of 1 kW (1.36 hp), a dry weight of 300 kg and a carrying capacity of 1000 kg.

For stability tests, the bench equipment for estimation of longitudinal and transverse stability indices of small-sized transport and transport-technological units was used to simulate both longitudinal and transverse inclination of the tested machine.

Breeding grain loaded in a drying container with a total weight of 510 kg was used as a payload.

During the stability tests, the angle measurements were carried out using a adjusting tool and a three-axis accelerometer Zetlab ZET 7152-N-VER.1, manufactured by LLC 'ETMS', along with an interface converter ZET 7176. The accelerometer is capable of tracking changes in the angle of inclination. We studied of traction force and determined the coordinates of the center of mass with the help of dynamometer DPU-20-1. The driving speed and the travelled distance were estimated with an external digital speedometer having an odometer function. Vibration parameters were measured with the help of a Zetlab vibration measuring system, including ADC-DAC module ZET 230 and analogue accelerometers BC-201, and additionally - by the readings of three-axis vibration sensor Zetlab ZET 7152-N-VER.1.

RuTrike 6-EVF-32 traction gel lead-acid batteries with a capacity of 38 Ah were chosen as the power source for the ECT (5 pieces connected in a series with a total voltage of 60V).

3 Results and discussion

For complete evaluation of the main consumer properties required for operation of a cargo multi-purpose tricycle with an electric drive featuring power up to 3 kW in conditions of modern agricultural production, we have developed a special set of tests to check all necessary consumer requirements. While developing this set of tests, we took into account the requirements for this type of machines, varieties of small-sized vehicles and means of trackless vehicles.

The complete test cycle includes the following activities: 1. Evaluation of the appearance and design of the machine. This affects the safety of movement and interaction. This procedure includes determining the dimensions and geometric parameters of the load, assessing the sensitivity of light and reflective elements, determining visibility, forces on the controls, identifying the compliance of the steering wheel turn to the travel direction of the vehicle, the return of the service brake pedal, compliance with the work of electrical equipment. 2. Evaluation of basic geometric parameters affecting the performance characteristics of the machine. This procedure includes determining the main overall dimensions, including loading and unloading operations, determining mass figures, determining the location of the center of mass and weight distribution in relation to loading (which is important for three-wheeled vehicles). 3. Climate testing to check the stability of

operation in a changing environment. Heat resistance, cold resistance, moisture resistance tests are checked here. 4. Reliability studies. This testing stage is intended to reveal the safety of operation in the long term. Here the permissible static load capacity is determined, as well as the mileage on a single battery charge under various loads and operating modes. 5. Testing of electrical components. In contrast to the first point, here the power electrics and electronics are tested for electrical safety under load and for protection against electric shock. This procedure includes electrical insulation strength testing, insulation resistance testing, and in-service thermal performance testing. 6. Braking performance test, or active safety tests. This procedure includes determining the effectiveness of braking operation while going uphill with a load; determining the braking distance, the strength of the controls, and the braking resistances. 7. Stability tests. Here dangerous and safe modes of the vehicle operation are identified, taking into account the specifics of the relief (hilly terrains, etc.). Here we determined critical angles of tipping and sliding, as well as critical speeds of tipping. 8. Study of hygienic characteristics. This procedure is necessary to identify the vibration load and the permissibility of its values, as well as the noise level using specialized equipment. The values of total and maximum vibration on the driver's seat and controls are determined. Noise is determined by the sound pressure level at the operator's seat when driving. 9. Set of dynamic tests developed in accordance with GOST 24282-97. Here various operating conditions are modelled. This procedure includes determination of traction and traction qualities at different load, determination of driving speeds, evaluation of economic qualities, and traction tests.

This list of evaluation activities was applied to an experimental sample of an electric cargo vehicle. Prior to this, we developed an experimental sample (prototype) of an electric cargo tricycle (ECT) designed to work in agricultural production conditions [2] (fig. 1).

ECT is a small-sized multi-purpose vehicle or transport-and-operational unit. The main purpose is to transport cargo and perform auxiliary transport operations, including loading and unloading of various agricultural products, delivery of seed and breeding material. It is possible to work in confined spaces and in closed premises. Due to this, it is possible to integrate the ECT into seed breeding and seed production operations. The general structure and design of the ECT corresponds to the main modern design solutions implemented in similar designs [2, 13-15]. The main equipment is a body with a volume of 0.5 m^3 and overall dimensions of $1.4 \times 1.0 \times 0.5 \text{ m}$.

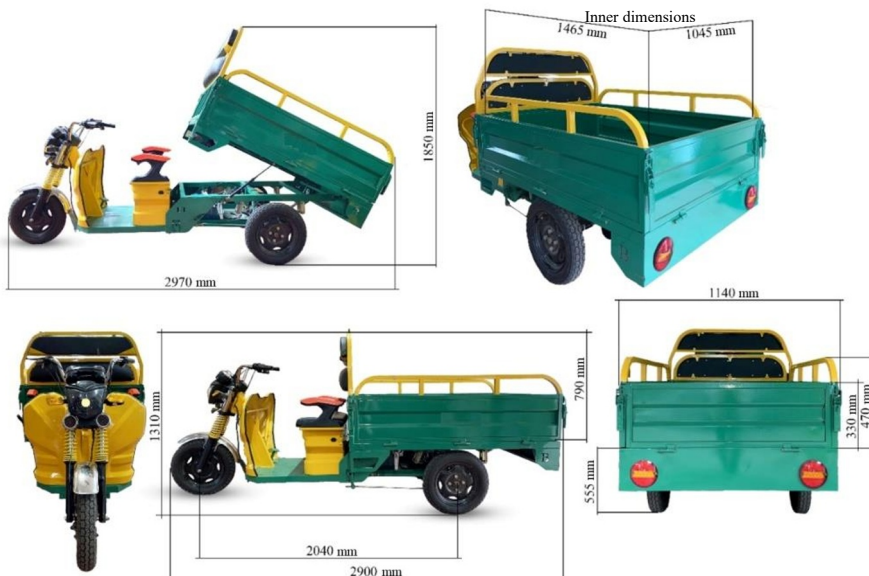


Fig. 1. Experimental model (prototype) of the ECT

The main research activities on list items 1, 2, 5 of the parameters of evaluated consumer properties require standard measuring equipment without the use of specialized methods [12, 14].

The stability tests according to list item 7 are especially noteworthy, for which a specialized bench was designed in the form of a platform tilting in two planes with the elements of the machine fixation on it (Fig. 2). The position of the machine and the sliding and tipping angles were measured using a three-axis accelerometer.



Fig. 2. Stability tests: a - transverse stability with the body lowered; b - longitudinal stability with the body raised

The longitudinal slipping and tipping angles were determined within the range between 20 and 60 degrees, and the transverse sliding and tipping angles ranged between 20 and 60 degrees. These values are sufficient for use of the machine in hilly terrains.

Figure 3 shows fragments of the tests for determining the coordinates of the center of mass and overall weight distribution (fig. 3, a) and measuring the tractive force (fig. 3, b).

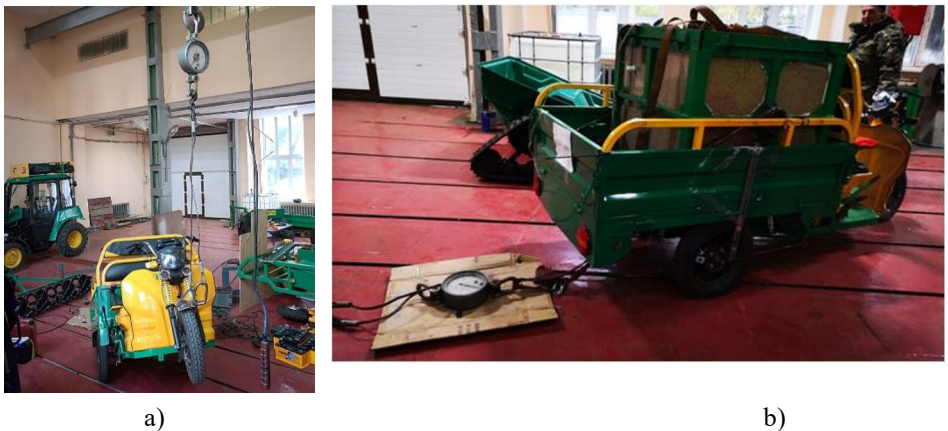


Fig. 3. Static studies: a – measuring parameters to determine the center of mass; b - traction tests

The studies showed that, depending on the load and the selected gear ratio, the tractive force varies between 1.2 and 2.8 kN, which puts the tricycle in traction class 0.2.

Figures 4, a - 4, d show fragments of dynamic tests related, respectively, to the determination of the maximum speed and braking distance (this type of tests was combined into one test) [13], the mileage on a single battery charge, the study of hygienic characteristics (vibration and noise), as well as seasonal climatic tests.



Fig. 4. ECT dynamic tests: a - speed and braking performance; b - mileage; c - vibration and noise; d - climatic tests

A separate study aimed to determine the mileage on a single battery charge [16]. It was found that with no load, the mileage on a single charge was 34 km and with a 510 kg load it was only 14 km (60% less) [16].

The maximum travelling speed was 31 km/h without a load and 29 km/h with a load. At the same time, the length of the braking distance increased from a minimum of 4.12 m without a load to a maximum of 5.52 m with a load in the body. Seasonal tests showed that the tricycle can be operated with a snow cover of no more than 5 cm.

4 Conclusions

The most important component in the production process of a new machine is functional testing. Its purpose is to determine whether the actual technical parameters obtained after the manufacture of the product correspond to the characteristics stated in the technical documentation.

The developed set of tests for an agricultural small-size multi-purpose cargo vehicle with the power up to 3 kW determines a full range of basic operational properties, from static mass-dimensional parameters to dynamic indicators.

The following results were obtained for the tested multi-purpose cargo vehicle:

- tipping and sliding angles are found to be within 20 and 60 degrees at longitudinal movement, and 25 and 30 degrees at transverse movement;
- the value of traction force varies from 1.2 to 2.8 kN;
- the mileage on one charge was 34 km without a load, and 14 km with a load of 510 kg;
- the maximum speed of movement was 31 km/h without a load, and 29 km/h with a load;

- the length of the braking distance - 4.12 m without a load, and 5.52 m with a load in the body.

In addition, the conducted research of the real sample of the small-size multi-purpose cargo vehicle confirmed the possibility of its year-round use on paved roads, as well as in light off-road and indoors. The tested tricycle sample has sufficient transverse and longitudinal stability for use on gradients/rolls and in hilly terrains.

Naturally, when fully loaded as well as when travelling continuously, the range on a single charge tends to decrease. It has been found that the battery is capable of partial charge recovery when stops are made.

The average mileage with and without a load is at least 25 km.

As the recommendations for the tested tricycle model show, it can be used for;

- transporting materials and products in sheaves, bags, and containers, as well as for delivery of tools, equipment, materials and fertilizers;

- transporting containers of produce from the combine to the edge of the field, to the road or to the warehouse;

- transporting sheaves for threshing to the seed breeding center.

The research goal has thus been achieved as the developed small-sized multi-purpose vehicle in the form of a tricycle meets the agrotechnical and reliability requirements and, therefore, can be used as a basic chassis for the superstructure of agricultural machinery and equipment, including those used in the treatment of heavy soils with stony inclusions.

Acknowledgements

The research got financial support of the Ministry of Science and Higher Education of the Russian Federation, issued in the form of a grant for scientific research carried out in collaboration with foreign organizations. Agreement No. 075-15-2023-467 dated April 24, 2023.

References

1. Vladimir Trukhachev, Otari Didmanidze, Mikhail Erokhin [etc.], *Modern agricultural engineering*. Moscow: Megapolis LLC (2022).
2. Alexei Dorokhov, Roman Fedotkin, Vitaly Kryuchkov, and Kirill Dmitriev, Proc. SPIE **12296**, *International Conference on Remote Sensing of the Earth*, 122960L (2022) [doi:10.1117/12.2642925](https://doi.org/10.1117/12.2642925)
3. Lorenzo Berzi, Massimo Delogu, Marco Pierini, Transportation research part d-transport and environment, **4**, 299-322 (2016).
4. Ma. Janice Gumasing, Daimler Araga, Francis Lord Baez, *IEEE 6th ICIEA*, 770-774 (2019) [doi:10.1109/IEA.2019.8714860](https://doi.org/10.1109/IEA.2019.8714860).
5. Muhammad Kurniawan, Vanee Chonhenchob, Sher Paul Singh, Sukasem Sittipod, Packaging technology and science, **Vol.28 Iss.836-850**, **9** (2015) [doi:10.1002/pts.2143](https://doi.org/10.1002/pts.2143)
6. Johannes Gruber, *Ergebnisse des größten Lastenradtests Europas Umweltfreundlich und effizient: Lastenräder im dienstlichen und gewerblichen Einsatz*, Berlin-Adlershof (2021).
7. Mariusz Kostrzewski, Communications in Computer and Information Science, **877**, 179-190 (2018) [doi:10.1007/978-3-319-95204-8_16](https://doi.org/10.1007/978-3-319-95204-8_16)
8. Sien Dieltiens, Jordi D'Hondt, Marc Juwet, Mark Versteyhe, Transport Problems, **Vol. 14, No. 4**, 151-160 (2019) [doi:10.20858/tp.2019.14.4.13](https://doi.org/10.20858/tp.2019.14.4.13)

9. Sally Cairns, Lynn Sloman, *Potential for e-cargo bikes to reduce congestion and pollution from vans in cities*, Transport for Quality of Life Ltd. (2019)
10. Elbrus Gutiev, Svetlana Gutieva, Proc. **7th International Scientific and Practical Conference "Prospects for the development of the agro-industrial complex in modern conditions"**, 320-324 (2017)
11. Gennadiy Krasnikov, Otari Didmanidze, Pavel Sirotin, Ekaterina Parliuk, *Boltinsky : collection of articles*, 10-32 (2023)
12. Laura Andaloro et al., International journal of hydrogen energy, **Vol. 45, Iss. 58**, 34011-34023 (2020).
13. Geras Mamiti, Marat Lyanov, Soslan Pliev, *Proc. of Gorsky State Agrarian University*, **Vol. 49, № 3**, 245-262 (2012)
14. Albert Suvac, Vasilica Stefan, Cristian Alionte, Liviu Ungureanu, Inmateh-agricultural engineering, **Vol.61 , Iss.127-134, 2** (2018) doi:10.35633/inmateh-61-14
15. Andrew Blum, Richard Long,.SAE international journal of passenger cars-mechanical systems, **Vol. 8, Iss. 565-572, 2** (2015) doi:10.4271/2015-01-1383
16. Otari Didmanidze, Roman Fedotkin, Aleksey Solntsev, Transport business in Russia, **3**, 308-310 (2024)