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Original article

DETERMINATION OF THE LIMITING STATIC CLIMBING ANGLE OF A MODULAR POWER AND TECHNOLOGICAL VEHICLE

A.V. Lavrov

Abstract

Background. Agricultural production is facing a shortage of tractors due to insufficient available machinery. To address this issue, a technological module was developed to increase the versatility of Class 1.4 tractors by upgrading them to a higher traction class. To assess the operational safety of a tractor equipped with a technological module, the maximum static climbing angle was calculated.

Purpose. Theoretical calculations were conducted to determine the maximum static climbing angle of a modular power and technological vehicle.

Materials and methods. The stability of the MTZ-82 tractor equipped with a technological module, including the coordinates of the overall center of gravity and the maximum static climbing (slope) angle, was analyzed using computational models.

Results. The horizontal and vertical coordinates of the center of gravity of the tractor and technological module were found to be 0.38 m and 0.885 m respectively. The maximum static climbing angle of the MTZ-82 tractor with technological module was found to be 71.7°.

Conclusion. Theoretical calculations of the maximum static angle of ascent have shown that the modular energy technology device is capable of performing the full range of technological operations without compromising operational safety.

Keywords: center-of-mass coordinates; climbing angle; energy module; technological module; modular energy technology vehicle

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Научная статья

ОПРЕДЕЛЕНИЕ ПРЕДЕЛЬНОГО СТАТИЧЕСКОГО УГЛА ПОДЪЕМА МОДУЛЬНОГО ЭНЕРГОТЕХНОЛОГИЧЕСКОГО СРЕДСТВА

А.В. Лавров

Аннотация

Обоснование. Технологическая обеспеченность сельскохозяйственного производства техникой характеризуется дефицитом тракторов. Для решения данной проблемы разработан технологический модуль, позволяющий повысить универсальность тракторов класса 1,4, путем перевода их в более высокий тяговый класс. Для оценки безопасности при эксплуатации трактора с технологическим модулем проведен расчет предельного статического угла подъема.

Цель. Провести теоретические расчеты по определению предельного статического угла подъема модульного энерготехнологического средства.

Материалы и методы. Для исследования устойчивости трактора МТЗ-82 с технологическим модулем с помощью расчетных схем определены координаты суммарного центра тяжести и предельный статический угол подъема трактора МТЗ-82 с технологическим модулем.

Результаты. Определены горизонтальная и вертикальная координаты центра тяжести агрегата, состоящего из трактора и технологического модуля: 0,38 м, и 0,885 м соответственно. Определен предельный статический угол подъема трактора МТЗ-82 с технологическим модулем: 71,7º.

Заключение. Проведенные теоретические расчеты предельного статического угла подъема показали, что модульное энерготехнологическое средство способно выполнять весь спектр технологических работ без ограничений по безопасности.

Ключевые слова: координаты центра масс; угол подъема; энергетический модуль; технологический модуль; модульное энерготехнологическое средство

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Introduction

According to the Agricultural Engineering Development Strategy for the Period up to 2030, it is assumed that the process of consolidation of agriculture will lead to an increase in demand for medium-power (100 to 200 hp) and high-power (over 200 hp) tractors [1]. However, as research has shown, agricultural production in Russia is characterized by a severe shortage and high depreciation of equipment, with the number of tractors and self-propelled harvesting machines having decreased more than threefold over the past 30 years [2]. The current shortage of tractor equipment in all traction classes except 1.4 leads to significant losses and shortfalls in agricultural yields.

To address the shortage of tractors in traction class 2, a technological module was designed and manufactured using commercially available components, allowing for an increase in the traction class of the commercially available 1.4-class tractor (MTZ-82) [3; 4]. The general appearance of the agricultural modular energy-technological vehicle is shown in Fig. 1.

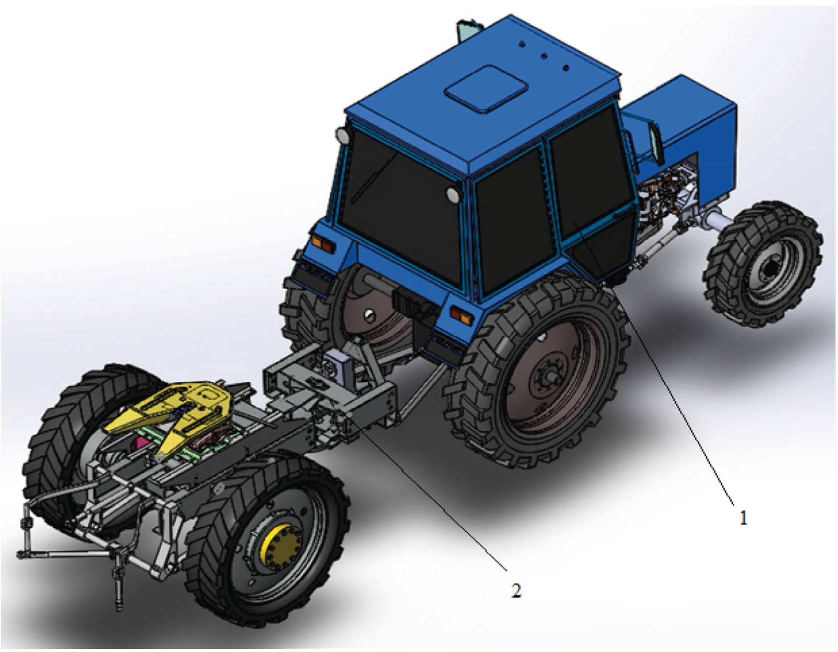

Fig. 1. Modular energy technology vehicle:
1 – power tractor, 2 – technological module

The basic requirements for the technological module were developed taking into account the existing scientific and technical background in the field of agrotechnical requirements for agricultural machinery [5-6].

The design and engineering development of the technological module was performed by scientists with experience in similar developments [7-10]. As a result of this research, a technological module design was developed that meets agricultural technology requirements and is compatible with MTZ-82 tractors.

To ensure the safe operation of the tractor–machine unit equipped with a technological module, it is necessary to determine its stability parameters, including the maximum static climbing angle, taking into account the design features of the modular power unit.

The static stability of agricultural tractors is influenced by various factors, including the tractor's mass-dimensional parameters, chassis design, mounted technological equipment, and attached agricultural implements. Tractor stability is critical when operating under soil and climatic conditions that involve fields with significant surface gradients.

According to Iovlev and Goldina [11], a comprehensive study was conducted on the influence of drawbar load on the tractor's longitudinal stability. The critical longitudinal and lateral stability angles were determined during operation with different types of agricultural implements.

Safety issues related to the operation of tracked tractors during technological processes are discussed by Lipkovich et al. [12]. The authors analyzed how the design characteristics of the undercarriage system and the attached implements affect the limiting static stability angles of tracked tractors. Gorobey and Moskalevich [13] proposed a method for calculating the maximum elevation angle of a tracked tractor equipped with mounted equipment.

The principal differences in the rollover dynamics of three-wheeled and four-wheeled tractors were analyzed by Pliev [14], who derived analytical expressions to determine the limiting stability angles of three-wheeled tractors. To assess the longitudinal stability of wheeled tractors, the concept of a Longitudinal Stability Index, which accounts for the tractor's mass and geometric parameters, was introduced in [15].

The authors of [16] proposed a method for calculating the maximum static angles of longitudinal and lateral stability when a tractor is equipped with gas cylinders.

Purpose. Theoretical calculations were conducted to determine the maximum static climbing angle of a modular energy-technology tool.

Materials and methods

To assess the stability of the MTZ-82 tractor equipped with a technological module, it was necessary to determine the combined center of gravity of the tractor and technological module. The calculation scheme shown in Fig. 2 was used to determine the combined center of gravity of the tractor and technological module.

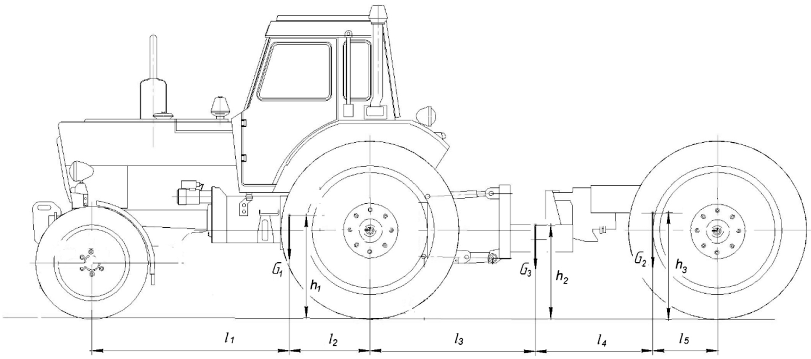

Fig. 2. Calculation scheme for determining the coordinates of the total center of gravity

The maximum static climbing angle of the MTZ-82 tractor equipped with a technological module was analyzed using calculation models presented in Fig. 3.

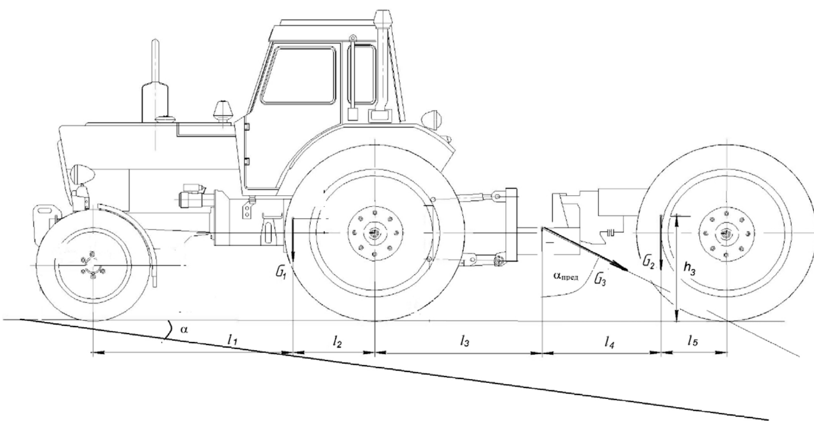

Fig. 3. Calculation scheme for determining the maximum static angle of ascent

Initial data for the calculation.

Tractor weight: G_1 = 3500 kg;

Weight of the technological module: G_2= 1500 kg;

Distance from the front axle to the tractor's center of gravity: l_1= 1,74 m;

Distance from the rear axle to the tractor's center of gravity: l_2= 0,7 m;

Distance from the axis of the process module to the center of gravity of the process module: l_5= 0,5 m.

Distance from the axis of the technological module to the rear axle of the tractor: $l_3+l_4+l_5$= 3,06 m.

Vertical coordinate of the tractor's center of gravity: h_1 = 0,95 m.

Vertical coordinate of the center of gravity of the technological module: h_2 = 0,85 m.

Results

The moment generated by the unit, consisting of the tractor and the technological module, relative to any point, must be equal to the sum of the moments created relative to that point by the tractor and the technological module according to the calculation scheme (Fig. 2), we write the following equation:

$$G_3 l_3 = G_2((l_3 + l_4 + l_5) - l_5) - G_1 l_2.$$

where G_3 is the weight of the modular energy-technological facility (kg);

G_2 is the weight of the technological module (kg);

G_1 is the tractor weight (kg);

l_3 is the distance from the rear axle to the center of gravity of the modular energy-technological vehicle (m);

l_4 is the distance from the center of gravity of the technological module to that of the modular energy-technological facility (m);

l_5 is the distance from the axis of the process module to its center of gravity (m);

l_2 is the distance from the rear axle to the center of gravity of the tractor (m).

Hence, given that $G_3 = G_1 + G_2$, we will receive:

$$l_3 = \frac{G_2((l_3+l_4+l_5)-l_5)-G_1 l_2}{G_1+G_2}.$$

Then

$$l_3 = \frac{1500(3,6-0,7)-3500*0,7}{3500+1500} = 0,38 \text{ m}.$$

The vertical coordinate of the center of gravity of the unit consisting of a tractor and a technological module:

$$G_3 h_3 = G_2 h_2 + G_1 h_1,$$

where h_3 is the vertical coordinate of the center of gravity of the modular energy-technological facility (m);

h_2 is the vertical coordinate of the center of gravity of the technological module (m);

h_1 is the vertical coordinate of the tractor's center of gravity (m).

Given that $G_3 = G_1 + G_2$, the following relation can be obtained:

$$h_3 = \frac{G_2 h_2 + G_1 h_1}{G_1 + G_2}.$$

$$h_3 = \frac{1500 * 0{,}85 + 3500 * 0{,}95}{3500 + 1500} = 0{,}885\ m.$$

The tangent of the maximum static climbing angle of the MTZ-82 tractor equipped with a technological module was determined based on the calculation scheme presented in Figure 3.

$$tg(x_{max}) = \frac{l_4 + l_5}{h_3} = \frac{3{,}06 - 0{,}38}{0{,}885} = 3{,}03.$$

Therefore, the maximum longitudinal stability angle of the MTZ-82 tractor with a technological module:

$$x_{max} = argtg\ 3{,}03 = 71{,}7°.$$

Tangent of the maximum longitudinal stability angle of the MTZ-82 tractor:

$$tg(x_{max.tr}) = \frac{l_2}{h_1} = \frac{0{,}7}{0{,}95} = 0{,}74.$$

Hence the maximum longitudinal stability angle of the MTZ-82 tractor:

$$x_{max} = argtg\ 0{,}74 = 36{,}5°$$

Discussion

Theoretical calculations determined the maximum static climbing angle of the MTZ-82 tractor to be 36.5º. In [16], similar calculations for the MTZ-82 tractor were performed, resulting in a maximum static lift angle of 39.9º. In [15], the calculated maximum static climbing angle was 43.22°. The deviation between the results was 3.4° (9.3 %) in the first case and 6.7° (18.3 %) in the second, which indicates the reliability of the proposed calculation approach.

The maximum static lift angle of the MTZ-82 tractor with the technological module increased to 71.7º, compared to the tractor without the technological module, indicating improved operational stability of the MTA based on the modular energy-technological unit.

For the MTZ-82 tractor equipped with gas cylinder equipment, the maximum static climbing angle was 37.4° with the cylinder cassette mounted on the roof and 42.7° when installed at the front section [16].

When aggregated with various agricultural implements, the maximum static climbing angles of the MTZ-82 tractor were 42° 6′ with the 2PTS-6 trailer, 39°

12′ with the KPD-6 cultivator, 42° 15′ with the PPTS-6 semi-trailer, and 42° 6′ with the PTS-10 semi-trailer [11].

The obtained value of 71.7° achieved through the use of the technological module significantly enhances the longitudinal stability of the mobile energy-technological system, while the agricultural implements coupled with the MTZ-82 tractor have a negligible impact on its longitudinal stability. Moreover, the obtained value exceeds the agrotechnical standard for permissible field surface inclination of 8° [6].

Conclusion

Theoretical calculations of the maximum static lift angle of a tractor equipped with a technological module showed that the use of the technological module allows this figure to be increased to 71.7º.

Therefore, the use of a modular power and technological vehicle enables the full range of technological operations to be performed without compromising safety.

Conflict of interest information. The authors declare that they have no conflict of interest.

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