Design and physical model of an electromechanical plant sprayer

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Abstract. The article explores the experience of developed countries in creating and implementing mobile electromechanical devices for plant processing, highlighting the low energy efficiency indicators and high fuel and lubricant costs of equipment running on organic fuel in the republic. The study emphasizes the relevance of transferring agricultural tractors with electric drives in the context of Uzbekistan. The composition and degree of structural compatibility of the mobile electromechanical device were designed based on operating modes, creating opportunities for organizing general services for farms. The energy efficiency indicators of a mobile electromechanical device powered by centralized and mobile energy sources were analyzed, determining that charging from a mobile power station operating on renewable energy sources is optimal. The following parameters were established for the area that can be processed by a mobile electromechanical device in one load (when hanging grain fields): equipment weight (including working solution and battery) - 420 kg, operating speed sprayer speed 11 km/s, and electric motor power 5.8 kW. Based on these parameters, the area that can be processed in one load is 2.46 hectares. This study provides valuable insights into the potential benefits of using mobile electromechanical devices powered by renewable energy sources in Uzbekistan's agricultural sector.

1 Introduction

Currently, the rapid introduction of electric tractors and other resource-saving electrical technology into agriculture occupies one of the leading positions. "Taking into account the research of world-famous agricultural machinery manufacturing companies on the conversion of tractors to electric drive," from the point of view of energy efficiency, it is necessary to put into practice the electric tractors created as a result of these studies. Currently, most of the mobile equipment used in agriculture runs on organic fuel, as a result

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of which the energy efficiency of agricultural activities is low. In this regard, due to the high costs of production, storage and delivery of fuels and lubricants, the use of electric tractors in agriculture is considered relevant [1].

With the large-scale introduction of power plants based on renewable energy sources (solar, wind, hydraulic, thermal, etc.) in the world, research and development work is being carried out aimed at creating electric tractors. In this regard, despite the creation of new technologies for producing food for the world's population, agricultural production will remain the main basis of food production for a long time, and for these purposes a large number of agricultural machinery is needed, taking into account the requirements of tools, special attention is paid to the development of energy-efficient mobile equipment , meeting high environmental requirements, carrying out agricultural activities without harm to the environment and with high economic efficiency, as well as justification of its parameters and operating modes [2].

2 Materials

The level of mechanization in the agricultural production of our republic is 75-88% in cotton and grain growing, 70-75% in planting food crops, 50-55% in their harvesting, 40-45% in horticulture and 35-40%. in vegetable growing. According to research, today there are some problems in the logistics of agriculture: - in addition to cotton and grain, for example, in horticulture and vegetable growing - about 35-40%; provision of them with mini tractors, agricultural machines and plant protection products is not systematically carried out [3,4]

The amount of fuels and lubricants necessary for the production of agricultural products in the main areas and territories freed from grain is more than 134 thousand tons, and the level of effectiveness of the use of some agrotechnical measures is low [5].

Currently, tractors, self-propelled chassis, internal combustion engines and electric motors are used as energy sources for agricultural production processes. Agricultural machinery running on fossil fuels consumes mainly diesel fuel [6].

Analyzing the performance indicators of equipment by fuel type, the following was revealed. Carburetor engines have an FIC of about 25–30%, while their transmissions have an FIC of about 85–90%. Typically, agricultural machinery is equipped primarily with diesel engines, the average FIC of which reaches 40-50%. In addition, in tractor transmissions, the FIC is about 85-90% [7]. It follows that only about 40% of the fuel energy consumed by tractors is used for useful work [8,9].

Converting existing mobile equipment to electric mode is of particular importance in ensuring energy efficiency in agriculture.

Solution method (methods). The study used methods for processing statistical data and theoretical and experimental research.

3 Methods

Analysis of results and examples. Physical models are designed to determine the numerical values of quantities that describe the behavior of a real object by measuring the corresponding values in the model. A physical model is a model made from special materials according to certain geometric proportions (or proportions). It maximally reflects the physical processes in the object being studied [10].

The similarity coefficients for the main indicators are as follows:

$$m_m = \frac{m_a}{k_m};\ H_m = \frac{H_a}{k_H};\ P_m = \frac{P_a}{k_P}; \quad (1)$$

in what km; kN; KP; weight of the sprayer of an electromechanical installation, volume of the liquid tank, power similarity coefficients of the electric motor.

The physical model preserves the properties of the real object. However, during full-scale experiments, the model and the real object may have the same or different physical nature. The following figures show the physical model of the device and the location of the control buttons [11].

Table 1. Energy parameters of the physical model of a mobile electromechanical device.

Parameter name	Size	Parameter value		
		Encoded	**coefficient**	**Real**
Tank capacity with working fluid	l	200	4	800
Maximum load capacity	Kg	300	4	1200
Between the wheels	Hm	1100	2	2200
Working width	M	7.2	2	14.4
Total weight of the structure	kg	650	2	1300
Rated power	kW	1.2	4	4.8
Distance traveled on one charge	km	40	4	160

Based on the design and functional purpose of a mobile electromechanical device, a circuit diagram has been created.

In the production of tractors and cars, 3 types of engines are usually used [9]:

- diesel internal combustion engine (IDOM);
- DC motor (DC motor);
- Asynchronous electric motor (AEM).

Table 2. Preliminary data for calculating tractor parameters.

Options	Values
Tractor traction weight utilization factor	0.4
Tractor wheel rolling resistance coefficient	0.08
Kinematic radius of tractor wheels, m	0.8
Gross tractor weight, kg	2100
Minimum tractor speed, km/h	4
Maximum tractor speed, km/h	24
Relative effective fuel consumption at rated power, g/kW s	300
Number of gears of the gearbox	6
FIC transmission	0.9
Charging FIC batteries	0.9
FIC battery extract	0.9
Semiconductor power converters COP	0.85
Conditional price of 1 liter of diesel fuel, sum/l	45
Conditional tariff rate for 1 kWh of electricity, soum/kWh	6
Reference background surface for determining tractor performance when slipping.	plowman

To consider the traction and economic performance of tractors with different types of engines, it is necessary to determine the initial parameters. As a basis for further computational studies, we can take the VTZ-1832 tractor (“Agromash-30TK”) with a D-120 diesel engine with a rated power of 18 kW at a rotation speed nH = 1800 min–1. When calculating the parameters, the same operating conditions, close to the real tractor, are taken into account [12,13].

This tractor is equipped with a manual transmission with 6 main gears. Various types of engines can be used for theoretical analysis based on this composition. Gravity calculation is based on the generally accepted methodology [14].

Based on the relationship between the parameters and the engine, you can determine the power of the tractor:

$$N_{puller} = \frac{(G_{trak}\varphi_{puller}+G_{trak}f_{puller})V_{Trak}}{\eta_{common}\cdot(1-\delta)} = \frac{(P_{puller}+P_f)V_{Trak}}{\eta_{common}\cdot(1-\delta)}; \quad (2)$$

where N cake – traction power, kW;

Ptort – voltage of the tractor on the tow bar, kN;

Pf – rolling resistance forces of tractor wheels, kN;

Vtrac – theoretical tractor speed, m/s;

total - the sum of the FIC of the elements involved in the generation and transmission of power, determined as follows: ēumumiy = ētr·ēzar·ēraz·ēyur);

d - mockery.

4 Results and discussion

From the method of calculating tractor traction it is known that its characteristics usually depend on the engine parameters and operating modes selected for IM, O'TD and internal combustion engines by approximation or other mathematical methods that describe the real function according to certain methods.[15]

The special energy price for a tractor that is electric and runs on a battery or other devices that store electrical energy is determined as follows:

$$g_{sol.energ} = C_{e.tarif}\frac{P_{motor}}{N_{puller}}; \quad (3)$$

where Se.tariff – electricity tariff rate, sum/kWh;

Motor - Electric motor power, kW;

puller – Output mechanical power, kW.

The parameters of lithium-ion batteries were used in calculations when considering the energy source for the electric drive. This is due to their high specific energy intensity - 432-864 kJ/kg, which is more than that of ionistors (7.5-30 times) and capacitors (1200-2400 times), as well as a low price of 5-45 sum/kJ . unit of energy is on average 100-130 times less than that of ionistors, 25-50 times less than that of capacitors. The power consumed by conductors determines their weight and efficiency during discharge. We will consider the traction characteristics of the VTZ-2032 tractor in a 6-speed gearbox based on the external speed characteristics of the D-120 diesel engine [16].

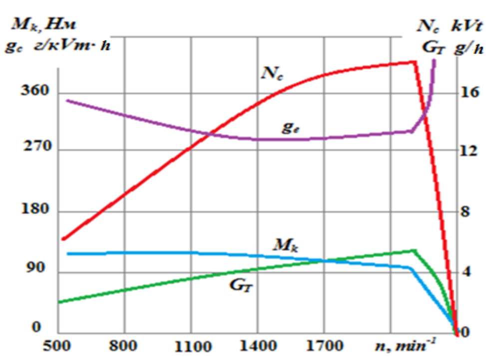

Fig. 1. Characteristics of a diesel internal combustion engine: Mk – torque; Ne – effective power; Gt – hourly fuel consumption; ge - specific effective fuel consumption.

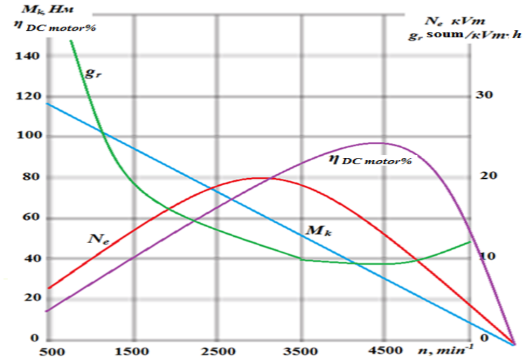

Fig. 2. Characteristics of a DC electric motor: Mk – torque; Ne – effective power; ηuvarmas . td - FIC of the engine; ge - specific effective fuel consumption.

Due to the traction characteristics of a DC motor tractor, it is clear that the number of unused power zones is higher than when using an internal combustion engine, and therefore you can get by with several transmissions, because their presence requires other transmissions with exactly the same transmissions. speed, it loses its meaning as soon as it can work at the level (Figure 2).

The mechanical characteristics of an induction motor of equivalent power differ from those of a DC motor with a narrower operating range [17,18].

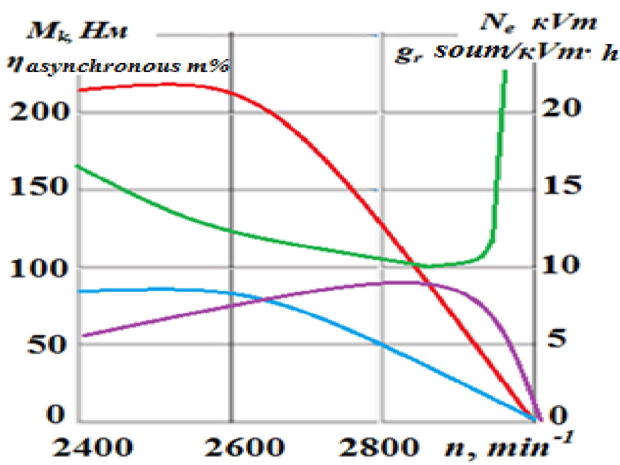

Fig. 3. Characteristics of an asynchronous electric motor: Mk – torque; Ne – effective power; η AD - asynchronous motor FIC; ge - specific effective fuel consumption.

It should be noted that an asynchronous machine can be controlled more flexibly by changing the frequency of the current and the voltage, which expands the scope of its application. Although this control increases labor costs, it provides versatility. When using an asynchronous machine, the minimum comparative cost of electricity is 16 sum/kWh, which corresponds to the performance of a DC motor. However, without the introduction of control systems, the characteristics of blood pressure, as a rule, are in a relatively narrow range [19].

Calculation of the electric motor power of a mobile electromechanical device. Calculations of the required electric motor power were carried out at a speed of 11 km/h, at an inclination angle of 0 degrees. State of smooth motion.[20]

- The total weight of the tractor in a ready-to-work state is 650 kg.
- The weight of one battery pack is 16 kg. A set of 4 batteries weighs 64 kg.
- Electric motor weight 17 kg.
- Controller weight 4 kg.
- Total average weight 760 kg.

Fig. 4. Electrical operation of a mobile electromechanical device.

Table 3. Technical characteristics of the BM 1412 ZXF -01(BLDC) brushless electric motor for electric vehicles.

No	Parameter name, unit of measurement	BM1412ZXF-01(BLDK)
1	Rated power, W	1200
2	Rated voltage, V	48
3	Nominal rotation speed, rpm	3000
4	Current at full load, A	25.2
5	Nominal torque, Nm	3.69
6	FIC, %	80
7	Gear ratio	1:5.4
8	Application	Medium to heavy load Electronic tricycle

We add the weight of the driver to 70 kg and the weight of the working fluid to 100 kg. As a result, we accept a calculated mass of approximately 1000 kg. Set the coefficient values:

- C_x = 0.342 (drag coefficient);
- S = 2m2 (cross-sectional area of the electric tractor);
- g = 9.81 m/s2 (free fall speed);
- m = 1000 kg (weight of the electric tractor);
- Ftr = 0.018 (wheel friction coefficient in field conditions);
- V 3 - (cube of electric tractor speed, m/h); 30 km/s = 8.33 m/h (speed by dividing "km/h" by "m/h" by 3.6);
- α = 0° (road slope angle);
- rv = 1.225 kg/m3 (air density).

$$W = gF_{tr} mV \cos\alpha + 0{,}5 S_x \rho v V^3 + gm \sin\alpha V \tag{4}$$

Let's calculate the power using this expression:

$$W = 9{,}8 \cdot 0{,}018 \cdot 1000 \cdot 16{,}67 \cdot 1 + 0{,}5 \cdot 0{,}342 \cdot 2 \cdot 2 \cdot 1{,}225 \cdot 16{,}67^3 + 9{,}8 \cdot 1000 \cdot 0 =$$
$$= 2940 + 1940 + 0 = 4880\ \ Vt.$$

Let's determine how much energy an electric tractor spends on movement as follows. Some energy is lost at the battery output. Therefore, taking the result approximately equal to the total total FIC (~0.76 for the transmission, ~0.90 for the electric motor, ~0.95 for the controller), we calculate their average value:

$$eel.tr = 0.76 \cdot 0.90 \cdot 0.95 = 0.65. \quad (5)$$

In practice, the battery should provide more energy, but some of this energy is lost before reaching the drive for various reasons (friction, heat, etc.). So, 4880/0.65=7509 W - this power must be supplied from the battery.

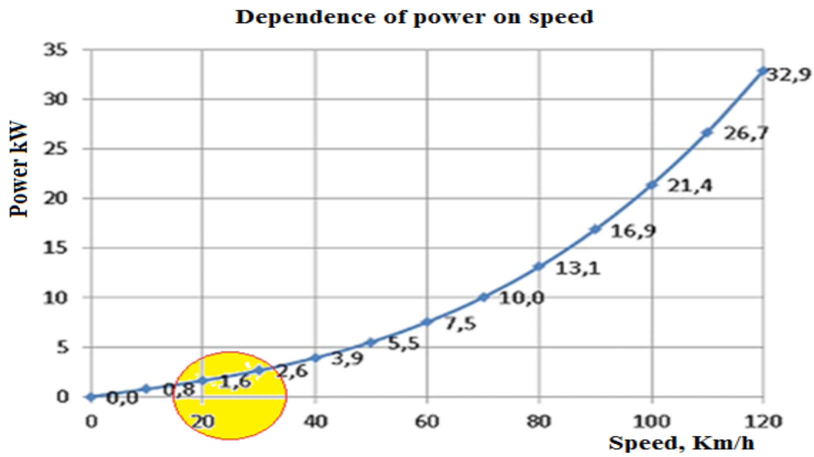

Fig. 5. Dependence of power on speed when moving an electric tractor on a flat field in working condition.

In total, 7509 W of system power is required to move an electric tractor across a flat field at a speed of 30 km/h. To understand how power depends on the speed and angle of the road, let’s carry out calculations and draw graphs in Excel-e [21-23].

5 Conclusion

The design features of mobile equipment with an electric drive in factory processing showed the advantage of electric motors with systematic disassembly over internal combustion engines in terms of converting them to an electric drive based on operating conditions.

When choosing the type of power unit for electric tractors, one of the main factors is the compatibility of batteries and their components in terms of reliability and safety.

Based on an analysis of the energy efficiency indicators of a mobile electromechanical device (class 0.4), when powered by centralized and mobile energy sources, charging from a mobile power station powered by renewable energy sources is allowed.

The composition of a mobile electromechanical device and the level of constructive harmony with similar technical means have been created, based on taking into account operating modes and the possibility of organizing general maintenance of farms.

References

1. Decree of the President of the Republic of Uzbekistan dated February 3, 2021 No. PF-6159 on the further development of the knowledge and innovation system and the provision of modern services in agriculture. National database of legal documents, 04/02/2021, No. 21/06/6159/0084
2. M.S. Yusupov, Scientific electronic journal of TDIU "Economics and innovative technologies" **6**, 1-2 (2015)
3. M.V. Danilov, *Parametric machine for spraying row crops*. Abstract of dissertation. (Stavropol, 2005), p. 36
4. A.V. Bizhaev, Agricultural machines and technologies **14(4)**, 33-42 (2020). https://www.doi.org/10.22314/2073-7599-2020
5. A. Bokiev, S. Sultonov, N. Nuralieva, A. Botirov, E3S Web of Conferences **365** (2023). https://www.doi.org/10.1051/e3sconf/202336504003
6. S.A. Ivanov, *Increasing the efficiency of berry-transport vehicles using energy storage devices: Abstract on special*. 05/20/01 – Technology and equipment for agricultural mechanization. dis. no fellow soldiers three. St. Doctor of Technical Sciences (M., 2013), p. 32
7. A. Bokiev, N. Nuralieva, S. Sultonov, A. Botirov, U. Kholiknazarov, E3S Web of Conferences **264** (2021). https://www.doi.org/10.1051/e3sconf/202126404022
8. A. Turdiboyev, D. Akbarov, T. Toshev, S. Sayfiyev, M. Mamutov, E3S Web of Conferences **434** 01032 (2023)
9. J.M. Storehouse, J. Agr. English Res. **54(3)**, 201-210 (1993)
10. A.S. Berdishev, Z.Z. Djumabayeva, A.A. Abdullaev, A. Mussabekov, IOP Conf. Series: Earth and Environmental Science **939** 012023 (2021). https://www.doi.org/10.1088/1755-1315/939/1/012023
11. P.A. Hobson, J. agr. English Res. **54(4)**, 293-305 (1993)
12. N. Eshpulatov, D. Yusupov, L. Akabirov, D. Dinikulov, N. Toshmamatov, IOP Conference Series: Earth and Environmental Science **1112(1)**, 012081 (2022)
13. A.A. Bokiev, N.A. Nuralieva, *Prospects for converting agricultural tractors to electric drive in the Republic of Uzbekistan until 2035,* Materials of the International Scientific and Practical Conference "Problems of increasing the efficiency of the use of electrical energy in the agro-industrial complex", Tashkent. November 28, 2018, pp. 162-168 (2018)
14. A. Turdiboyev, N. Aytbaev, M. Mamutov, T. Toshev, N. Kurbonov, IOP Conference Series: Earth and Environmental Science **1142(1)** 012027 (2023)
15. A.Ya. Yakushev, T.M. Nazirkhanov, I.P. Vikulov, K.V. Markov, News of the St. Petersburg University of Transport **16(4)**, 592-601 (2019)
16. A.S. Berdishev, Z.Z. Djumabayeva, A.A. Abdullaev, A. Mussabekov, AIP Conference Proceedings **2612** 020037 (2023)
17. I.E. Ovchinnikov, *Valve electric motor and drive based on ix* (SPb., CORONA-Vek, 2016), p. 336
18. N. Eshpulatov, T. Khalmuradov, F. Rakhimov, S. Abdurayimov, A. Khurramov, U. Ruziyeva, T. Normetov, I. Maftuna, IOP Conference Series: Earth and Environmental Science **1142** 012006 (2023)
19. M. Ibragimov, D. Akbarov, I. Tadjibekova, E3S Web of Conferences **365** 04019 (2023)

20. A. Djalilov, E. Sobirov, O. Nazarov, M. Begmatov, M. Abdullaev, S. Urolov, IOP Conf. Ser.: Earth Environ. Sci. **868** 012031 (2021)
21. M. Ibragimov, D. Akbarov, T. Toshev, K.S. Safarov, O. Zayniyeva, E3S Web of Conferences **434** 01017 (2023)
22. R.F. Yunusov, A.B. Imomnazarov, N.E. Sattarov, D. Akbarov, A.A. Abduganiev, IOP Conference Series: Earth and Environmental **1142(1)** 012019 (2023)
23. M. Ibragimov, D. Akbarov, M. Fayziyev, R. Beytullaeva, K. Nimatov, Kh.S. Safarov, IOP Conference Series: Earth and Environmental **1142(1)** 012031 (2023)