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Tractor on Electric Traction with a Backup Gas Turbine Engine

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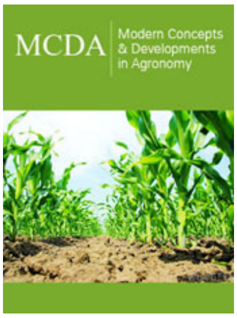

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Abstract

This work is devoted to scientific research carried out on the basis of the T-16 tractor self-propelled chassis, according to the developed new kinematic scheme, not previously used in the Russian tractor industry. The proposed new kinematic scheme includes an electric drive with frequency control with a power of 11kW, powered by a battery with a nominal voltage of 480V, a standard six-speed manual transmission, a parallel power supply source, which is a gas turbine power generator designed to charge batteries in the field, move the tractor and power the external loads with standard voltage. The proposed kinematic scheme is more reliable in terms of technical operation, provides more comfortable working conditions for machine operators, improves the local environmental situation, and ensures the economic efficiency of technological cycles. The paper provides a description of the proposed kinematic diagram of the tractor, the technical characteristics of units, assemblies and their work schedules. The technical characteristics of the torque of the electric motor, which was replaced by a diesel engine, are presented. The positive aspects of the tractor on electric traction are shown, its design is presented.

Keywords: Tractor; Storage battery; Frequency regulation; Asynchronous electric motor; Gas turbine power generator; Thermal energy; Electric power

Introduction

Now in the world there is an increase in vehicles with electric drive and batteries [1-4]. Passenger cars are produced in large numbers, of various capacities, differing structurally, in terms of battery capacity, and comfort level [5-9]. It is known that in factories and warehouses, for lifting and transporting goods, vehicles powered by batteries are used [10-13]. In many countries, research is being funded to develop technological transport for agriculture, road and public works, loading and harvesting equipment [14-17]. All these machines have a different design of electric motors, power, battery capacity and kinematic schemes, as they perform different operations [7,18-20].

Figure 1: Tractor T-16.

For experimental studies on the use of a new kinematic scheme, the T-16 tractor was chosen, designed for transport work on the transportation of goods weighing 1000kg, performing field technological operations, and plowing light soils. The power plant is a diesel two-cylinder engine with a power of 16kW and a maximum torque of 89Nm. The transmission consists of a mechanical gearbox with six gears forward, one reverse, one downshift with blocking of the rear drive wheels. Drive wheels are mounted on final drives. Figure 1 shows the T-16 tractor.

Research task. The scientific task is to develop a new kinematic scheme with an electric drive for this tractor. Initially, the diesel engine and clutch basket were dismantled. The total weight of the dismantled equipment is 360kg. Technical documentation has been developed for connecting an asynchronous electric motor to the input shaft of the gearbox through an adapter. In accordance with the project, the tractor is equipped with a battery to power the electric motor and a backup gas turbine generator to charge the batteries. The general block diagram of a tractor with an electric drive and a gas turbine generator is shown in Figure 2. The choice of the electric motor was determined by the technical characteristics, which must correspond to those of the diesel engine.

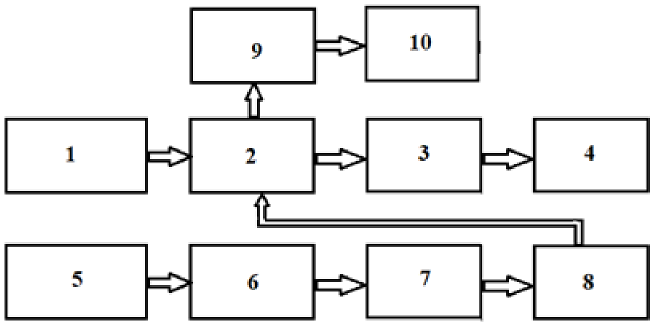

Figure 2: Block diagram of tractor units.
1. Network charger;
2. Rechargeable batteries;
3. Control unit for the rotation of the electric motor;
4. Asynchronous electric motor;
5. Fuel tank;
6. Gas turbine engine;
7. Electric generator;
8. Charger from the turbogenerator;
9. Inverter;
10. External electrical load connection cabinet.

Theoretical calculation

For installation on a tractor, an asynchronous electric motor AIR 132-M4 with a power of 11kW and a rotation speed of 1430rpm was selected. at 50Hz. The change in speed is made by the Goodrive 200A frequency controller with a power of 15kW. The rated torque of the squirrel-cage induction motor is 73.3Nm, the maximum torque can be 50 to 100% more. Figure 3 compares the characteristics of a diesel engine with maximum torque and an induction motor with rated and maximum torque and speed.

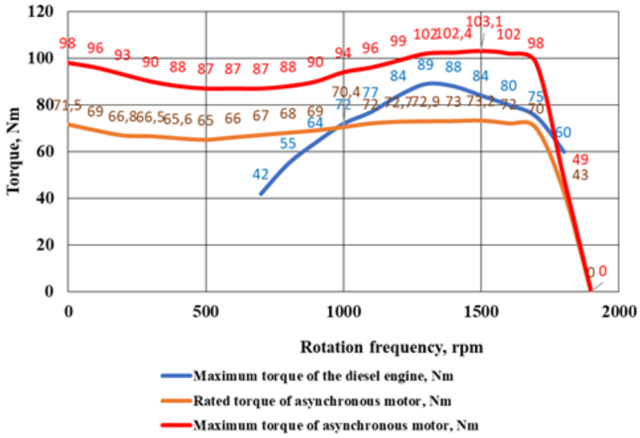

Figure 3: Torque characteristics of diesel and asynchronous motors.

The diesel engine has a maximum speed of 1800rpm. To create a rotational speed of an asynchronous motor of 1800rpm. the maximum frequency of rotation of the electromagnetic field is set to 65Hz on the frequency regulator. The battery pack is installed under the cargo platform and is shown in Figures 3&4.

Figure 4: Battery pack.

The unit consists of 40 series-connected "Delta 20-12" batteries with a capacity of 20Ah, rated voltage 480V. These batteries are charged from a centralized network with a voltage of 230V through an on-board automatic charger up to a voltage of 540V. The energy of a charged battery is 10kWh. In order to avoid battery discharge, in the field there is a gas turbine electric generator on board the tractor, it simultaneously provides battery charging, tractor movement, power supply to the connected external load with an alternating three-phase voltage of 380V. The kinematic diagram of the gas turbine power generator is shown in Figure 5. The gas turbine engine operates on the Brayton cycle.

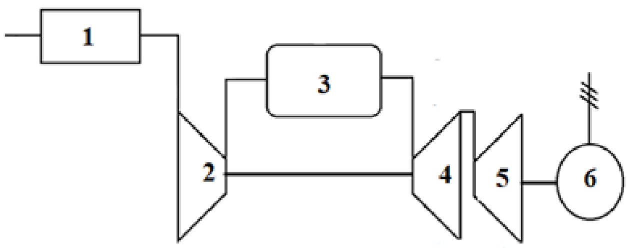

Figure 5: Kinematic diagram of a gas turbine generator.
1. Input starting device;
2. Radial compressor;
3. Combustion chamber;
4. Centripetal turbine;
5. Three-stage free power turbine;

In accordance with the technical characteristics of the radial compressor and the centripetal turbine, the performance is determined, N_B, g/s, [21].

$$N_B = \frac{N_{el} \cdot \alpha_{ob} \cdot L_0}{Q_t \cdot \eta_{eg} \cdot \eta_{sst} \left(1-P\right)} \quad (1)$$

N_{el} - power plant capacity, 11kW;

Q_t -is the specific heat of combustion of kerosene, 13,0 kWh/kg, [22];

L_0 -air consumption required for the combustion of propane-butane, 15,0, kg/kg;

η -is the theoretical electrical efficiency of the turbogenerator, 25%;

η_{eg} -is the efficiency of the electric generator, 0,75, [23];

η_{sst} -is the efficiency of a three-stage free turbine, 0,75, [24];

P -Theoretical coefficient of compressor work, 0.7, [25].

α_{ob} - coefficient of excess air, 8.0;

The design capacity of the compressor is not less than, kg/s:

$$N_B = \frac{11,0 \cdot 8,0 \cdot 15,0}{13,0 \cdot 0,75 \cdot 0,75\left(1-0,7\right)} = 0,167\, kg/s \quad (2)$$

A free three-stage turbine has been developed, placed on one disk and with the direction of rotation opposite to the rotation of the rotor of the gas turbine engine, has the initial data:

1. turbocharger speed n_1= 30000÷96000rpm;
2. free turbine output shaft speed n_{2B} = 2000÷4000rpm;
3. fuel consumption G_T = 2,5 g/s;
4. air consumption N_B = 170g/s = 0,17kg/s;

Circumferential speed on the middle diameter for the first stage in the hot state, $V_{1\,st}$, m/s:

$$V_{1st} = \frac{\pi \times D \times n_2 \times \sqrt{k_2}}{60} \quad (3)$$

$$V_{1st} = \frac{3.14 \times 0.25 \times 4000 \times 1.05}{60} = 54,95\, m/s \quad (4)$$

Circumferential speed on the middle diameter for the second stage in a hot state, V_{2st}, m/s:

$$V_{2st} = \frac{\pi \times D \times n_2 \times \sqrt{k_2}}{60} \quad (5)$$

$$V_{2st} = \frac{3.14 \times 0.28 \times 4000 \times 1.05}{60} = 61,54\, m/s \quad (6)$$

Circumferential speed on the middle diameter for the third stage in a hot state, V_{3st}, m/s:

$$V_{3st} = \frac{\pi \times D \times n_2 \times \sqrt{k_2}}{60} \quad (7)$$

$$V_{3st} = \frac{3.14 \times 0.31 \times 4000 \times 1.05}{60} = 68,14\, m/s \quad (8)$$

Actual gas expansion work in the turbine, , :

$$L_T = \frac{C_{p\Gamma}}{A} \times \Delta T^*_{T\Sigma} \quad (9)$$

$$L_T = 23,17 \times 208,24 = 4824,92\, kgm/kg \quad (10)$$

Estimated power developed by a free turbine, kW:

$$N_T = \frac{G_{\Gamma CB} \times L_{T2}}{104.6} \quad (11)$$

$$N_T = \frac{0.251 \times 4824.92}{104.6} = 11,53 kW \quad (12)$$

Figure 6 shows a gas turbine power generator mounted on a tractor.

Figure 6: Gas turbine electric generator on a tractor.
1. Gas turbine engine;
2. Three-stage free turbine;
3. Asynchronous electric generator;
4. Switching cabinet for external connections;
5. Air cleaner; 6. Power asynchronous electric motor.

An inverter with an output voltage of 230V and a power of 3kW is connected to the battery, which is necessary to power the gas turbine engine start system and power an external load with a voltage of 220V.

The communication cabinet contains: a connector for charging the battery, for connecting an external load, a single-phase 230V socket and a three-phase 380V socket.

Exhaust gas temperature is 440 °C, gas quantity is 1040m^3/h. The mass of the installed equipment, including the battery pack, power asynchronous electric motor, gas turbine power generator, electronic devices and equipment, is 346kg.

Experimental studies

The first sea trials were carried out on a flat paved area without cargo. The results of the experimental studies are presented in Table 1.

Table 1: Results of running experimental studies.

Transmission	Rotational speed of the electric motor, min^{-1}	Experiment time, min.	AB voltage before testing, V.	AB voltage after the end of tests, V.	Maximum current, A	Power, W.
First gear	1600	30	520	503	0,68	342
Second gear	1600	30	520	501	0,77	386
Third gear	1600	30	520	499	0,88	439
Fourth gear	1600	30	520	497	0,98	487
Fifth gear	1600	30	520	495	1,07	530
Sixth gear	1600	30	520	493	1,23	606

The operating time of the tractor with uniform movement on a horizontal asphalt road, with a load of 500kg, in 4th gear, a speed of 11km/h and a temperature of 17 °C is 4 hours 46 minutes.

The graph of the dynamics of the speed of rotation of the rotor of the power electric motor over time when the pedal is fully depressed is shown in Figure 7.

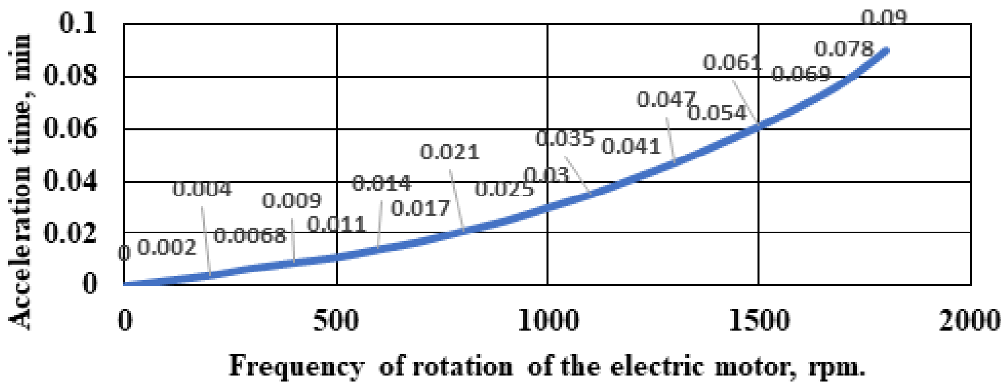

Figure 7: Graph of the dynamics of the rotor speed asynchronous power motor.

Such dynamics of the action of the electric motor on the standard gearbox does not depend on the behavior of the driver and prevents the effect of high torque on the main and final drives of the transmission, ensuring high reliability and a longer service life of these units. The forced stop of the tractor by the electric motor, with a sharp decrease in the engine speed, is set to two seconds by default, but experimental studies have shown that it is possible to stop from 18km/h to 0km/h in 4,5 s. Figure 8 shows a graph of the change in the speed of the tractor when braking by the electric motor.

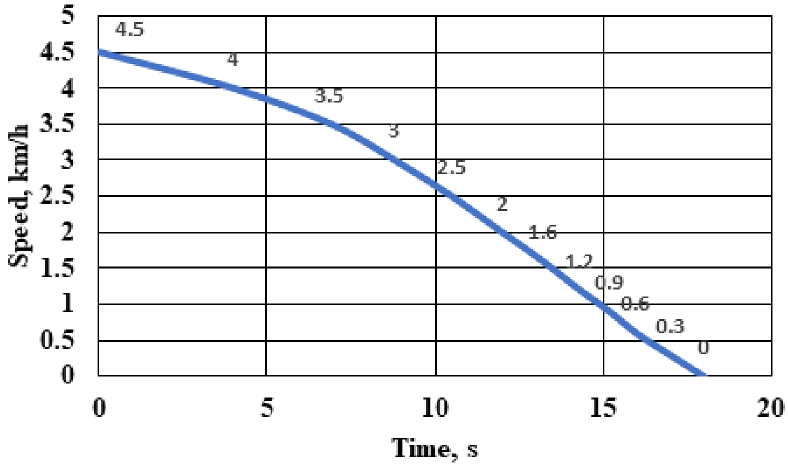

Figure 8: Graph of the change in the speed of the tractor when braking by the electric motor.

Conclusion

The modernized tractor has more opportunities to perform various agricultural technological operations compared to its analogue, using mechanical, thermal and electrical energy for external consumers becomes the most cost-effective. Its application in agricultural technological operations associated with the use of heat, heat treatment is possible, which improves the storage conditions of grain crops, drying of hay and straw. Heat treatment is used to improve the quality of food and feed. Heat treatment includes: boiling, frying, sterilization of vegetables and fruits, pasteurization of milk, juices, wines, steaming of feed. The generated standard voltage electricity can be used to power water pumps, field repair shops, connect cow milking machines, sheep shearers, fans.

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