Power balance of all-wheel drive mobile power vehicle

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Abstract. The article studies the components of the energy balance of an all-wheel drive self-propelled power vehicle, presents and analyzes the results of a practical determination of all the components of the energy balance within the field experiment.

1. Introduction

When developing and creating new models of agricultural machinery, it is very important to choose the optimal combination of its design parameters, which makes it possible to most effectively realize all the potential capabilities of the future machine embedded in the design [1-3].

In recent years, researchers have increasingly used various methods for modeling rolling resistance, traction and other indicators of tractors and machines [4-6]. Nevertheless, obtaining a tractor power balance in the field, using modern sensors and a new generation of recording equipment, allows a more objective assessment of the processes occurring in the machine-transmission-tire-soil system [7-9].

It is well known that the power balance of any mobile power tool moving uniformly on a horizontal surface can be written as follows:

\[ N_b = N_{bs} + N_d + N_\delta + N_f + N_{PTO} + N_{DB} \] (1)

Where:
- \( N_{bs} \) – power costs for the drive of engine systems, kW;
- \( N_d \) – power costs for the drive of controls, kW;
- \( N_\delta \) – power consumption to overcome wheel slip, kW;
- \( N_f \) – power consumption for self-movement on various types of support surface, kW;
- \( N_{PTO} \) – power consumption for PTO drive, kW;
- \( N_{DB} \) – power consumption for overcoming the pull on the hook, kW.

To assess all the components of the energy balance, it is necessary to determine the torques and rotational speed of the power take-off shaft and the axle shafts of the driving wheels, the speed of the machine, the pulling force on the hook, engine speed, fuel consumption and other indicators [10]. The authors were given the following tasks:

- Obtaining initial data for the development of a mathematical model for calculating the performance of an all-wheel drive mobile power vehicle of the traction and energy concept of class 0.6 based on the components of the power balance;
- Study of the potential possibility of using the experimental sample as a sprayer and as a tractor of traction class 0.6.
2. Materials and methods
The object of research was an experimental sample of an all-wheel drive mobile power vehicle weighing 4530 kg, equipped with an articulated frame and wheels with tires of dimension 11.2R28. An operator's cabin and a 40 hp engine are installed on the front half-frame; a boom sprayer with a nominal tank volume is mounted on the rear half-frame.

To carry out the research, work was carried out on sticking strain-resistive strain gauges on the wheel drive axle of the power vehicle and on the rear power take-off shaft, assembling them into bridge circuits, setting up measuring channels and calibrating. The axle shafts were calibrated after they were installed in the final drives with the brake band clamped. The torque, taking into account the directions (sign), was provided with a load by a jack through a lever with a shoulder of one meter. The load was measured using a dynamometer. The measuring circuit included an end current collector, previously tested in the dynamic mode (rotation and vibration) for the stability of the transient resistance and the corresponding channel of the measuring and recording equipment. The torque meter on the power take-off shaft was calibrated in a lathe chuck mounted on the frame of the calibration stand using a lever with a working length of 1 m. The machine speed was determined using a travel wheel, and fuel consumption was measured with a chamber flow meter of increased accuracy. The traction force developed by the mobile power vehicle was measured using an S-shaped dynamometer, which was mounted on a special bracket fixed on the rear axle. The Belarus MTZ-80 tractor was used as a hook power absorber in engine braking mode. The same tractor was also used to determine the rolling resistance force of a mobile power vehicle.

Before the start of the research, the regulatory characteristic of the D-130 engine was obtained on the GPF-17h test bench. Its maximum power was 29.8 kW, with a shaft speed of 1970 rpm and fuel consumption of 9.3 kg / h.

Water was used as the working fluid in the sprayer. The studies were carried out on a field prepared for sowing with a moisture content of 24% in a layer of 0-10 cm with three options for filling the tank (the weight of the machine was: 4530 kg, 5280 kg, 5920 kg).

3. Results
The rolling resistance force was determined by towing a mobile power vehicle on an asphalt road and on a field prepared for sowing. At the same time, the torques on the axle shafts, the rolling resistance force, the vehicle speed, the wheel speed and other parameters were recorded.

On asphalt, the following values of the total power lost in the power transmission and in the tires (hysteresis losses) were obtained: s, power losses were 1.90 kW, 2.78 kW and 3.52 kW; with a completely filled sprayer tank (m=5920 kg) at speeds of 1.62 m/s, 2 m/s and 2.37 m/s, respectively: 2.65 kW, 3.45 kW and 4.32 kW.

The results of the assessment of the power spent on towing the power tool across the field prepared for sowing are shown in table 1.

The assessment of losses due to self-movement of a mock-up sample of an all-wheel drive mobile power vehicle was also carried out against a soil background. As a result, it was found that the power consumption for creating tangential traction force by the wheels increased both with an increase in the speed of the machine and with an increase in its weight (table 2). Moreover, the thrust was created mainly by the front wheels, due to the kinematic discrepancy caused by the difference in peripheral speeds of the wheels of the front and rear axles. Power loss in the transmission increased with vehicle speed and decreased slightly as the engine was loaded.

The data in table 2 shows that only 21 kW is required for self-propelling across the field in 3rd gear of a fully loaded machine, which is 64.4% of the maximum engine power. Thus, the power reserve for the PTO drive is only 11.6 kW. However, the power consumed by the sprayer pump at the maximum supply of the working fluid is 18.2 kW, so the measurement of energy characteristics with power take-off was carried out at an average PTO load of 9...13 kW (table 3).
Table 1. The results of evaluating the rolling resistance forces of a mobile power vehicle when towing it across the field.

| Weight, kg | Speed, m/s | Rolling resistance, kN | Power consumption, kW |
|------------|------------|-----------------------|-----------------------|
|            |            | rear axle | front axle | total | for rutting | general |
| 4530       | 1.92       | 4.95      | 0.40       | 0.15   | 0.55       | 8.97    | 9.52 |
|            | 2.45       | 5.05      | 0.56       | 0.21   | 0.77       | 11.6    | 12.37 |
|            | 2.80       | 5.27      | 0.67       | 0.25   | 0.92       | 13.84   | 14.76 |
|            | 1.99       | 6.23      | 0.07       | 0.41   | 0.48       | 11.94   | 12.42 |
| 5280       | 2.43       | 6.10      | 0.12       | 0.56   | 0.68       | 14.15   | 14.83 |
|            | 2.88       | 5.96      | 0.13       | 0.71   | 0.84       | 16.30   | 17.14 |
|            | 1.94       | 7.28      | 0.30       | 0.74   | 1.04       | 13.06   | 14.10 |
| 5920       | 2.44       | 6.52      | 0.02       | 0.98   | 1.00       | 14.86   | 15.87 |
|            | 2.88       | 6.17      | 0.01       | 1.29   | 1.29       | 16.47   | 17.76 |

Table 2. The results of measuring the energy characteristics of a mobile power tool when moving without a traction load and without power take-off to the PTO drive.

| Weight, kg | Speed, m/s | Fuel consumption, kg/h | Power consumption, kW |
|------------|------------|------------------------|-----------------------|
|            |            | rear axle | front axle | total | transmiss ion losses | general |
| 4530       | 1.73       | 4.62      | 0.01       | 8.14   | 8.16       | 1.64    | 9.80 |
|            | 2.24       | 5.53      | 0.08       | 11.74  | 11.82      | 2.98    | 14.80 |
|            | 3.20       | 6.27      | 0.14       | 15.52  | 15.38      | 3.22    | 18.60 |
|            | 1.74       | 5.15      | 0.35       | 10.51  | 10.86      | 1.89    | 12.75 |
| 5280       | 2.21       | 5.96      | 0.83       | 13.34  | 14.17      | 2.83    | 17.00 |
|            | 2.67       | 6.69      | 0.78       | 16.44  | 17.21      | 3.49    | 20.70 |
|            | 1.72       | 5.14      | 1.05       | 11.17  | 12.22      | 1.48    | 13.7 |
| 5920       | 2.20       | 5.67      | 0.94       | 13.82  | 14.76      | 2.15    | 16.91 |
|            | 2.67       | 6.71      | 1.66       | 17.4   | 19.06      | 2.96    | 22.42 |

Table 3. The results of measuring the energy characteristics of a mobile vehicle when driving with a power take-off on the PTO and without a traction load.

| Weight, kg | Speed, m/s | PTO power, kW | Power consumption, kW |
|------------|------------|--------------|-----------------------|
|            |            | rear axle | front axle | total | in transmission | general |
| 4530       | 1.72       | 9.64      | 0.11       | 8.09   | 8.20       | 4.73    | 22.57 |
|            | 2.22       | 9.31      | 0.12       | 10.86  | 10.98      | 4.81    | 25.10 |
|            | 2.67       | 9.14      | 0.17       | 13.27  | 13.44      | 5.22    | 27.80 |
|            | 1.68       | 12.93     | 0.88       | 9.92   | 10.80      | 4.72    | 28.45 |
| 5280       | 2.12       | 11.66     | 1.43       | 12.42  | 13.85      | 3.64    | 29.15 |
|            | 2.27       | 10.74     | 1.59       | 14.04  | 15.63      | 3.28    | 29.65 |
|            | 1.70       | 10.77     | 1.05       | 10.30  | 11.35      | 3.80    | 25.92 |
| 5920       | 2.16       | 10.50     | 1.19       | 12.91  | 13.94      | 3.11    | 27.71 |
|            | 2.52       | 9.29      | 1.73       | 15.42  | 17.15      | 3.36    | 29.80 |

Traction tests of the studied sample were carried out in 2nd gear at three levels of sprayer filling. For a machine weight of 4530 kg, the maximum traction power was 13.3 kW, with a traction force of 7.0 kN, and a speed of 1.89 m/s. The conditional traction efficiency in this case was 0.45. With a mass
of 5280 kg, the maximum traction power was 12.4 kW, with a traction force of 7.14 kN, a speed of 1.74 m/s (= 0.42). For the heaviest variant (5920 kg), the maximum traction power was 13.4 kW, with a traction force of 7.44 kN, a speed of 1.8 m/s.

Figure 1 shows a fragment of the traction characteristic obtained in 2nd gear with a machine weight of 5280 kg.

![Figure 1. Traction performance of a class 0.6 mobile power tool on a field prepared for sowing (2nd gear, weight 5280 kg).](image)

4. Discussion
The results obtained, presented in Table 1, indicate the presence of power circulation in the power train. Such circulation is due to differences in the kinematic radii of the driving wheels of the machine, which in turn were caused by differences in the vertical loads along the axles: with an empty sprayer tank, the load on the front axle is 1930 kg, the rear axle is 2600 kg, with a full tank, respectively 2020 kg and 3920 kg. Due to circulation, power losses in the power transmission amounted to 0.5…1.3 kW (in the investigated speed range). The main power costs go to hysteresis losses in tires and rutting - 9 ... 16.5 kW. Thus, the maximum power required to tow the machine on a loosened soil base was 17.8 kW.

An analysis of the results of measuring the energy characteristics of a mobile vehicle when driving with a power take-off on the PTO and without a traction load, given in Table 3, indicates a significantly increased level of engine load in terms of power. With a slight decrease in the power consumption for the sprayer pump drive ($N_{PTO}$), the power consumption for the implementation of the tangential thrust force increased both with an increase in speed and with an increase in the mass of the machine. The decrease in PTO power is primarily due to a change in the engine shaft speed with an increase in load. Accordingly, the performance of the sprayer pump also decreased.

The complex nature of the interaction of many factors influencing the process of slipping and rut formation determined the nature of the flow of the curve of the corresponding engine power costs as a function of the hook load. The nature of the change in power losses in the transmission is also of interest: they first increase with an increase in the traction force developed by the machine, and then some decrease is observed. This phenomenon is explained by the fact that when working on a soil
background, with an increase in traction load and a corresponding increase in slippage, the losses due to parasitic power circulation in the closed transmission circuit of the power tool are reduced.

5. Conclusion
Thus, as a result of the conducted experimental studies, the following conclusions can be drawn:

- The power required for towing an all-wheel drive self-propelled power vehicle on an asphalt surface is 1.9…4.3 kW, depending on its weight and speed;
- Power consumption for the movement of an all-wheel drive self-propelled energy vehicle across a field prepared for sowing varies from 9.5 to 17.8 kW, depending on the speed and mass, and the main energy costs, many times greater than the hysteresis losses in the tires, go to soil deformation (rutting);
- The power of the engine of the studied power tool is clearly not enough both to realize the traction potential of the machine weighing 4.5 tons, which is incorporated in the design, and to meet the needs of the sprayer installed on it;
- Power losses in the power transmission of an all-wheel drive self-propelled power vehicle increase with an increase in the load on the transmission, and then, after reaching its maximum, they begin to decrease, which is due to a decrease in power circulation losses in the transmission circuit due to the kinematic discrepancy between the front and rear wheels.

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