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Increasing the efficiency of using the SUTB technology in the operation of agricultural units

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Abstract. The article proposes a method for determining the energy parameters of a machine-tractor unit to increase the efficiency of using the SUTB (shifted-up and throttled-back) technology for stepped transmissions of agricultural tractors. The theoretical substantiation of the new method and the results of practical testing in real field conditions are presented.

1. Introduction

Agricultural tractors operate in an aggregate with implements mainly as tractors and energy sources through a power take-off shaft, thus forming a mobile energy device that should provide high productivity and economy when performing the entire range of agricultural work.

According to the analysis of test reports [1] published by the Nebraska Tractor Test Laboratory [2], the specific energy saturation of most models of agricultural tractors is 1.8-2.1 kW/kN and can reach 2.4 kW/kN, which allows for maximum performance and versatility in agricultural work. At the same time, the high energy saturation of the tractor often leads to a decrease in the economic efficiency of agricultural production due to engine underload [3].

The best way to solve the problem of rational use of tractor power for tractors with stepped transmissions is the use of SUTB (shifted-up and throttled-back) technology, which assumes maintaining a constant speed of the unit movement by choosing a gear and changing the crankshaft rotation speed [4-7]. At the same time, the operator (driver) must independently and subjectively assess the energy requirement necessary for performing the technological operation and compare it with the power, fuel and economic characteristics of the engine and a possible range of transmission gear ratios and decide on the possibility of increasing the speed of the unit or the possibility of reducing the frequency rotation of the engine crankshaft and the transition to an increased stage of the transmission to maintain the same speed. As input data for such an analysis, the operator can use information obtained from the tractor instrument panel (engine crankshaft speed, tractor setting speed), as well as information obtained by the organoleptic method (tonality and nature of engine sound, color and opacity of exhaust gases, uniformity of movement, change in vibration, etc.). In this case, the effectiveness of the analysis and subsequent decision-making is subjective and largely depends on the qualifications and experience of the operator. The operator's availability of objective information about the current load and the developed engine power will allow him to significantly facilitate and improve the quality of decisions made on the choice of the unit's operating mode [8-10].

As a result of studying the existing methods for determining the energy performance of agricultural machine and tractor units, it was found that they do not allow solving the problem of real-time assessment of the engine operation mode, as well as the degree and potential of using its power.

2. Materials and methods

To achieve the goal of the study, the authors used the following materials and methods:

- Analysis of the published research results of methods for the practical determination of the energy parameters of the operation of agricultural machine and tractor units;
- Mathematical modeling of the performance of a diesel engine;
- Comparative field experience.

3. Results

As a result of the study, the authors drew attention to such an engine operation parameter as the turbocharging pressure p_k, which has a stable relationship with the average effective pressure p_v (conditional constant pressure in the engine cylinder, at which the work carried out in it in one stroke would be equal to the effective work in cycle), which is one of the engine indicators characterizing the current load. This relationship is manifested in the fact that the amount of air supplied by the compressor changes with load change, since the degree of gas pressure reduction in the turbine P_t and the degree of gas pressure increase in the compressor P_k are interrelated:

$$P_k^{\frac{k-1}{k}} = 1 + \beta\tau\left[1 - \left(\frac{1}{P_t}\right)^{\frac{k_g-1}{k_g}}\right] \quad (1)$$

where k, k_g - the ratio of the heat capacities of the fresh charge and exhaust gases, respectively (a variable value depending on the temperature of the working fluid T, the fraction of burned out air x and the excess air coefficient α $k = F(T, x, \alpha)$;

β is a parameter determined by the thermophysical properties k and R (gas constant) of the fresh charge and exhaust gases;

τ - engine stroke (2 or 4).

Thus, by measuring the air pressure in the intake manifold, using the dependencies known for a particular engine, it becomes possible to determine the current engine power N_e and the engine power utilization factor K_N using the formulas:

$$N_e = f(p_k, n_d) \quad (2)$$

$$K_N = \frac{N_e(p_k, n_d)}{N_{max}(n_d)} \quad (3)$$

where $N_{max}(n_d)$ is the maximum effective power developed by the engine at the engine speed n_d.

Practical verification of the possibility of obtaining information on the energy parameters of the machine and tractor unit during the technological process and using this data to increase efficiency using the SUTB technology was carried out on stubble plowing with a Challenger Sunflower 1435-29 disc harrow in a unit with a Versatile 2375 tractor. in two stages: the purpose of the first stage was to check the dependence of the air pressure in the engine intake manifold on the load on the tractor created by the disk harrow during the technological operation, and the purpose of the second stage was to check the possibility of increasing the efficiency of the technological operation based on the analysis of information on the energy parameters of the unit operation obtained by measuring the pressure in the turbocharger line.

To carry out the first stage, an electronic pressure transducer of the measured medium was installed on the turbocharging line into a unified DC signal PD100I-DA1.0-111-0.25 manufactured by the OVEN company, and the readings of the force-measuring strain-gauge sensor Meradat K- were taken as a reference load characteristic. 20G-10-S3, by means of which the trailed harrow was connected to the tractor's drawbar. The values of the turbocharging pressure and the traction resistance created by the harrow were recorded synchronously with a frequency of 20 Hz using the IP-264 measuring information system. Measurements were carried out on straight sections of the unit movement in various modes (starting, deepening, and deepening of the harrow's working bodies, uniform movement, acceleration, and deceleration, etc.). Figure 1 shows a plot of the diagram of the values of the traction resistance of the harrow and the pressure in the turbocharging line in the mode of deepening the working bodies with uniform movement.

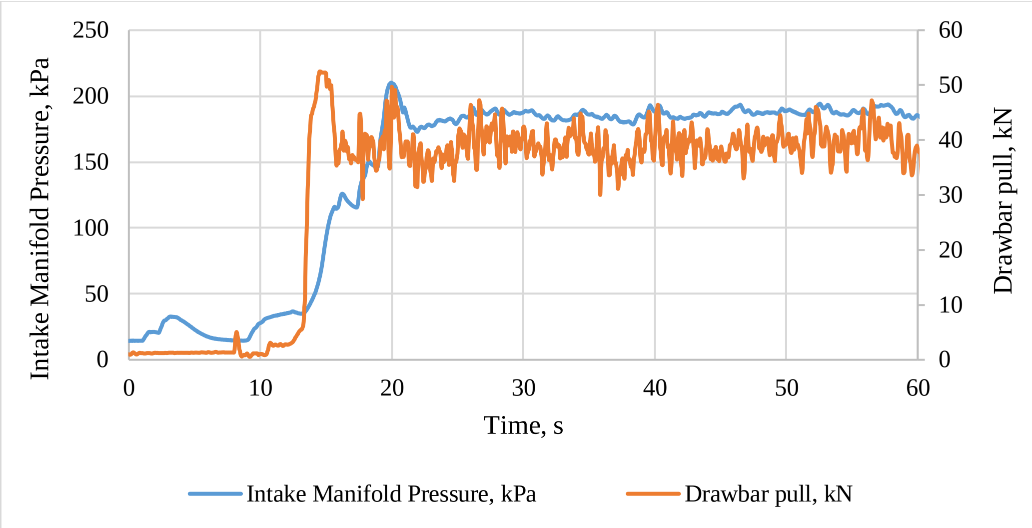

Figure 1. Diagrams of the values of the traction resistance of the harrow and the pressure in the turbocharging line during the deepening of the working bodies.

From the graph presented in figure 1 it follows that there is a dependence with a high degree of correlation between the values of traction resistance and pressure in the turbocharging line.

The second stage consisted in determining the energy performance of the unit by measuring only the pressure in the turbocharging line when performing the technological process in the mode selected by the operator, calculating the possibility of increasing efficiency using the SUTB technology and further comparing the performance and fuel efficiency of the unit in the basic and alternative modes.

To calculate the energy performance of the unit according to formulas 2 and 3, it is necessary to know the specific, for a given engine, the relationship of the boost pressure with the torque, power, and speed of the engine crankshaft. The characteristic of the engine was modeled based on the data presented in the operating manual of the tractor, placed in the public domain, as well as obtained by the method of acceleration and free runout of the tractor [8-10]. The resulting combined characteristic of the Cummins QSM11 engine is a contour plots of specific fuel consumption (figure 2) and turbo line pressure (Figure 3) in terms of speed and torque. These graphs are superimposed on isolines of equal powers (dashed lines in figures 2 and 3) and a graph of the external torque characteristic determined by the regulator settings and limiting the area of possible motor operation (line T in figures 2 and 3).

The combination of the set engine crankshaft speed n_x and transmission stage X to select the SUTB mode was selected by solving the equation:

$$\left(\frac{n_x}{2100}\right) v_X = v_x \tag{4}$$

where n_x is the required engine crankshaft speed, rpm;

v_X is the speed of the tractor at the transmission stage X at the rated speed of the engine crankshaft (2100 rpm), km/h;

v_x is the required speed of the tractor, km/h.

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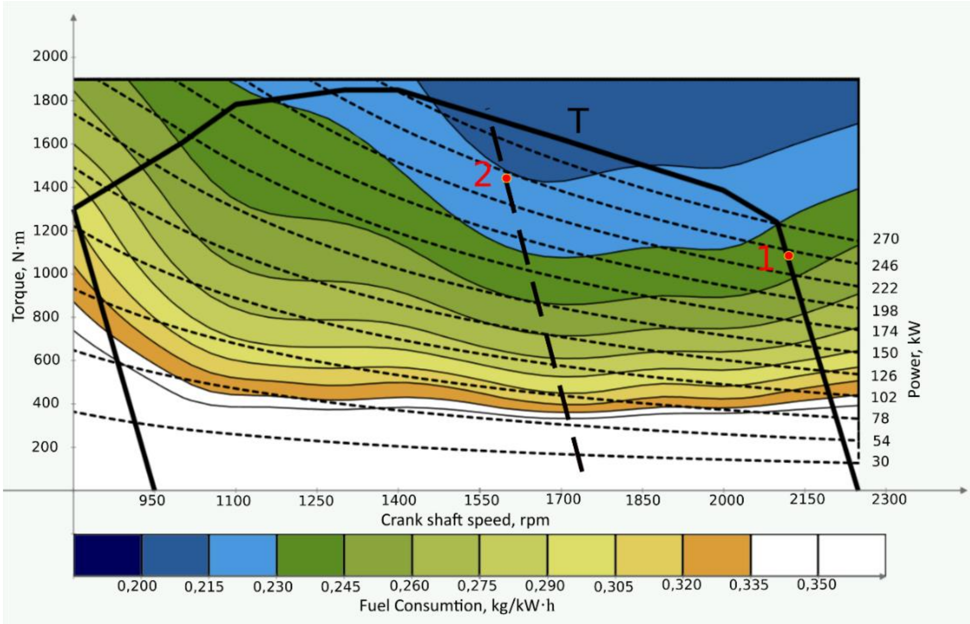

Figure 2. Calculated combined characteristic of the Cummins QSM11 engine (fuel consumption).

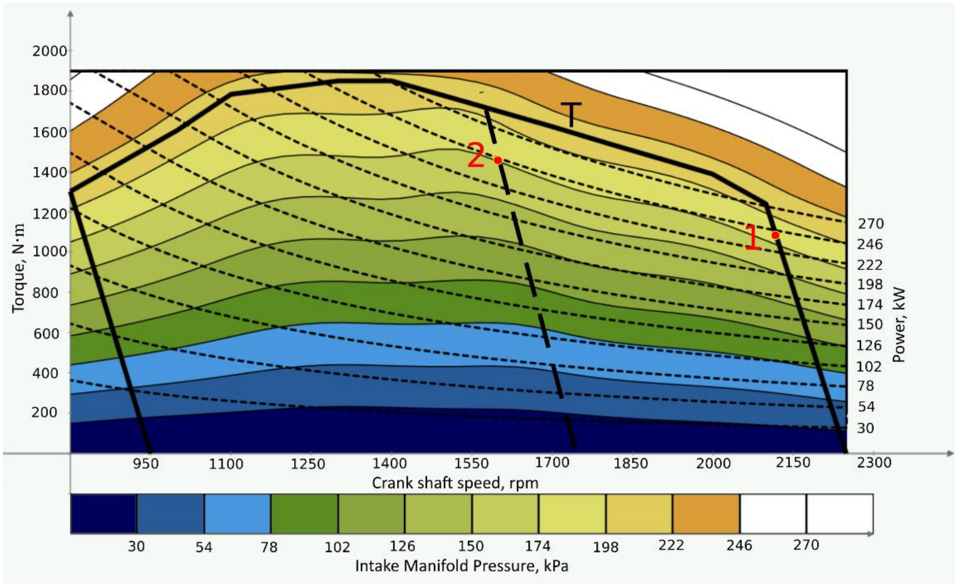

Figure 3. Calculated combined characteristic of the Cummins QSM11 engine (turbocharger pressure).

The second stage of field experiments was carried out when performing disc stubble cultivation of corn stubble residues (second pass). Guided by the goal of maximizing the performance of the unit and relying on his own experience and knowledge, the operator selected the mode of operation in 4th gear in the middle range with the accelerator position corresponding to the maximum crankshaft speed. The energy parameters of the unit operation, calculated from the results of measuring the pressure in the turbocharging line, are presented in table 1. After analyzing the data obtained, an alternative operating mode of the tractor in the 1st gear of an increased range with a reduced crankshaft speed was set. The performance indicators obtained for both operating modes of the unit are presented in table 2.

Table 1. Energy parameters of the Challenger Sunflower 1435-29 harrow in the unit with the Versatile 2375 tractor.

Index	Value
Unit speed, km/h	11.9
Working width of capture, m	7.8
Unit productivity for 1 hour of basic time, ha/h	9.3
Average depth of travel of working bodies, m	0.067
Pressure in the turbocharging line during main operation, kPa:	
- Average	181.29
- Standard deviation	2.51
Harrow traction resistance, kN	37.39
Power, kWt:	
- Consumed by the harrow	123.39
- Consumable for self-propelling of the tractor	114.92
- Total power consumption	238.31
Fuel consumption for 1 hour of main time, kg/h	58.1

Table 2. Performance parameters of the Challenger Sunflower 1435-29 harrow in the unit with the Versatile 2375 tractor.

Index	Value	
Working hours	Base	SUTB
Transmission stage	4 medium range	1 high range
Engine crankshaft speed during main operation, rpm	≈ 2130	≈ 1610
Unit operating speed, km/h	11.9	12.1
Working width of capture, m	7.8	7.8
Unit productivity for 1 hour, ha/h:		
- Main time	9.3	9.4
- Shift time	7.5	7.5
Average depth of travel of working bodies, m	0.067	0.067
Fuel consumption per hour of shift time, kg/ha	5.7	5.0

4. Discussion

From the analysis of the materials obtained as a result of the first stage of field experiments, it was noted that the nature of the change in the values of the boost pressure quite accurately repeats the fluctuations in the tractive resistance exerted by the harrow, although in the mode of deepening the working bodies, the increase in boost pressure is somewhat lagging behind the growth of traction resistance (figure 1). To finally confirm the hypothesis about the possibility of describing the nature of the load on the tractor by measuring the pressure in the turbocharging line, the time sweeps of the signals in different modes were subjected to the Fourier transform. The spectra of the values of the turbocharging pressure and traction resistance of the harrow in the steady state show the unambiguous identity of the amplitude-frequency characteristics of the measured parameters. Thus, there are sufficient grounds to proceed to the second stage of field experiments.

Based on the results of determining the energy parameters of the unit operation (table 1) in the mode selected by the operator, the tractor engine power is used quite fully (the parameters corresponding to this mode are indicated by point 1 in figures 2 and 3) and to move to the next transmission stage, implying an increase driving speed by ≈3.9 km / h, the engine power will no longer be enough. However, figure 2 shows that the average power of 238 kW required for the execution of the technological process at the same high-speed mode, the engine is able to develop with a decrease in the rotational speed up to 1200 rpm, while the fuel efficiency is significantly increased. The maximum decrease in fuel consumption to 0.217 kg/kW·h occurs at a speed of 1600 rpm (point 2 in figures 2 and 3), which is

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10.7% lower than fuel consumption in the current mode (0.243 kg/kW·h). Calculation according to formula 4 showed that the speed in the 1st gear of the increased range at a rotational speed of 1600 rpm will be 12.6 km/h and considering the slipping of the tractor wheels, the expected speed of the unit should be approximately equal to the basic mode. The results of determining the operational performance of the unit in the basic mode and the SUTB mode, presented in table 2, fully confirmed the calculated data. In the SUTB mode, the unit steadily performed the technological process with equal productivity, but with a saving of 0.7 kg of fuel per hectare of area treated during a work shift.

5. Conclusion

As a result of the study, the following conclusions can be drawn:

- Providing the operator with objective information about the current energy parameters of the agricultural machine-tractor unit and the degree of use of the engine power of the power unit significantly expands the possibilities and increases the efficiency of the SUTB technology application;
- Objective information on the energy parameters of the agricultural machine-tractor unit and the degree of use of the engine power of the power unit can be obtained using the developed method by measuring the pressure in the turbocharging line;
- Measurement of the pressure in the intake manifold of the engine does not cause technical difficulties, the need to change the design of the engine and does not affect the processes occurring in it. In addition, since the range of the air pressure at the outlet of the compressor depends on the range of the air pressure at the inlet to the turbine, it will not differ significantly for different engine models of different power.

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