Parameters of wheeled tractors and arable aggregates taking into account zonal conditions

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Abstract. The article considers the justification of the parameters of wheeled tractors and arable aggregates taking into account zonal conditions. The system of forming a promising size range of wheeled tractors and agricultural units for separate enterprises, agricultural zones and the whole country was based on scientifical principles of operational technologies of mechanized work that establish the basic levels and tasks of adapting energy resources to natural-production conditions. In developing models and an algorithm for optimizing operational parameters, the most objective indicators were applied, including the optimal net productivity of the arable aggregate for different classes of rut length and the tractor’s density. We established the optimal ($m_{den} = 67.30$ kg/kW) and maximum permissible in operation ($m_{denmax} = 75.70$ kg/kW) values of the density of wheeled tractors for the set of production conditions, regardless by rut length according to the results of modeling and field tests. The rational mass and energy parameters of the tractors for each rut length class were justified, included in the size range of the proposed two-parameter classification system and the corresponding values for the width of the arable unit.

1. Introduction
The widespread introduction in agricultural zones of the Russian Federation of the adapted resource-saving tillage and sowing technologies has activated the market of wheeled tractors with the improved classic 4k4a and unconventional 4k4b layouts on a single unit-aggregate base with variable mass and energy parameters [1–3]. In this way, the efficiency of the formed tillage and sowing units depends on the compliance of the tractor standard size with the natural and production conditions. The main requirement for establishing the optimal structure of energy facilities is a minimum of a combination of standard sizes and models with the maximum compliance with environmental conditions and production technologies while maintaining continuity and economic feasibility.

The analysis of developments concerning this problem [2–4] showed the priority direction for the promising tractor park formation on the basis of a standard size range of energy resources with an adjustable operating weight for the effective implementation of a set of technological operations of different energy intensity, taking into account the rut length distribution of fields.

The structure and content of the system for the formation of a standard-sized series of wheeled tractors and aggregates based on them, taking into account zonal conditions, involves the application of fundamental specific adapter parameters and optimization criteria that determine the algorithm for calculating the requirements for these energy sources.
2. Statement of the problem
The purpose of the work is the substantiation of the standard size range parameters of wheeled tractors and arable aggregates taking into account zonal conditions.

The object of research is the adapter parameters of wheeled tractors and arable aggregates to natural production conditions.

Research objectives:
1) to develop a structure and models of a system for optimizing parameters of wheeled tractors and arable aggregates on their basis;
2) to justify rational sizes of wheeled tractors for different classes of rut length.

3. Conditions and research methods
The basis for the structure and content formation of the justification system for parameters and indicators for the promising tractor size use [3] is based on scientifical principles of operational technologies for mechanized work that establish the basic levels and tasks of adapting energy resources to operating conditions.

The minimum resources consumption is the main criterion for solving optimization problems at each level. The high-level optimization parameters are initial ones for the subsequent parameters.

The formation structure and the algorithm for optimizing the parameters of standard series tractors for a separate enterprise, the agricultural zones of the federal district and the whole country include five levels of solving adaptation problems.

The first level contains the estimation of the natural-production conditions of tractors operation.

The influence of natural factors characterizes a rut length class \( l_{RL} \) (m), which determines the net productivity \( W^*_i \) \((m^2/s)\) of arable aggregate at the lowest cost, as the most objective and reliable generalized output parameter for a long period of time.

The averaged characteristics of the resistivity of adapted working machines \((\bar{K}_0, \Delta \bar{K}, \bar{\mu}_K)\), the structure of the perspective tractor park are the main production factors that determine the nominal values and operating speed intervals \( V^*_i \pm \Delta V \) \((m/s)\) for arable units as output parameters [3-4].

The second level provides for the optimization of the adapter parameters of tractors and aggregates, which are adjustable before the beginning of the workflow, for typical natural-production conditions.

The rational ratios of the operating mass \( m_{op} \) and the required power \( N_{rp} \) of the basic tractor for arable work, regardless of size, determine the specific mass values set [5-6] \( m_{den} = m_{op}/N_{rp} \) \((kg/kW)\) with minimal energy consumption \( E_{ec} = N_{rp}/W \) \((kj/m^2)\) to \( \min \) and specific width \((m/kW)\) of the plow \( B_{den} = \eta_{T_H}/K0 \cdot \mu_k \cdot V_t \).

The optimal values of specific indicators are estimated according to the operating condition of the tractor in the nominal traction and speed mode corresponding to the utilization coefficient of the weight \( \varphi_{KPH} \) at the maximum drawbar efficiency \( \eta_{T_H} \rightarrow \eta_{T_{max}} \) and speed \( V_H \). Limitations of \( m_{den} \) are the limits of regulation by doubling the front and rear wheels, the installation of removable ballast weights and the use of hydraulic superchargers (HSH).

The output parameters of the second level optimization are the energy potential \( N_{epi}^* \) (required power), the operating mass of the tractor \( m_{opi}^* \), as well as the working width of the arable aggregate \( B_{pi}^* \) for the corresponding rut length class:

\[
\begin{align*}
N_{epi}^* &= \left( \frac{W_i^* \cdot K0 \cdot \mu_k}{\eta_{T_H}} \right); \\
m_{opi}^* &= \left( \frac{W_i^* \cdot K0 \cdot \mu_k}{\varphi_{RMS} \cdot V_H^*} \right) \cdot 10^3; \\
B_{pi}^* &= B_{den} \cdot N_{epi},
\end{align*}
\]

where \( \mu_k = 1 + \Delta K (V_H - 1.4) \).
The third level provides the rationale for the size range of wheeled tractors for the main rut length classes. Taking into account the recommendations [2], it is advisable to use the nominal traction force and the effective engine power required for its implementation, with the rated speed on the stubble, as the main parameters. In addition, each size should provide the highest performance within its range of traction, and the entire size range overlap the overall range. Adjacent sizes with a common boundary in the zone of sufficiently high traction efficiency determine the conditions for their effective use in tillage operations in the main classes of the rut length.

At the fourth level, justified conditions are determined for the formation and use of a promising type of tractors, which is a combination of sizes and models to meet the needs of individual producers and the national economy as a whole. Taking into account the sufficient complexity of the general solution to the problem, practical calculations are reduced to justifying the size range of energy machines for a combination of natural-production conditions.

The trends in the constructions development, the structure of the tractor market, technical condition, staffing and engineering support for the tractor park and the financial situation of the main producers are subjects to analysis at the initial stage of this level as auxiliary tasks. The value of the adaptability coefficient of the engine at the moment \( K_M \) determines the optimal exploitation factor of the tractor’s operational power [4] with the mechanical transmission \( \xi_0 \) in traction load variation \( \nu_{KO} = 0.10 - 0.12 \),

\[
\xi_0 = 0.755 + 0.550(K_M - 1). \tag{2}
\]

A rational standard size of the serial tractor’s operational power of with a known technical characteristic of the engine and \( K_M \) is estimated according to the condition

\[
N_{eop} = \frac{\bar{N}_{op}}{\xi_0} \tag{3}
\]

at operating mass for the first (plowing) group of tillage operations

\[
m_{op} = m_{den} \cdot \xi_0 \cdot N_{eop}. \tag{4}
\]

The width of the aggregate, taking into account \( B_{den}^* \),

\[
B_p^* = B_{den}^* \cdot N_{eop}. \tag{5}
\]

For a new generation of constant-power tractor diesel engines with the electronic fuel supply control, the adaptability coefficient is \( K_M = 1.35-1.45 \), therefore, \( \xi_0 = 1.0 \) and \( N_{eop} = N_{eop}^* \) should be taken. As the base, we take the values of the adapter parameters of the basic tractor \( (N_{eop}, m_{den}, m_{e}) \) for dump plowing with an average rut length class \( \bar{l}_r \) [7].

At the fifth level, it is advisable to use the basic values of the operating parameters of the tractor as a reference unit for the methodology development for applying the conditional coefficients for transferring tractors into reference when determining the requirements for their needs. At the same time, the replaceable productivity of the reference tractor \( P^R_{f}(ha/h) \)

\[
P^R_f = \frac{\xi_0 \cdot N_{op} \cdot \eta_m}{K_0 \cdot \mu_k} \cdot \tau. \tag{6}
\]

The utilization factor of the shift time \( \tau \) depends [8] on the rut length class and tractor power.

4. Results and their analysis

On the basis of the modeling results and field tests of wheeled tractors Belarus 1523 and K-744 P2 in an aggregate with plows PPO-5.6 and PSK-9, respectively, the averaged characteristics of the resistivity \( \bar{K}_0 = 12.65 \) kN/m and \( \Delta K = 0.13 \) s/m, which made it possible to substantiate the nominal \( V_{th} = 2.22 \) m/s (8.0 km/h) and the maximum \( V_{max} = 2.78 \) m/s (10.0 km/h) high-speed arable work.

The required power and operating mass at \( \varphi_{rms} = 0.40 \) and \( \eta_{rms} = 0.66 \) are proportional to the productivity \( W^* \) and increase in 2.90 times with increasing head length from minimum (\(<150m\)) to maximum (>1000m).

Taking into account the employment of tractors in tillage operations of different energy intensity, the basic value of the operational mass \( m_{op}^* \) for each class of rut length and high-speed operating modes from 9.0 to 15.0 km/h corresponds to the specific weight \( m_{den}^* = 67.30 \) kg/kW. In the range of operating speeds below 9.0 km/h, which is typical for individual energy-intensive operations, it is advisable
$m^*_\text{denmax} = 75.70 \text{ kg/kW}$ to increase the operating mass in the operating mode to $m^*_{\text{opmax}} = 1.125 m^*_\text{op}$ due to the installation removable ballast weights or hydraulic loader. This will make it possible to realize the potential capabilities of tractors, regardless of the single or double wheeled configuration, in the entire speed range of use in tillage operations with the optimum working width of the plow $B^*_p$ or other working machines.

The values of operational power $N^*_{\text{eop}}$ for $\xi^*_N = 0.9-1.0$ and mass $m^*_\text{op}$ are included in the standard size series [3] of the two-parameter classification system for wheeled tractors. Their rational parameters depend on the headland class and correspond to the pulling power classes from 2.4 ($N^*_{\text{eop}} = 68.99 \text{ kW}$, $m^*_\text{op}$=4.62-6.92 tons) to 8.10 ($N^*_{\text{eop}} = 321-399 \text{ kW}$, $m^*_\text{op}$= 18.45 -27.68 t).

**Table 1.** The rational parameters of wheeled 4k4 tractors and arable aggregates with different rut length ($K_0 = 12.65 \text{ H/M}$ ($\eta_T = 0.66$)) $V_H = 2.22 \text{ m/s}$.

| Parameter | $<150$ | 150-200 | 200-300 | 300-400 | 400-600 | 600-1000 | $>1000$ |
|----------|--------|---------|---------|---------|---------|----------|---------|
| $W^*$, ha/h | 1.699 | 2.187 | 2.657 | 3.229 | 3.430 | 3.847 | 5.006 |
| $N^*_{\text{eop}}$, kW | 91.87 | 116.44 | 141.5 | 171.9 | 182.6 | 204.8 | 266.5 |
| $m^*_{\text{opmax}}$, ton | 6.85 | 8.82 | 10.71 | 13.01 | 13.82 | 15.50 | 20.13 |
| $m^*_\text{op}$, ton | 6.09 | 7.84 | 9.52 | 11.57 | 12.29 | 13.78 | 17.96 |
| $m^*_{\text{bmax}}$, ton | 0.76 | 0.98 | 1.19 | 1.44 | 1.53 | 1.72 | 2.20 |
| $P^*_{\text{RMS}}$, kH | 26.90 | 34.62 | 42.02 | 51.07 | 54.00 | 60.84 | 78.99 |
| $B^*_p$, m | 2.13 | 2.74 | 3.32 | 4.04 | 4.29 | 4.81 | 6.26 |
| $N^*_{\text{eop}}$, kW | 92-116 | 117-140 | 141-170 | 171-183 | 184-204 | 205-266 | 267-330 |
| Size range | 2.4-2.5 | 3.5-3.6 | 4.6-4.7 | 5.7 | 5.8-6.8 | 6.8-6.9 | 6.9-8.10 |

It is advisable to adopt a conventional 4k4 wheeled tractor of the basic configuration as a reference one, with the average rut length class for the agricultural zone. The basic values of the operational parameters of the reference unit are the basis for the development of a methodology for using conditional transfer ratios of tractors in determining their requirements.

5. Conclusion

The structure of the system for the parameters formation of the promising size range of wheeled tractors and arable aggregates including five levels of solving optimization problems using the most objective criteria and adapter parameters has been developed. According to the modeling results and field tests, the optimal $m^*_{\text{den}} = 67.30 \text{ kg/kW}$ and the maximum $m^*_{\text{denmax}} = 75.70 \text{ kg/kW}$ values of the specific gravity of wheeled tractors for the set of production operating conditions regardless of the rut length were established. The rational mass-energy parameters of tractors for each class of rut length on a dump plow are within the limits of traction-power classes 2.4-8.10 of the proposed two-parameter classification system.

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