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Agricultural tractors of the fifth generation

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Abstract. In this study, the problem of substantiation of Mobile Power Units (MPUs)-tractors for agriculture of the fifth generation–is described. The aim is to analyze agricultural tractors of the fifth generation. Technogenic interaction of MPUs with production processes in agro-ecosystems of grain production in the zonal conditions of arid agriculture in Southern Russia is described. Proposals for new MPUs are developed and the technological structures of machine aggregates based on the MPUs of the fifth generation of classes 3, 5–6 and 8, to determine their technical schemes, are determined. Analytical models are provided for calculating the power characteristics of MPUs of the mentioned classes in deterministic and stochastic modes in relation to the most energy-intensive operations with definitions of the mathematical expectations of Machine-Tractor Aggregate (MTA) power and performance. Effectiveness of MTAs is analyzed for the new MPUs based upon on the criterion of the time spent on cultivating crop rotations for classes 2 and 5–6 in wheeled and caterpillar performances and they are applied to the new generation of Machine-Tractor Station (MTS) of the technological services type. A comparison is carried out for the same sites with MTAs using the fourth-generation tractors. It will be observed that the time costs are reduced by 1.4–1.5 times and for the MPU of class 8, the reduction is up to 2.3 times.

1. Introduction

For more than a century, the world's agriculture has been using agricultural tractors, which have been transformed from a simple primitive machine with steel wheels equipped with metal grippers and small-sized engines at a rate of 1.5 dozen hp. to robotic technical tools with excellent ergonomic conditions, space control of technological process, and Internal Combustion Engine (ICE) capacities 20 to 30 times that of the early models. This new modern machine has raised labor productivity at least 20 times.

However, one property of the modern tractors of both wheeled and caterpillar types has remained unchanged. In the aggregating agricultural machines with

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tractors, which have remained virtually unchanged, the tractor becomes a "steel horse" by its technological scheme, having one rear hook and a single rear hinged system. At the present time, the tractors are equipped with a multi-section, rather long train of successively working tools requiring a wide turning strip on the field being processed. Despite achieving the highest level of automation with increase in the number of operations in a single machine and tractor unit, the Machine-Tractor Aggregate (MTA) cumbersomeness consistently increases and, if anything, its technological reliability (also consistently) decreases.

In addition, the increased mass of the tractors, especially the wheeled ones, sharply worsens the ecological working conditions by increase in the specific pressure on the soil with a deep force effect on the arable and subsoil layers. The actual pressing of the soil along the wheel tracks and the relatively high slipping and grinding of soil aggregates attenuate the structure of the arable layer and contribute to the occurrence of wind erosion [1-3].

Therefore, it is required to find ways of improving the technological capabilities of modern tractors in order to increase the adequacy of mechanical and technological systems in the form of MTAs for production processes in agrocenoses.

The current problem in the development of mobile power engineering in the agroindustrial complex (AIC) is to find and justify the ways of optimal technogenic interaction of agricultural tractors with the technological MTAs developed based on them. The goal is to reduce the negative impact of running systems on the arable layer of the soil, decrease the intensity of erosion processes, and increase the reliability of multi-operation MTAs synthesized (collected) on the coupling devices.

2. Materials and methods

Different methods were used to achieve the set goal. Numerous studies in the Russian and the world agro-engineering were analyzed to find the ways of reducing the harmful man-caused impact of mobile aggregates on the productive layer of soil. The results showed that one of the rational ways was organizing soil cultivation and cultivating field crops with a minimum number of drills along the processed field surface, while reducing the specific pressure from the impact of running systems. The necessity of reducing the impact on soil is unassailable. This requires, on the one hand, replacing the wheeled propellers of MPUs and technological rovers with caterpillars for cultivating, sowing, or harvesting the soil and, on the other hand, cutting the number of MTA passes through the field, which is still a difficult problem to resolve. The latter is unattainable to the full even with the capabilities of the modern tractors, no matter wheeled or caterpillar. It should be noted that in this paper, we consider heavy tractors of agricultural class 3 and above, which basically "make" the harvest of significant commodity producers. This applies to those Mobile Power Units (MPUs) that are still operating today, representing the fourth generation of mobile power engineering and having the technical structure developed at the dawn of their use (i.e., their technical structure, as noted above, has remained unchanged).

One more feature of the MTA composition should be noted, which is related to the rear trailing device or hinged system of the tractor. It is clear that a set of trailer machines ensures carrying out a multi-process complex operation in the expected positions (transitions), which can practically be performed within a single agro-term, simultaneously [4]. Multiprocessing aggregates are exactly aimed at reducing the number of passes through the field, which is the essence of public soil-saving measures. However, these aggregates are generally rather complicated, poorly controlled, and not flexible on the trajectory of motion when performing the technological process. The creation of multiprocessing tools and machines, e.g., the so called disk headers and the multi-purpose tillers for preparing soil in sowing winter crops on non-steam predecessors in Russia, seems to be an improvement to the process [5]. However, combined guns and their aggregates are rather cumbersome and heavy and they include several robot-like working elements in the unit, which are not connected geometrically by the sequence of operations. All the structural, technological, and organizational difficulties mentioned here have a common root: the imperfection of the engineering and technical structure of the fourth-generation tractors, which is also the case for the previous generations. This imperfection has gradually and consistently manifested itself and reached its peak at the present level of machine and technological support evolution.

In other words, in its development, the world's tractor equipment has lagged behind itself considering the fast-growing characteristics, fast-growing mass, the level of control systems, the ergonomic level [6,7], the requirement of ecological balance of technogenic interaction with production agroecosystems, and finally the level of machine technologies for field crop production and the systems for organizing field work development. Once again, a certain imbalance has occurred in technology development. The huge growth and development of engineering has not resolved the organizational and technological issues that arise in the field of mobile energy [8].

The solution of the problem posed may lie in the ways of justifying and developing mobile energy resources in the *fifth generation* of machines-MPUs, not tractors-which have greater capabilities than the traditional tractors and are more sophisticated at the core components. However, it is inevitably achieved by considering and preserving all technological properties of the tractors of the fourth generation to retain the fundamental properties of modern tractors. Different generations of machines are distinguished based on their classes of thrust and, correspondingly, mass-energy characteristics [9,10]. Therefore, the fifth generation of MPUs can confidently be aggregated with the same tools and machines as those of the fourth generation of tractors, but with various functional or multifunctional MTAs.

3. Results and discussion

Machine-tractor units with MPUs of the fifth generation are directly synthesized for field work in zonal rotations on a multifunctional, *multiprocess* basis, i.e., with the potential of performing several technological operations that have the *same* agro-term or can be technologically carried out in a single agro-term. This reduces the total number of operations and the *number of passes* of heavy equipment on the *plow layer*. On the other hand, considering the significant increase in the use of tracked propellers, which were originally implemented in the system of tractors for agriculture, including in the US, the structure of the MPU of the fifth generation gets closer to realizing the requirements of ecological balance of technogenic processes of agrocenosis production [3,11–13].

In fact, agrocenoses, implemented by zonal crop rotations or operations of technological services in agricultural organizations, Agricultural Product Companies (APCs), and peasant farms as the most labor-intensive institutions with large volumes of production, directly set the agrotechnological structure of MTA, the derivatives of which are MPUs of different classes [10,14,15].

The structure of MPU of the fifth generation, in order to ensure a rational synthesis of technological MTAs in zonal rotations and service and technological work, should include the following features (the preliminaries):

- Presence of 2 universal hinged systems, front and rear;
- Presence of 2 independent unified shafts of power take-off, front and rear, providing up to 80 to 85% energy transfer of rotary motion to power-driven machines mounted on the front or rear attachment system or traction device;
- Stepless drive of the undercarriage, hydraulic or electric (in this paper, we consider MPU of the fifth generation with a stepless hydrostatic drive, which has been sufficiently developed and successfully used for a long time in the world agricultural machinery);
- Wheeled MPUs of classes 3 and 5-6 equipped with an easy-shift caterpillar chassis; MPUs in wheel designs weighing more than 11.000 kg, based on numerous studies conducted in a long period of time as well as long-term observations, *should fall into disuse in field work*.

We have chosen, so to speak, the following field work of new MPUs:

- South-Russian grain-fodder crop rotation in arid agriculture by the use of black steam in the peasant farms, eight fields, with an area of 960 ha (farmer rotation);
- A large crop rotation in the same grain-fodder area, nine fields, with 2.250 hectares for agricultural organizations (APC, CAE, etc.) by the use of black steam;
- A set of labor-intensive field work in the form of technological service for surface tillage (400 ha), subsoiling and other heavy surface tillage operations (3.500 hectares), harvesting of cereals (1.200 ha), and maize for silage (800 ha).

Operations on these volumes of work set the technical structure of the MPUs of the three classes we are developing, namely 3, 5-6, and 8, which are the main machines that "make" the harvest [10].

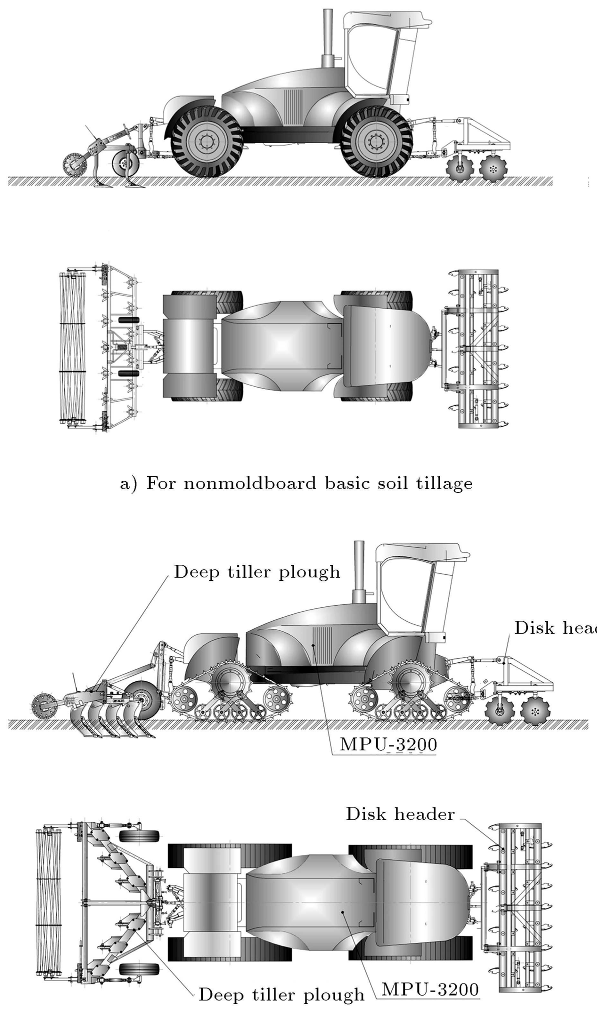
In Figure 1, the general layout of MPU-3200 of class 3 with power of 184 kW in wheel (a) and caterpillar (b) variants by the use of a replaceable running gear is shown. The MPUs are equipped with MTA for processing the mentioned farmer crop rotation, with the exception of the spiked cereals harvesting process, which is performed by a self-propelled combine harvester (of medium or even small class).

The second crop rotation is processed by a complex of machines based on the caterpillar MPU-5400 of class 5 with power of 260 to 280 kW (Figure 2). It provides all the necessary acquisition of MTA, including the process of harvesting spiked cereals by a trailed non-motorized combine (Figure 3).

Figure 4 shows the schematics of fodder-soil-cultivating MTA on the basis of caterpillar MPU-5400. The MTA is equipped with a trailing implement AKM-4 (6) to prepare the soil for sowing winter crops on non-steam predecessors (multi-process MTA), simultaneously, by harvesting maize for silage.

Figure 5 shows the physical model of MPU-5400 (scale 1:12) with two mounted tillage tools: disk (on the front) and a deep scraper (on the rear).

Finally, MTAs, equipped with a caterpillar MPU-8470 of class 8 with power of up to 380 kW (Figures 6 and 7) are used in service technological operations. At the same time, MPU of class 8 performs all harvesting operations, including harvesting of spiked cereal crops



a) For nonmoldboard basic soil tillage

b) In caterpillar performance (changeable chassis)

Figure 1. Mobile power unit MPU-3200 of cl. 3 with power of 180 kW.

using a trailed, non-motor, high-performance combine harvester (Figure 8).

Synthesized MTAs for all three uses of MPU-3200, MPU-5400, and MPU-8470 with mounted machines and implements are given in Table 1.

In justifying and calculating the MPU transmission, it is of particular interest to determine the energy characteristics combining mechanic, analytic, and hydrodynamic constructions in both deterministic and probabilistic executions.

Let us consider the hardest working conditions of MPU in the traction and drive modes, when the MTA on the basis of MPU not only performs operations with trailed and mounted implements, but also threshes spiked cereals with a trailed non-motorized combine harvester or harvests corn for silage using a mounted adapter.

We will write the determined ratio of energy consumption in the expanded form for MTA on the

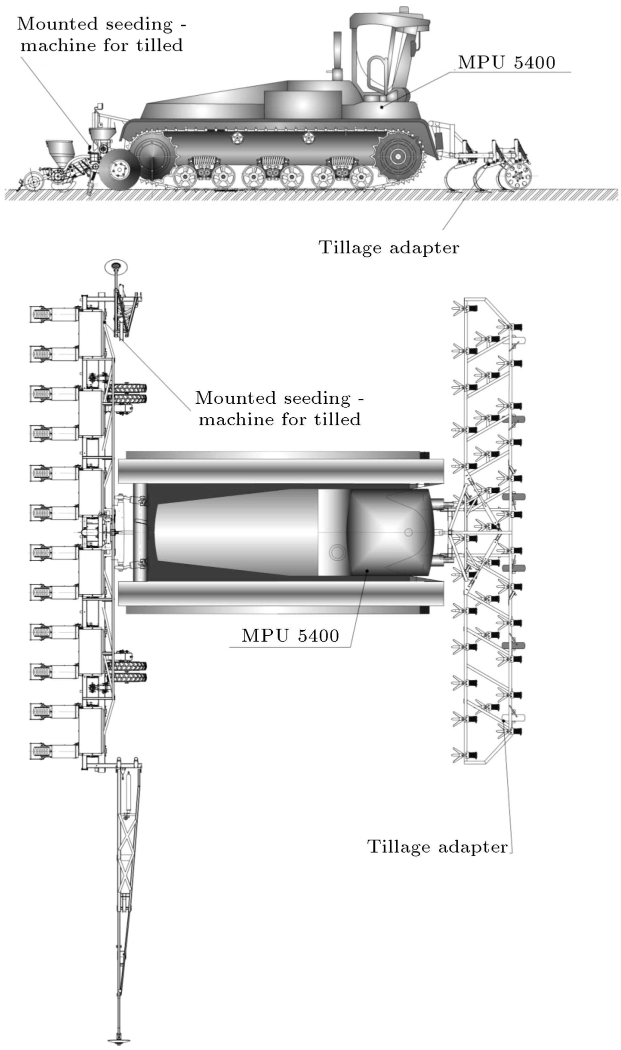


Figure 2. Mobile power unit MPU-5400 of cl. 5 with power of 280 kW with mounted tools.

basis of MPU-5400 (Eq. (1)):

$$N_{eff} = \Delta p_{21} B_{21} \cdot \frac{\vartheta_{mov}}{75} + m_{5400} \cdot f_{roll_{tr}} \cdot \frac{\vartheta_{mov}}{75} + m_{harv} \cdot f_{roll_{harv}} \cdot \frac{\vartheta_{mov}}{75} + m_{corn} \cdot f_{roll} \cdot \frac{\vartheta_{mov}}{75} + \Delta p_{harv} \cdot B_{21} \cdot \frac{\vartheta_{mov}}{75}. \quad (1)$$

Here, N_{eff} is the effective power providing the operation of the MTA. If we take the whole of the right side of Eq. (1) as the energy resistance N_{tmr}, then $N_{eff} \geq N_{tmr}$. The first term on the right side corresponds to energy resistance of the disk header with width B_{21} (it is the same for all working elements), which moves with the translational velocity, ϑ_{mov} (it is the same for all MTAs). Δ_{p21} is specific resistance of the disk header (kgf/m).

The second additive determines the resistance of the MPU-5400 mass to rolling (m_{5400} is the operational

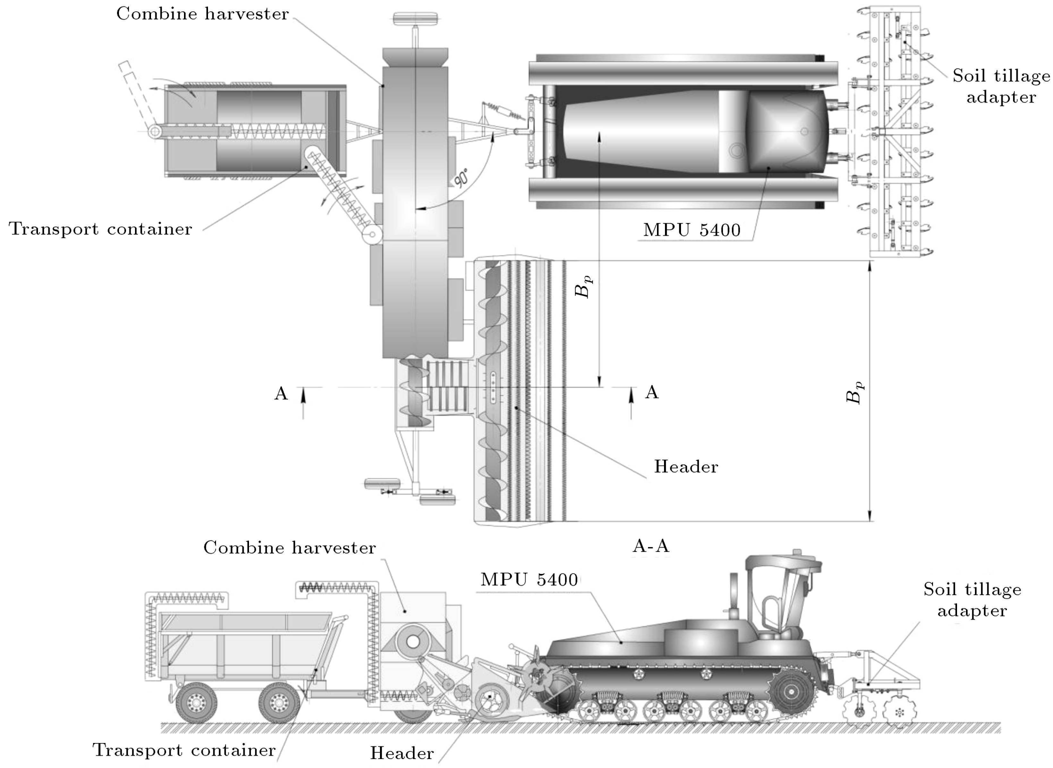


Figure 3. Grain-harvesting and soil-cultivating MTAs on the basis of MPU-5400: the mounted adapter for post-harvest closing of moisture; trailed non-motor combine by axial-rotary with the capacity of 5 to 6 kg/s by means of a transverse arrangement of threshing-separating devices; tank grain trailer.

mass of the energy source; $f_{roll_{tr}}$ represents the rolling factor of the track-type machine; and $f_{roll_{tr}} = 0.08$) and the third additive reflects the cost of energy for rolling the total operating weight of a non-motor combine (m_{harv} is mass of the combine; $f_{roll_{tr}}$ stands for rolling ratio; and $f_{roll_{tr}} = 0.12$). The fourth additive corresponds to the amount of energy spent on rolling the mass of grain m_{corn} in the trailer bunker and the last additive estimates the energy input to the technological process of the combine itself, the value of which depends on the yield of the plant mass. Its per-second feed q (kg/s) into the grinder at the corresponding translational speed, ϑ_{mov}, can be calculated on the basis of the value of the specific energy consumption for threshing, which we estimate to be equal to 17 $\frac{\text{kW}}{\text{kg/s}}$ under the given conditions.

Also, N_{tmr}, after the substitutions and calculations, will be 190.7 kW.

Now, let us introduce the hydraulic drive, keeping in mind that the moment M_{eff}, created by the hydraulic drive to supply energy to MPU-5400 for all its mounted, trailed, and driven machines and implements, obeys the relation $M_{eff} \geq M_{trm}$, where M_{trm} is the total moment of resistance (Eq. (2)):

$$M_{eff} = \frac{N_{eff} \cdot 9449}{n_{gm}} = \frac{190.7 \cdot 9449}{1900} = 948.4 \text{ N} \cdot \text{m}. \quad (2)$$

Eq. (2) corresponds to hydrodynamic regularities [16]). n_{gm} is frequency of rotation of the ICE shaft, to which the value of frequency of rotation of the drive motor is given.

The value of M_{eff}, developed by the hydraulic drive, will be (Eq. (3)):

$$M_{eff} = \frac{1.56 \cdot \vartheta_{gm} \cdot \Delta \cdot \eta_{mh}}{100}. \quad (3)$$

Therefore, we have:

$$\vartheta_{gp} = \frac{948.4 \cdot 100}{1.56 \cdot 350 \cdot 0.95} = 182.8 \text{ sm}^3. \quad (4)$$

At $\Delta p = 350$ kgf/sm^2, the flow rate Q of the working fluid in accordance with [16] is (Eq. (5)):

$$Q = \frac{\vartheta_{gm} \cdot n_{gm}}{1000 \cdot \eta_{mh}} = \frac{182.8 \cdot 1900}{1000 \cdot 0.95} = 365.6 \text{ l/min}. \quad (5)$$

Accordingly, N_{tp}, the total power consumed by the hydraulic drive, will amount to (Eq. (6)):

$$N_{tp} = \frac{Q \cdot \Delta p}{612 \cdot \eta} = \frac{365.6 \cdot 350}{612 \cdot 0.9} = 232.3 \text{ kW}. \quad (6)$$

Finally, we determine the mathematical expectation of the drive (consumed power [17] based on the calculations of analytical constructions by Prof. L.Ye. Ageyev (Eqs. (7)–(9)):

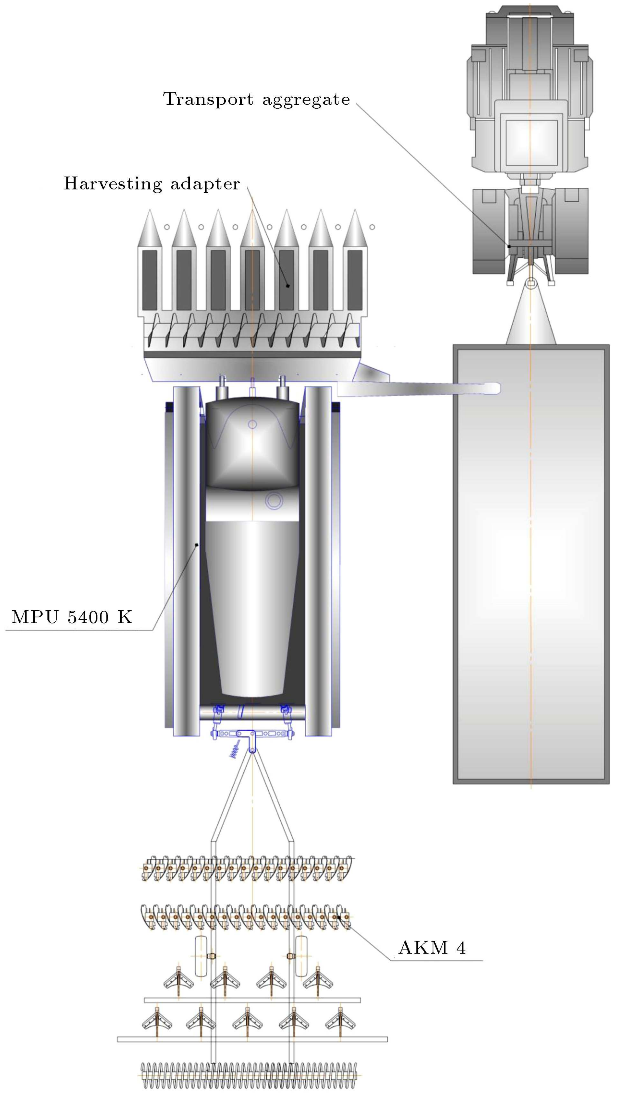


Figure 4. Forage-soil cultivating MTA on the basis of wheel MPU-5400 of class 5: mounted silage harvester for harvesting and chopping maize for silage; AKM aggregate for soil preparation for sowing of winter crops on non-steam trailed predecessor.

$$N_{e_{\max}} = \bar{N}_e + 3\sigma_{N_e}, \quad (7)$$

$$N_{e_{\min}} = \bar{N}_e - 3\sigma_{N_e}, \quad (8)$$

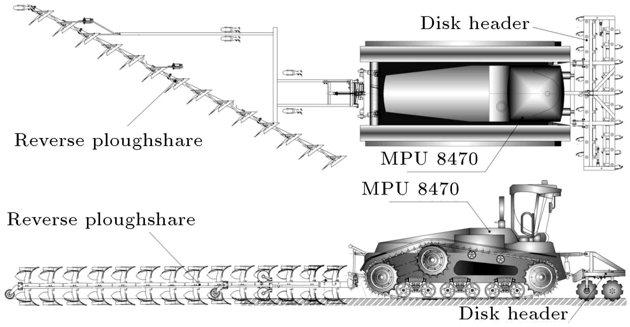


Figure 6. Mobile power unit MPU-8470 of class 8 with power of 380 kW with trailed 12-hull reverse plow and hinged disk header for post-harvest moisture closure in the production layer of the soil.

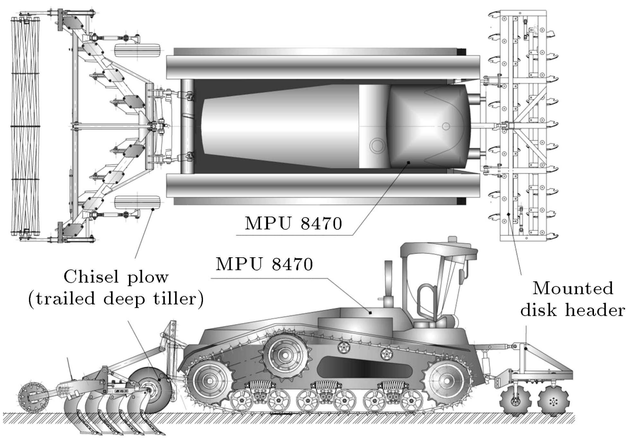


Figure 7. Mobile power unit MPU-8470 with mounted disk header and trailed deep tiller (chisel plow).

$$\lambda_{\bar{N}} = \frac{M(N_e)}{N_e}. \quad (9)$$

Hence, the mathematical expectation $M\ (N_e)$ of the power will be (Eq. (10)):

$$M(N_e) = \lambda_{\bar{N}} \cdot N_e. \quad (10)$$

Here, $\lambda_{\bar{N}} = 0.89$ (the degree of ICE loading) at $\sigma_{N_e} = \frac{232.3 \cdot 0.2}{3} 15.5$ kW. Then Eq. (11) is obtained:

$$N_{tp} = M(N_e) = 232.3 \cdot 0.89 + 3\sigma_{N_e} = 252 \text{ kW}. \quad (11)$$

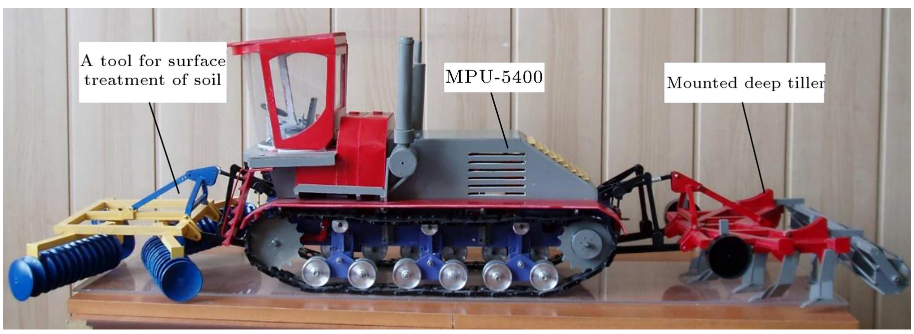


Figure 5. Tillage caterpillar MTA; MPU of class 5 (model in scale 1:12).

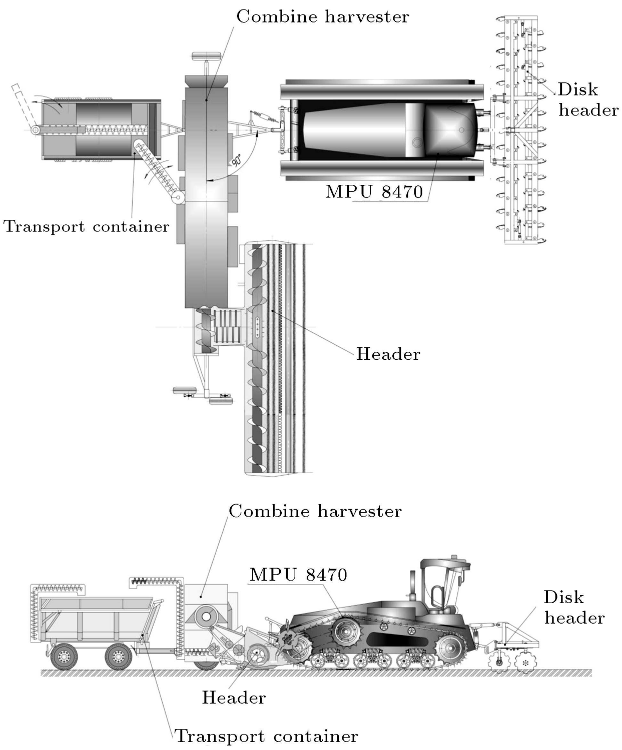


Figure 8. MPU-8470 with a trailed high-performance, non-motorized combine harvester by means of a transverse axial-rotor threshing separating device with a throughput capacity of 8 to 8.5 kg/s with a trailer hopper and a disk header to cover moisture.

We take the power of the installed ICE as 265 kW (or 360 hp.).

In this way, the power of the ICE in the MPU-5400 drive and other new types of MPUs with a hydraulic drive is calculated. According to the data obtained, it is already possible to perform a detailed calculation of the hydrostatic transmission and engage in the design of the hydraulic drive as a whole.

The economic efficiency of the use of new MPUs (of the fifth generation) has been calculated in relation to those conditions that are determined by the operational platforms using the methodologies of VNIPTIMESKH and ACHII. All the new MPUs participating in the technological processes are equipped with working bodies, machines, and tools forming multi-process MTAs (as presented in Table 1 with reference to MPU-3200, MPU-5400, and MPU-8470).

As a basis for comparison, traditional technologies and MTAs based on tractors of the fourth generation are used for the first variant (crop rotation applied to the PF area of 960 hectares) in the new ATM-3180 wheeled tractor (class 3, 132 kW). For the second variant (crop rotation of 2250 hectares for agricultural organizations), on the basis of a new crawler tractor of class 6, named "Ruslan," with a capacity of 246 kW. The third item is for service technological operations by the same "Ruslan," because it is the most powerful agricultural tractor in Russia. By considering the duration of the original work as the evaluation criterion at the MTA synthesis stage, the effectiveness evaluations are first carried out in accordance with the criteria for the type of discounted income in this study.

The calculated data for the third variant (as an example) are given in Table 2.

Table 2 shows that the number of working hours for four operations performed by multi-process MTAs based on the MPU-8470 is 1402.3. The traditional MTAs based on the fourth-generation caterpillar tractor performed the same work in six operations spending 3229.1 hours. It can be concluded that the new complex of machines, combined into multiprocess MTAs based on MPU-8470, ensures 2.3 times reduction in the duration of work, proving high technical and operational efficiency of the innovative technology and equipment. Appropriate, though not so high, indicators have been obtained for two other innovative machine complexes. Multiprocess MTAs based on MPU-3200 in wheeled and, in some operations, caterpillar performances (with replaceable running gear) reduce the estimated duration of original operations to 831.7 h, against 1143.8 h by traditional technology based on the fourth-generation-tractor ATM-3180, i.e., 1.38 times.

The second variant, which is analyzed using the fifth-generation MPU-5400 MPU in innovative MTAs, leads to the total duration of 1408.5 hours for multiprocessing operations, reducing it compared to the traditional technology based on the fourth-generation Ruslan tractor with 2155.2 h, i.e., 1.53 times.

Thus, it can be concluded that in the mass work in agricultural production, labor costs from the use of innovative MTAs based on the MPU of the fifth generation will be reduced by 1.3 to 1.5 times. In general, this is a fairly significant reduction in labor costs.

The values of the mathematical expectation of the hourly performance of $M(W)$ multiprocess MTAs based on MPU of the fifth generation are determined by the dependence relation (Eqs. (12) and (13)):

$$M(W) = c_1 M(N_e), \tag{12}$$

where

$$c_1 = 0,36\eta_m \tau \frac{1}{k_a}, \tag{13}$$

where η_m is the tractive efficiency, τ is the degree of use of the operating time of the MTA, and $1/k_a$ is the specific resistance of MTA in kN/m. Table 3 shows the values of $M(W)$ for the three MPU classes considered for $\eta = 0.6$, $\tau = 0.7$, and $1/k_a = 11 \ldots 13.3$ kW/T.

The proposed mobile energy of the *fifth generation* for agriculture has a much greater potential for

Table 1. Complex operations and composition of multi-process Machine-Tractor Aggregates (MTA) based on Mobile Power Units (MPU) of the fifth generation.

Crop rotation of 960 ha (PF)		**Crop rotation of 2250 ha (AS, CAE, APC)**		**Technological service of MTS type**	
Name of operation	MTA composition: MPU-3200	Name of operation	MTA composition: MPU-5400	Name of operation	MTA composition: MPU-8470
Pre-sowing tillage with sowing of spiked cereals	Mounted cultivator + MPU caterpillar variant + sowing complex-coupling	Harvesting winter crops with primary field processing	Harrow disk medium + MPU-5400 + harvester trailed non-motorized	Surface tillage + subsoiling	Harrow medium + MPU + deep tiller
Pre-sowing tillage with simultaneous sowing of tilled	Mounted cultivator + MPU wheel variant + tilled mounted seeding-machine 8 m	Soil preparation for sowing with corn sowing	Cultivator + MPU + tilled mounted seeding-machine	Subsoiling with soil leveling	Disk header + MPU + deep tiller
Harvesting of corn for silage with preparation of soil for sowing of winter crops	Mounted forage harvester adapter + MPU wheel + AKM-4	Harvesting of corn in cobs with preparation of soil for sowing of winter crops (according to non-steam predecessors)	Adapter cob sweeper mounted + MPU + AKM-4	Cultivation without waste treatment	Cultivator + MPU + AKM-8
Dump plowing - basic sow tillage	Mounted disk header + caterpillar MPU + mounted plow six-hull 2.1 m	Harvesting of peas from the rolls with preparation of soil for sowing winter crops (by non-steam predecessors)	AKM-6 + MPU + harvester trailed	Primary soil tillage with leveling	Disk header + MPU + reversible plow 12-hull
Preparation of soil for sowing with subsoiling	Mounted disk header on the front attachment + MPU caterpillar version + mounted deep tiller	Cleaning of winter crops with primary soil treatment	Harrow medium + MPU + harvester trailed	Harvesting of spiked cereals with comber	Combing adapter + MPU + mounted MSU with cleaning + towed trailer
–	–	Harvesting of corn for silage with preparation of soil for sowing of winter crops (for non-steam predecessors)	Mounted feed-harvesting adapter (for front hitch) + MPU + AKM-6	Mowing of corn for silage with preparation of soil for sowing of winter crops	Feed-harvesting adapter + MPU + AKM-8A

reducing the time required to implement technological processes in the cultivation of field crops. Real ways of ecological balance of technogenic processes in grain production are identified, which include reduction in the number of driveways across the field by the creation of multiprocess MTAs and use of a replacement chassis. It is beyond doubt that adapting the existing agricultural tractors of the fourth generation for multiprocessing operations, for example, by a set of a line loop of tools and machines, is extremely inconvenient in operation with simultaneous loss of productivity. However, by the *development of special machines of a new generation*,

Table 2. Technical and operational indicators on labor-intensive and complex technological operations of traditional and innovative Machine-Tractor Aggregates (MTA) based on Mobile Power Unit (MPU) of class 8.

No	Name of operation	Name of transition	Scope of 6 work, ha	Acquisition of operations; MTA; parameters — Traditional (fourth generation): MTA composition	Width of grip, m	Progressive speed, km/h	Productivity, ha/h	Duration, h	Innovative (fifth generation): MTA composition	Width of grip, m	Progressive speed, km/h	Productivity, ha/h	Duration, h
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Soil-cultivating operation	Surface tillage of soil	400	"Ruslan" + disk tiller	10	10	6,4	156,2	MPU-8450 + medium tiller + deep tiller	6	8	3,84	260,4
		Subsoiling	1000	"Ruslan" + deep tiller	5	7	2,8	357,1					
2	Soil-cultivating operation	Subsoiling with soil leveling	750	"Ruslan" + deep tiller	5	7	2,8	357,1	MPU-8450 + disk header on the front hinge + deep tiller	7	8	4,5	155,0
				"Ruslan" + disk header	6	7	3,4	220,0					
3	Soil-cultivating operation: soil preparation for sowing	Cultivation	1200	"Ruslan" + deep tiller	12	8	7,68	97,6	MPU-8450 +cultivator + AKM-6	8	10	6,4	117,2
		Nonmold board layer-by-layer processing		"Ruslan" + AKM-6	6,8	10	4,8	156,2					
4	Soil-cultivating operation: moldboard processing	Main moldboard processing (plowing)	1000	"Ruslan" + deep tiller	3,15	8,0	2,0	500,0	MPU-8450 + reversible plow 12-hull + disk header	4,2	8	2,56	390,6
		Processing of plowing by disk header		"Ruslan" + disk header	7,0	8,0	4,4	227,2					
5	Harvesting of spiked cereals with comber	Harvesting of spiked cereals with comber	1200	"Torum-740"	8,0	5,0	2,8	428,6	MPU-8450 + mounted combing adapter + mounted MSU with cleaning, trailing bunker				
				"Ruslan" + AKM-6	6,0	10,0	4,8	250,0		6	8	3,84	312,5
6	Harvesting corn for silage	Mowing with grinding and loading into a container	800	"Don-680"	4,0	8,0	2,56	312,5	MPU-8450 + feed-harvesting adapter + AKM-6	6	10	4,8	166,6
		Soil preparation for sowing of winter crops		"Ruslan" + AKM-6	6,0	10,0	4,8	166,6					
In all operations, the fifth generation's innovativeness can be seen (according to our innovation scheme)				The amount of hours: - traditional technology – 3229.1 h - innovative technology – 1402.5 h Decreased 2.3 times					–				

Table 3. Mathematical expectations of the hourly performance of multiprocess Machine-Tractor Aggregates (MTAs) based on the fifth-generation MPU.

MPU: Conventional brand	Meanings				
	τ	η_m	k_a, kW/t	$M(N_e)$, kW	$M(W_u)$, ha/h
MPU-3200	0.7	0.6	11.0	169.0	2.3
MPU-5400			12.0	252.0	3.17
MPU-8470		0.65	13.3	320.0	3.94

synthesis of mobile aggregates can be carried out quite comfortably and they can "genetically" be adapted for multi-process operations. At the same time, a radical modernization of transmissions in the direction of steplessness is envisaged and there is no limit on the wide opportunities for MTA automation. This problem could have been solved in the fourth-generation tractors much earlier, given that one of the authors of this work participated in creating a prototype of a real fifth-generation class three MPU with a hydrodrive 30 years ago.

The same applies to the replacement caterpillar chassis, which was created in the b. VNIPTIMESKH (Zernograd) also about 30 years ago. Nevertheless, now, the problem has shifted to the real plane of its solution and the technical documentation for the fifth-generation MPU is being developed.

4. Conclusions

Modern tractors of the fourth generation have reached such a high power to weight ratio in their development that their loading requires synthesis of rather bulky trailed and mounted complex structures, which reduces productivity to some extent. Heavy energy resources have a negative impact on the soil, contribute to a significant decrease in yield, worsen the structure of the arable layer, destroy soil aggregates, and lead to more wind erosion.

A family of (MPUs) of the of classes 3, 5-6, and 8 was developed with a power from 180 to 350 kW and weight from 7600 to 14500 kg. They were equipped with two unified mounted systems, two independent PTOs, a stepless drive transmission, and a replaceable caterpillar chassis. The so-called multi-process Machine-Tractor Aggregates (MTA) could be synthesized based on them to ensure the ecological balance of the technogenic interaction of the MTA with the production layer in agroecosystems and reduce the duration of field operations both in individual processes and in zonal rotation as a whole.

The use of stepless transmission allowed for utilizing full power of the MPU energy unit at any point of the MTA's trajectory to the max and opened up wide possibilities for automation of dynamic systems in order to increase the stability of the output parameters of technological processes.

The use of the light-weight crawler tracker on MPUs of classes 3 and 5 with a mass not more than 11.000 kg, by the simultaneous removal of machines with larger masses in the wheeled version from field work, effectively resolved the problem of negative man-made impact on the production layers of the soil.

Carrying out design and calculation work for the creation of a fifth-generation MPU with stepless hydraulic drive of the transmission to improve accuracy implied the introduction of hydrodynamic regularities and the apparatus of random functions into the computational algorithms.

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