УДК 631.171

UDC 631.171

4.3.1. Технологии, машины и оборудование для агропромышленного комплекса

4.3.1. Technologies, machinery and equipment for the agro-industrial complex

МЕТОДИКА ОБОСНОВАНИЯ КОНСТРУКТИВНЫХ ПАРАМЕТРОВ ЗЕРНОУБОРОЧНЫХ КОМБАЙНОВ

METHODOLOGY OF SUBSTANTIATION OF DESIGN PARAMETERS OF COMBINE HARVESTERS

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Производство зерновой продукции всецело зависит от производства зерноуборочных комбайнов и покупательной способности, которые все больше зависят от климатических, политических и экономических изменений в мире. Все это требует от разработчика умения оперативно перестраивать свою работу, быстро и эффективно менять направления производства, модернизации и разработки новых зерноуборочных комбайнов, обеспечивая максимальные показатели их качества и эффективности. Рассматривается математическая модель зерноуборочного комбайна, как реакция на входные внешние факторы и управляющие воздействия. Общая задача обоснования выбора основных конструктивных параметров зерноуборочных комбайнов формулируется как многокритериальная задача математического программирования, которая для ее решения делится на этапы. По результатам официальных

The production of grain products is entirely dependent on the production of combine harvesters and purchasing power, which increasingly depend on climatic, political and economic changes in the world. All this requires the developer to be able to quickly rebuild their work, quickly and efficiently change production directions, modernize and develop new combine harvesters, ensuring maximum performance of their quality and efficiency. The mathematical model of a combine harvester is considered as a reaction to external input factors and control effects. The general problem of justifying the choice of the main design parameters of grain harvesters is formulated as a multi-criteria mathematical programming problem, which is divided into stages for its solution. Based on the results of official tests, regression models of combine harvesters' technological processes are being built, which are modeled in limited conditions of culture and zone with the construction of испытаний строятся регрессионные модели технологических процессов комбайнов, которые моделируются в ограниченных условиях культуры и зоны с построением условий качества и эффективности. По результатам моделирования формируется информационное поле основных конструктивных параметров зерноуборочных комбайнов, на основании которого строится регрессионная модель основных конструктивных параметров. Решая задачи оптимизации по математическим моделям основных конструктивных параметров, обосновываются сами значения конструктивных параметров из условий происходящих изменений

quality and efficiency conditions. As a result of the modeling, an information field of the main design parameters of combine harvesters is formed, on the basis of which a regression model of the main structural parameters is built. Solving optimization problems based on mathematical models of the main structural parameters, the values of the design parameters themselves are justified from the conditions of the changes

Ключевые слова: ЗЕРНОУБОРОЧНЫЙ КОМБАЙН, МАТЕМАТИЧЕСКАЯ МОДЕЛЬ, КОНСТРУКТИВНЫЕ ПАРАМЕТРЫ, УСЛОВИЯ ЭКСПЛУАТАЦИИ, ЭКСПЛУАТАЦИОННО-ТЕХНОЛОГИЧЕСКИЕ ПОКАЗАТЕЛИ

Keywords: COMBINE HARVESTER, MATHEMATICAL MODEL, DESIGN PARAMETERS, OPERATING CONDITIONS, OPERATIONAL AND TECHNOLOGICAL INDICATORS

http://dx.doi.org/10.21515/1990-4665-213-027

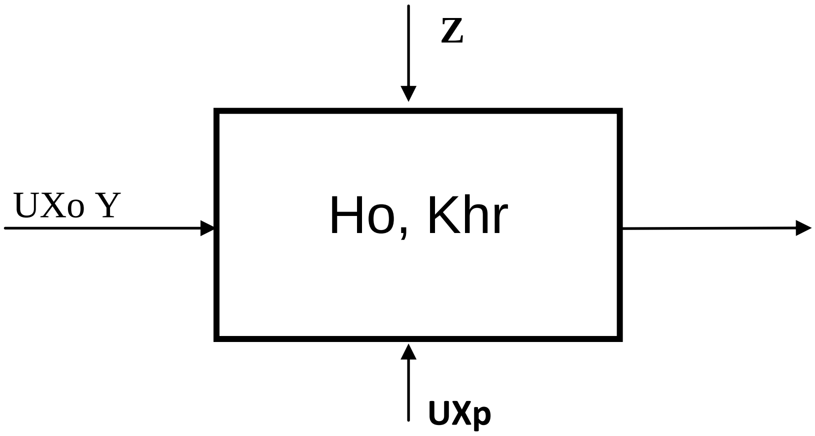
Introduction and purpose.

Grain production in Russia is becoming part of the global economic market, which is entirely dependent on the production of grain harvesters and the purchasing power of agricultural producers.

Now we have a market economy and the requirements for the production of grain harvesters are supplemented by consideration of the purchasing power of agricultural producers, in connection with climatic, political and economic changes in Russia and the world**.** WITH The current state of domestic combine harvester manufacturing does not fully address the technical challenges of highly profitable grain production with minimal losses using a small range of grain harvesters. Market conditions require a willingness to adapt to changing conditions and requirements for newly developed grain harvesters. This requires the ability of developers to quickly restructure their operations, quickly and effectively shift production, modernization, and development of new grain harvesters, ensuring maximum operational and technological performance in terms of quality and efficiency [1, 2].

Materials and methods.

The diagram of a mathematical model of a grain harvester (see figure) proposed in vector form in works [3-7] is considered.



Y - indicators (parameters) of the quality of the technological process (output operational and technological indicators of quality and efficiency);
Z - indicators (factors) of the operating conditions (characteristics of the harvested crop);
Xo – technical characteristics of the combine (main design parameters);
Xp - modes of execution of the technological process (setting parameters);
UXo, UXp - control actions from the developer and the machine operator.
Figure - Diagram of a mathematical model of a grain harvester in vector form

Output parameters(Y) of the mathematical model of grain harvester operation: combine harvester performance, t/h; total grain losses behind the combine, %; trash content, %; crushed grain content, %, etc. External factors (Z) influencing the output parameters (Y): yield, c/ha; grain moisture content, %; straw moisture content, %; grain lodging, %, etc. Internal factors controlled (UXo) by the developer are the main design parameters (Xo): thresher width, mm; engine power, kW; sieve area, m2; straw walker length, m, etc., and controlled (UXp) by the combine operator are the parameters of the combine technological process setup (Xp): combine travel speed, km/h; threshing drum rotation frequency, s-1; cleaning fan shaft rotation frequency, s-1, etc.

Under these conditions, the mathematical model of the functioning of a grain harvester can be considered as a response to input external factors and control actions

$$\left.\begin{array}{c} Y = F\,(Xo,\, Xp,\, Z), \\ Xo \subset G1,\ Xp \subset G2,\ Z \subset G3,\ Y \subset G4,\ (1) \end{array}\right\}$$

where G = {G1UG2UG3UG4} is the state space of technical characteristics, technological process (TP) modes, operating conditions and indicators of quality and efficiency of the grain harvester.

When substantiating (Xo) the main design parameters of a grain harvester, a mathematical model of the functioning (1) of a grain harvester is considered, which operates under conditions of constantly changing external influences (Z), caused by numerous and varied disturbances.

In the context of the existence of a problem of justifying the choice of the main design parameters of grain harvesting combines taking into account external conditions, the general problem (1) is formulated as a multi-criteria problem of mathematical programming:

find: Xo*,

from the condition: max(min): Y = F(Xo, Xp, Z), (2)

under restrictions: $Xo \subset G1$, $Xp \subset G2$, $Z \subset G3$, $Y \subset G4$. (3)

The general solution to problem (2), (3) is represented as the optimization of the main design parameters (Xo*) of grain harvesters within the state space G, in which the required or optimal values of the main quality and efficiency indicators (Y) must be achieved. However, an exact solution to a multicriteria problem is associated with significant difficulties, both in terms of the number of unknowns and the number of constraints. To accurately solve a multicriteria problem, a single-criteria approach is usually employed. Therefore, from the perspective of implementing a method for solving such a problem, it seems advantageous to reduce it to the solution of several smaller problems. One such method is decomposition and dimensionality reduction, where the main problem is divided into parts and its solution utilizes models that reduce the number of independent variables.

Results.

Stage 1. We will use the well-known problem [3-7] of constructing a mathematical model of the technological process in vector form, analyzing the influence of (Z) operating conditions and (Xp) operating modes, in specific zones, on the operational and technological indicators of quality and efficiency of different models of grain harvesters for crops and types of work:

$$\left.\begin{array}{c} Yo/Xo = Fo(Xp, Z) \gtreqless V; \quad (4) \\ Xo = const,\ Xp \subset G2',\ Z \subset G3',\ Yo \subset G4', \end{array}\right\}$$

where V is the vector of constraints on quality and efficiency indicators;

G'= {G2'UG3'UG4'} - the state space of the zone corresponding to a certain model (Xo⊂G1') grain harvester.

To construct a mathematical model of the grain harvester's technological process, it is necessary to have statistical data characterizing the system's state during operation. For this purpose, from an organizational and technical perspective, official results of agrotechnical and operational-technological assessments of acceptance and control tests of grain harvester prototypes being prepared for serial production, as well as periodic tests used during serial production of grain harvesters, conducted at the MIS and R&D facilities, should be used.

Let's use a fragment of the mathematical model of the TP of the grain harvester type NOVA:

$$\left.\begin{array}{l} W/Xo = 0.094*U - 0.046*Vs + 1.066*V \geq 7; \\ q/Xo = 0.049*Y \leq 3.0; \\ D/Xo = 0.096*U - 0.098*Vz - 0.123*V \leq 2; \quad (5) \\ C/Xo = 0.124*U - 0.045*Vs - 0.540*V \leq 2; \end{array}\right\}$$

where V = [7; 3; 2; 2; 1.5], meets the requirements of the technical specifications for NOVA grain harvesters,

and a fragment of the mathematical model of the TP of the Acros 530 type combine, obtained during direct combining of wheat in the 6th zone at KubNIITiM [3]:

$$\left.\begin{array}{l} W/Xo = 0.056*U - 0.0768*P + 2.639*V \geq 13.5, \\ q/Xo = 0.0547*P + 0.417*V \leq 3, \\ D/Xo = 0.0596*U + 0.181*V + 0.367*T - 3.23*V \leq 2, \quad (6) \\ C/Xo = 0.055*P + 0.111*Vz - 0.189*V \leq 2, \end{array}\right\}$$

where V = [13.5; 3; 2; 2; 1.5], meets the technical specifications for Acros 530 grain harvesters;

Y - quality indicators of the technological process (W - combine productivity, t/h; q - losses behind the combine, %; D - grain crushing, %; C - foreign matter, %);

Z - operating conditions (U - grain yield, c/ha; P - crop lodging, %; Vz - grain moisture, %; Vs - straw moisture, %; T - soil hardness, MPa (n/cm2); V - plant height, m);

Xp - setting parameters (V – combine speed, km/h),

obtained taking into account the restrictions on the conditions and modes of operation in the KubNIITiM zone: U = 28.2-55.2 c/ha; V = 4-6.0 km/h; P = 0.9-18.4%; Vz = 11.6-35.1%; Bc = 8.5-66.0%; T = 0.32-1.1 MPa; B = 0.70-1.02 m, which make it possible, by varying the speed (V), to evaluate the preferred operating conditions of combines without disrupting the technological process of combine operation.

Stage 2. The primary objective of mathematical modeling, when reducing the dimensionality of the feature space of a complex technical system's functioning, is to establish patterns of its behavior across the entire range of possible operating conditions under various operating modes. To achieve this:

- calculation mathematical models (5) and (6) of the operation of grain harvesting combines of different classes according to throughput on a specific crop in the work zone are used, obtained from the results of tests at KubNIITiM on direct combining of wheat;

- the process of modeling is carried out under operating conditions of grain harvesters in the KubNIITiM zone.

A fragment of the simulation (5) taking into account 50% confidence intervals for the conditions and operating modes of NOVA, common for the zone: U = 10-40 c/ha; V = 4-6 km/h; Vz = 12.3-15.0%; Bs = 12.7-30.0%, etc., gives the following results, Table 1.

Table 1. Results of modeling based on the results of tests of the NOVA type grain harvester for direct combining of wheat at KubNIITiM

Fixed parameters working conditions (Z') →			Quality and efficiency indicators (Y')				← Parameters settings (X'p)
U (10-40 c/ha)	Vz (12.3-15%)	Sun (12.7-30%)	**W≥7, t/h**	**q≤3%**	**D≤2%**	**C≤2%**	V (4-6 km/h)
42.5	13.5	12.7	**9.81**	**2.07**	**2.00**	**1.48**	6.0
36.3	12.3	12.7	**7.09**	**1.76**	**1.77**	**1.79**	4.0
40.0	13.7	22.7	**8.15**	**1.94**	**1.85**	**1.21**	5.1
38.0	15.0	30.0	**8.59**	**1.85**	**1.42**	**0.15**	6.0
30.0	14.0	15.0	**8.53**	**1.46**	**0.76**	**0.00**	6.0
…	…	…	**…**	**…**	**…**	**…**	…

The zonal operating conditions of the Acros 530 grain harvester at KubNIITiM, in which the simulation fragment (6) was carried out taking into account 50% confidence intervals for the operating conditions and modes common to the zone: U = 25-60 c/ha; V = 4-6 km/h; Vz = 12.3-15.0 %; Bs = 12.7-30.0 %; P = 2.8-18.4 %; T = 0.3-1 MPa; B = 0.89-0.94 m, etc., give the following results, Table 2.

Stage 3. Principal component analysis plays a key role in reducing the dimensionality of multidimensional statistical space. These principal component analysis methods, which represent (Y) operational and technological quality and efficiency indicators (in this case, from Tables 1 and 2) and the associated key design parameters (Xo), play a key role in the information field. The solution to the problem of improving combine harvesters, related to the substantiation of (Xo) key design parameters, involves identifying statistical relationships between the impact of a significant number of internal and external (Xp, Z) factors on operational and technological indicators (Table 3).

Table 2. Results of modeling based on the results of tests of the grain harvester type Acros 530 for direct combining of wheat in KubNIITiM

Fixed parameters working conditions (Z') →						← Quality and efficiency indicators (Y')				Parameters settings (X'p)
U (25-60 c/ha)	P (3-18, %)	Vz (12.3-15%)	Sun (12.7-30%)	T (0.3-1 MPa)	IN (0.9-1 m)	**W≥13.5, t/h**	**q≤3%**	**D≤2%**	**C≤2%**	V (4-6 km/h)
44.70	0.90	17.70	40.00	1.00	0.94	**15.63**	**2.14**	**0.90**	**1.07**	5
55.50	7:30	12:30	13.80	1.30	0.93	**13.10**	**2.09**	**1.69**	**1.01**	4
25.00	10.00	20.00	22.70	0.50	0.80	**16.47**	**3.08**	**0.00**	**1.64**	6
30.00	14:00	15.00	30.00	0.60	0.89	**13.80**	**2.89**	**0.04**	**1.49**	5
50.00	10.00	14:00	15.00	0.30	0.99	**16.81**	**2.91**	**0.80**	**1.05**	5.6
…	…	…	…	…	…	**…**	**…**	**…**	**…**	...

Note: There are as many tables as there are models of grain harvesters, types of harvesting and zones.

Table 3. Fragment of the construction of the information field for substantiating the main design parameters of a grain harvester with a classic threshing apparatus design in the KubNIITiM zone for direct wheat harvesting

Эксплуатационно-технологические показатели (Y)				Основные конструктивные параметры зерноуборочных комбайнов (Xo)									
W, т/ч	q, %	D, %	C, %	$L_б$, мм	$F_п$,м^2	$F_р$,м^2	$V_б$,м^3	N, квт	M, кг	$F_с$,м^2	$D_б$, мм	$L_к$, м	α, град.
9,81	2,07	2,00	1,48	1200,00	0,94	2,35	3,00	103,00	8100,00	4,34	600,00	3,64	146,00
7,09	1,76	1,77	1,79	1200,00	0,94	2,35	3,00	103,00	8100,00	4,34	600,00	3,64	146,00
8,15	1,94	1,85	1,21	1200,00	0,94	2,35	3,00	103,00	8100,00	4,34	600,00	3,64	146,00
8,59	1,85	1,42	0,15	1200,00	0,94	2,35	3,00	103,00	8100,00	4,34	600,00	3,64	146,00
8,53	1,46	0,76	0,00	1200,00	0,94	2,35	3,00	103,00	8100,00	4,34	600,00	3,64	146,00
15,63	2,14	0,90	1,07	1500,00	1,38	4,74	6,00	173,00	12600,00	6,15	800,00	4,10	130,00
13,10	2,09	1,69	1,01	1500,00	1,38	4,74	6,00	173,00	12600,00	6,15	800,00	4,10	130,00
16,47	3,08	0,00	1,64	1500,00	1,38	4,74	6,00	173,00	12600,00	6,15	800,00	4,10	130,00
13,80	2,89	0,04	1,49	1500,00	1,38	4,74	6,00	173,00	12600,00	6,15	800,00	4,10	130,00
16,81	2,91	0,80	1,05	1500,00	1,38	4,74	6,00	173,00	12600,00	6,15	800,00	4,10	130,00
...	...	...	...	...	...	...	...	...	...	...	...	...	...

As the main design parameters(Xo) grain harvesters, the following designations are accepted: L_b - length of threshing drum, mm; F_p- concave area, m2; F_r - sieve area, m2; V_b- bunker volume, m3; N - engine power, kW; M - weight with header, kg; Fc - separation area, m2; D_b - diameter of the threshing drum, mm; L_{To}- length of straw walker keys, m;α- deck wrap angle, degrees.

Stage 4. Construction of a regression model for substantiating the main design parameters in the KubNIITiM zone for direct wheat combining according to Table 3 (fragment) [3].

$$\left.\begin{aligned} &W/\,Xp,\,Z = 17.8^*\,F_p + 2.075^*\,V_b - 0.002^*\,M,\ R2 = 93.13;\\ &q\,/Xp,\,Z = 0.004^*\,L_b - 0.737^*\,Fc + 0.30^*\,L_{To},\ R2 = 91.38;\\ &D/Xp,\,Z = 0.004^*\,L_b - 1.384^*\,F_p - 0.273^*\,V_b - 0.338^*\,Fc\ +\\ &\qquad + 1{,}663^*\,L_{To},\ R2=82.27;\\ &C/\,Xp,\,Z = -\,0.005^*\,L_b + 1{,}759^*\,F_r - 1.202^*\,V_b - 0.058^*\,N + 0.001^*M\ +\\ &\qquad + 1{,}642^*\,L_{To},\ R2 = 83.31, \end{aligned}\right\} \quad (7)$$

where R2 is the coefficient of determination.

Stage 5. Formation and solution of a single-criterion mathematical programming problem (optimization) of the main design parameters of a grain harvester in the KubNIITiM zone for direct wheat harvesting (7):

Find: $Xo^* = [\,L_b, F_p, F_r, V_b, N, M, Fc, L_{To}\,]$,

from the condition: max: $W/\,Xp, Z = 17.8^*\,F_p + 2.075^*\,V_b - 0.002^*\,M$, (8)

under restrictions:

$$\left.\begin{aligned} &q\,/Xp,\,Z = 0.004^*\,L_b - 0.737^*\,Fc + 0.30^*\,L_{To} \leq 3;\\ &D/\,Xp,\,Z = 0.004^*\,L_b - 1.384^*\,F_p - 0.273^*\,V_b - 0.338^*\,Fc + 1.663^*\,L_{To}, \leq 2;\\ &C/Xp,Z = -\,0.005^*L_b + 1.759^*F_r - 1.202^*V_b - 0.058^*N + 0.001^*M + 1.642^*L_{To} \leq 2, \end{aligned}\right\} \quad (9)$$

where the productivity of the grain harvester (W) is taken as the optimization criterion, with the solution in Table 4.

The results of the solution of the problem of optimization of the main design parameters of grain harvesting combines were carried out by the simplex method [3, 8] for the KubNIITiM zone for direct combining of wheat, for constraints (G): L_b = 1200-1500 mm; F_p= 0.94-1.4 m2; F_r = 2.34-4.74 m2; V_b=

3-6 m3; N = 100-180 kW; M = 8000-13000 kg; Fc =4-6.2 m2; D_b = 600-800 mm; L_{To}= 3.6-4.2 m;α= 130-146 degrees.

A simpler version of justification of the main design parameters is considered in the article [9].

Table 4. Results of solving the problem of optimizing the main design parameters of a grain harvester for direct combining of wheat in the Southern Federal District (Kuban Research Institute of Tractor and Machine Building)

```
Final solution reached after 44 pivots.
Maximum value of objective function = 17.47 (W)
variable value
  Lb        1200.00
  Fp           1.40
  Fr           3.48
  Vb           6:00
  N 130.876
  M 11000.000
  Fc 4.725
  LTo           4,500
Slack value
   S 2 300.00000
   S 4 0.00000
   S 6 1.16879
……………………..
```

Conclusions.

1. Calculations show that by upgrading the SK-5M (NOVA) grain harvester, under Russian conditions, it is possible to achieve wheat productivity of up to 17 tons per hour without disrupting the production process or relying on very expensive foreign harvesters. This fully satisfies the purchasing power of domestic agricultural producers in terms of both price and quality.

2. Regarding changes in Russia and the world due to climate, political, and economic changes, it is necessary to regularly conduct statistical studies based on the results of a sufficient number of combine harvester tests at the MIS and R&D facilities, and to justify new projects for the development of grain harvesters taking into account the zones, changing climate conditions, and

global market conditions, while competently using modern information technology, rather than directly copying foreign equipment.

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