Improving the adjustment process of the technological parameters of agricultural machines

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Abstract. In the process of performing technological operations, any agricultural machinery is exposed to a large number of changing factors. The result of technological operations, in most cases, is performed by an organoleptic method, which is characterized by a significant error (up to 40%) and labor input. Given the complexity and labor input of assessing the performance quality indicators of agricultural machines, even partial automation of this process in practice gives a tangible (tens of percent) economic effect and becomes the basis for the formation of digital agriculture. We have analyzed existing methods for monitoring the quality indicators of technological operations using the example of the grain harvesting process. In particular, the possibilities of improving the methods for monitoring the performance quality indicators of a combine harvester have been considered. The correlation between the external signs of the quality violation of the technological process (losses) and adjustable parameters has been demonstrated using the example of a combine harvester thresher. A technique for adjusting the technological settings of the combine on the basis of electronic means of grain losses control, as an element of introducing the Precision Farming technologies, has been developed.

1 Introduction

It is advisable to divide the problem of setting up agricultural machines into two subproblems: pre-setting the operating devices and adjusting the technological settings in the process [1]. This problem is valid for both machines for sowing seeds [2] and for machines involved in harvesting.

As an illustrative example, we consider the pre-setting of the harvester, which is carried out on the basis of the analysis of the harvesting conditions taking into account the goals of harvesting. At the same time, the choice of the initial values of the adjustable parameters is not an easy task. The initial values are set in accordance with the reference material outlined in the technical description of the combine and the personal experience of the operator or agronomist [3].

However, it is not uncommon when during the operation of the combine, the values of losses or other indicators of performance quality exceed the permissible level. Then it is

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necessary to make adjustments to the technological settings of the operating devices of the combine. It is recommended to adjust the operating devices of the combine harvester at least two or three times during the day, depending on changes in harvesting conditions.

At this point it is important to quickly identify the causes of violations and know how to eliminate them. The reasons for the violation appearance of the performance quality are determined on the basis of recommendations and personal experience of the operator or agronomist. However, the process of identifying and eliminating the causes of deviations of the parameters of the technological process of harvesting from the norm requires a significant investment of time and proceeds in conditions uncomfortable for the operator. This circumstance significantly reduces the value of operations on adjusting the technological settings because of the increase in biological yield losses due to long downtime.

2 Research status and work relevance

The threshing and separating device (TSD) is one of the most important units of the combine harvester, and the quality of the technological process of harvesting largely depends on the optimality of its settings. In this connection, we consider the aspects of improving the process of adjusting the technological settings of the combine using the example of the TSD.

Consider the quality indicators of the technological process of grain harvesting associated with the operating modes of the threshing and separating device. These include: grain purity in the hopper, grain crushing and various types of losses. Figure 1 shows in detail the various types of grain losses that occur at various stages of the process.

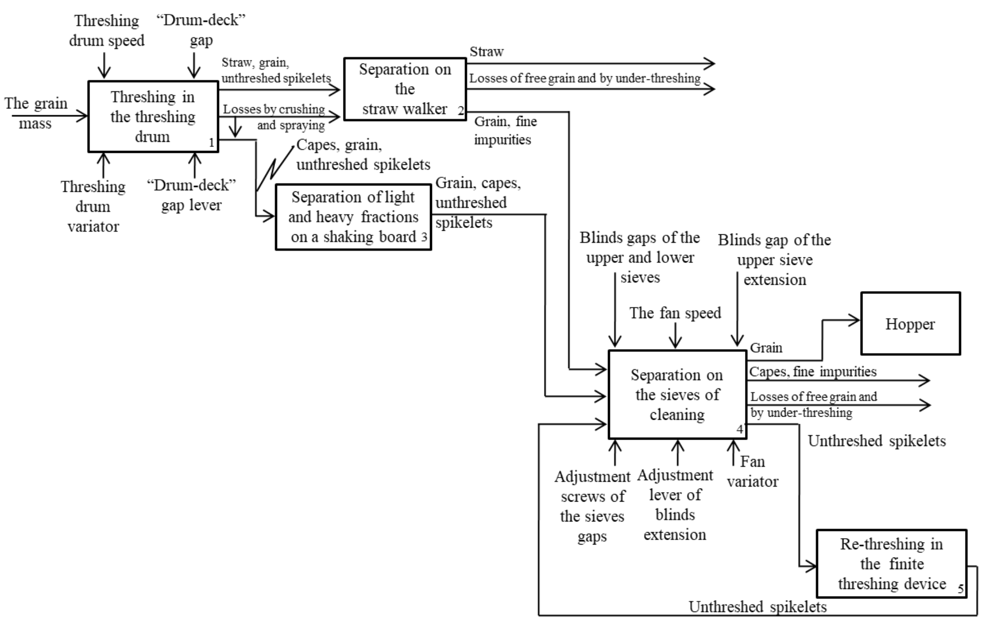

Fig. 1. Functional model of the TSD of the combine harvester.

The analysis of the existing methods for determining the values of quality indicators of the technological process of harvesting allows us to highlight a number of disadvantages that significantly reduce their practical value:

- high error of the results (20...40%);

- significant labour input (up to 4...6 man-hours);
- the need to use additional technical means;
- the impossibility of a clear separation of the loss sources (grain losses with straw and capes are inevitably mixed without the use of special samplers);
- determination of harvesting quality indicators, as a rule, is associated with the suspension of the technological process.

The presence of the aforementioned drawbacks of the existing methods leads to the fact that the frequency of the quality control of mechanized harvesting is not often respected, or the control is not carried out at all.

Solving this problem requires improving the methods for determining the quality indicators of the harvesting process. Opportunities for solving this problem provide automatic means of control.

The devices for continuous monitoring of grain losses have existed since the second half of the last century. Electronic means, consisting of the devices and primary converters directly perceiving the impact of the grain flow, have become widespread [4-6].

The principle of operation of such devices is as follows. A free grain, sifted at the gathering sites of straw and chaff, falls on the membrane of the sensors. An acoustic wave that occurs when a grain hits a membrane affects a piezoelectric element, causing a voltage on its electrodes. The received electrical signal is sent to the input of the measuring unit through the cable.

The advantage of these devices is the ability to obtain information on the level of grain loss without stopping the harvesting process and without the direct involvement of the operator. At the same time, the grain loss levels after cleaning and after the straw walker are clearly delineated and presented on different scales of the loss indication block. With a slight change in the design of these devices, you can get a convenient tool that allows getting information about the intensity of grain losses after cleaning and straw walkers, as well as information about the intensity of under- threshing in real time.

Thus, improving the means of monitoring and measuring losses after the thresher will allow the implementation of more advanced methods for adjusting the technological settings of the combine harvester thresher.

The adjustment of technological settings of the TSD can be reduced to solving the problem of conditional optimization. The objective function, which should be minimized, is the total number of losses after the combine thresher, and the limitations are the intervals of the variations in values of the technological parameters of the operating devices, due to the design of the machine. The analysis has shown that it is advisable to apply one of the random search algorithms to the task of adjusting the technological settings of the TSD.

The result of the preliminary adjustment of the thresher is a set of values of the parameters of the operating devices $x_1;...x_n$, that is, some point $X_1(x_{1.1};...;x_{n.1})$, at which the value of the objective function $f(X_1) = F_1$. Then we can assume that the desired minimum of the objective function is in some area *D*, bounded by an n-dimensional parallelepiped, the boundaries $A_{left.n};A_{right.n}$ of which are equal $x_{n.1} - \varepsilon_n; x_{n.1} + \varepsilon_n$. Where ε_n – is a certain constant that determines the size of the search area (Figure 2).

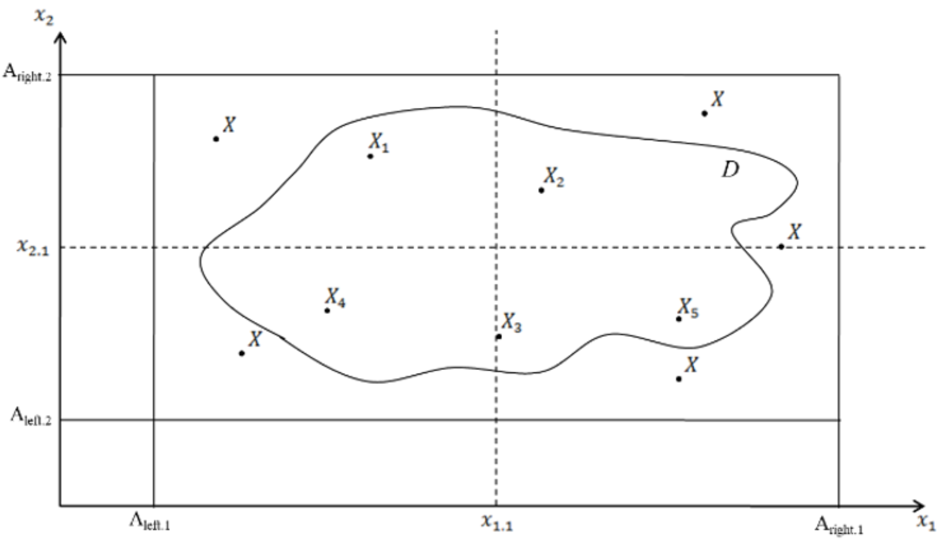

Fig. 2. Search area for the optimal value of the objective function.

In the area *D*, the point $X_2(x_{1.2};...;x_{n.2}) \in D$ is randomly generated (the simplest way is to take the point $X_2 = X_1$). From this point, the descent to the point of local minimum $X_2^* \in D$ is carried out. Then a new random point $X_3 \in D$ is selected and the descent to the minimum point $X_3^* \in D$, is performed in the same way, and so on. The search stops after the algorithm is carried out a specified number of times, the point with the minimum value of the objective function is taken as a solution [7-10].

To search for the local minimum point, it is possible to use various optimization methods for the function of many variables. However, the specifics of the subject area impose the following restrictions: the terrain of the objective function is unknown, which makes it difficult to choose the most suitable optimization method; the harvesting conditions imply minimizing the number of iterations of optimization algorithms[11, 12].

Therefore, to search for the points of local minima of the objective function, it is advisable to use the coordinate-wise descent method (Gauss's method) with some changes.

The F_1 value consists of the following indicators:

$$F_1 = q_{u.s.1} + q_{u.c.1} + q_{f.s.1} + q_{f.c.1} + q_{c.1} \quad (1)$$

where $q_{u.s.}$ – the loss of grain by under-threshing in the straw,
$q_{u.c.}$ – the loss of grain by under-threshing in the capes,
$q_{f.s.}$ – loss of free grain in the straw,
$q_{f.c.}$ – loss of free grain in the capes,
$q_{c.}$ – losses by crushing and spraying.

Losses by crushing and spraying ($q_{c.}$) cannot be determined using existing technical devices, therefore this component will be determined only at local minimum points in accordance with the testing methods of combine harvesters. Therefore, discarding the component $q_{c.}$, we obtain the objective function $F(q_{u.s.} + q_{u.c.} + q_{f.s.} + q_{f.c.})$. Then, receiving the sensor signals about the intensity of losses, as well as about the intensity of under-threshing, it is possible to search for a local minimum as follows.

3 Results and discussion

Table 1 presents the possible deviations of the performance quality indicators of the TSD from the norm and ways of their elimination. The table shows only those reasons for deviations and methods for their elimination that are caused by adjustment parameters, without taking into account the parameters of the technical condition.

Table 1. Possible malfunctions in the operation of the TSD of the combine harvester and the methods for their elimination.

Problem	Reason for occurrence	Way of elimination
Incomplete selection of grain from ears (under-threshing).	Insufficient impact of the thresher on the grain mass.	Increase the speed of the threshing drum. Reduce the gaps between the drum and the concave.
Increased mechanical damage to grain (crushing).	Increased impact of the thresher on the grain mass.	Reduce the speed of the threshing drum. Increase the gaps between the drum and the concave.
Increased grain loss after the straw walker.	Strong grinding of the straw mass.	Reduce the speed of the threshing drum. Increase the gaps between the drum and the concave.
Increased loss of full grain with capes.	Excessively large grain heap thickness. Inadequate separating effect of cleaning.	Reduce the speed of the combine. Increase the fan speed. Increase the degree of opening the blinds of the upper sieve.
Increased loss of hollow grain with capes.	The fan airflow is large.	Reduce the fan speed.
Loss of capes of unthreshed spike.	Insufficient separating effect of the extension of the upper sieve.	Increase the degree of opening of the extension blinds. Increase the degree of opening the blinds of the upper sieve.

There is a correlation between the external signs of a violation of the quality of the technological process by the parameters of the technical condition and the adjustable parameters of the thresher [13, 14]. Without taking into account the parameters of the technical condition and quality indicators of the technological process that are not associated with grain losses, this correlation can be presented as follows (Figure 3).

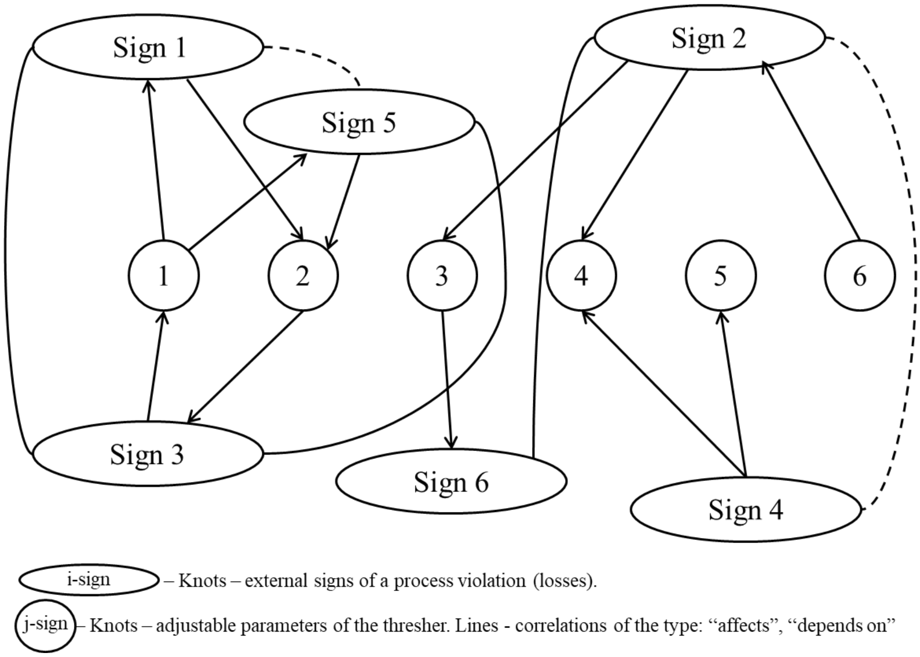

Fig. 3. The correlation between external signs of a violation of the quality of the technological process (losses) and adjustable parameters of the thresher.

Figure 3 shows the deviations of the quality indicators of the technological process from the norm (losses) presented in the “ovals”: 1. Increased loss of free grain after the straw walker. 2. Increased loss of free grain with capes. 3. Increased grain loss in the unthreshed spike after the straw walker (under-threshing in the straw). 4. Increased grain loss in the unthreshed spike with the capes (under-threshing in the capes). 5. Mechanical damage to the grain (crushing). 6. Increased loss of hollow grain with the capes. The adjustable parameters of the thresher are presented in the "circles": 1. The frequency of rotation of the threshing drum. 2. The gap "drum - deck." 3. The frequency of rotation of the fan. 4. The gap of the upper sieve. 5. The gap of the extension of the upper sieve. 6. The speed of the combine harvester.

The arrow directed to the sign means an increase in the number of losses with an increase in the value of the adjustable parameter. The arrow directed from the sign means a decrease in the number of losses with an increase in the value of the adjustable parameter. With a decrease in one of the two signs connected by a continuous line, the other may increase. The signs connected by a dashed line change equally when the adjustment parameters are changed.

All the signs, except for grain crushing, are characterized by the readings of groups of sensors. The arithmetic average value of the output signals of the sensors, fixed at constant values of the adjustable parameters during the harvesting of a certain section of the field, should be taken as the readings of the sensors. The length of such a section should be at least 40 ... 50 m. The readings of the sensors at changing the adjustable parameters should be recorded 20 ... 30 seconds after the new operating modes of the thresher are set.

Thus, the value of the objective function can be judged by the readings of three groups of sensors, which depend on six adjustable parameters of the thresher. Then, in accordance with the method of coordinate-wise descent, all adjustable parameters of the thresher should be taken $x_1, x_2, ..., x_n = const$. Then select those sensor readings that indicate the highest intensity of losses, and change those adjustment parameters that affect the intensity of these losses by the value of the working step. Continue to change the values of the adjustment parameters until the value of the intensity of losses recorded by other sensors becomes maximum. Then it is necessary to change those adjustable parameters of the thresher, on which the maximum intensity of losses depends. When it is impossible to find a point $X_n(x_{1.n}.;...;x_{n.n.})$, at which the value of the objective function $f(X_n)$ is less than $f(X_{n-1})$ a specified number of times, then the point, at which $f(X)$ is minimal, should be considered the point of local minimum.

We have assigned the code name D1 to the indications of the group of sensors registering the value of the sign 1, D2 to the readings of the sensors registering the values of the signs 2 and 6, D3 and D4 to the readings of the sensors registering the values of signs 3 and 4 respectively.

Adjustable parameters and the direction of the working step should be selected in accordance with the rule base given below:

1. If D1 is larger than D2 and D1 is larger than (D4-D3), then the parameter 1 should be decreased while the parameter 2 increased.

2. If D2 is larger than D1 and D2 is larger than (D4-D3), then the parameters 3 and 4 should be increased while the parameter 6 decreased.

3. If D2 is larger than D1 and D2 is larger than (D4-D3), and after applying the rule 2, the objective function $f(X_n)$ has increased, then the parameter 3 should be decreased by two working steps.

4. If (D4-D3) is larger than D1 and D4/D3 is larger than D2, then the parameters 1, 4, 5 should be increased while the parameter 2 should be decreased.

The magnitude of the working step for the adjustment parameters is given in table 2.

Table 2. Work step values for adjustable parameters of the TSD.

№	**Name of the adjustable parameter**	**Limits of change in the value of the adjustable parameter**		**The value of the working step**
		min	**max**	
1	Threshing drum rotation speed	512 min^{-1}	954 min^{-1}	30 min^{-1}
2	Drum-deck gap at the outlet	2 mm	40 mm	2 mm
3	Fan speed	582 min^{-1}	1093 min^{-1}	20 min^{-1}
4	Gap of blinds of the top sieve	0 mm	20 mm	1 mm
5	Gap of the blinds of the extension of the upper sieve	0 mm	20 mm	1 mm
6	Combine speed (working)	0 km/ hour	10 km/ hour	0,4 km/hour

The order of operations for adjusting the technological settings of the TSD of the combine harvester is shown in Figure 4.

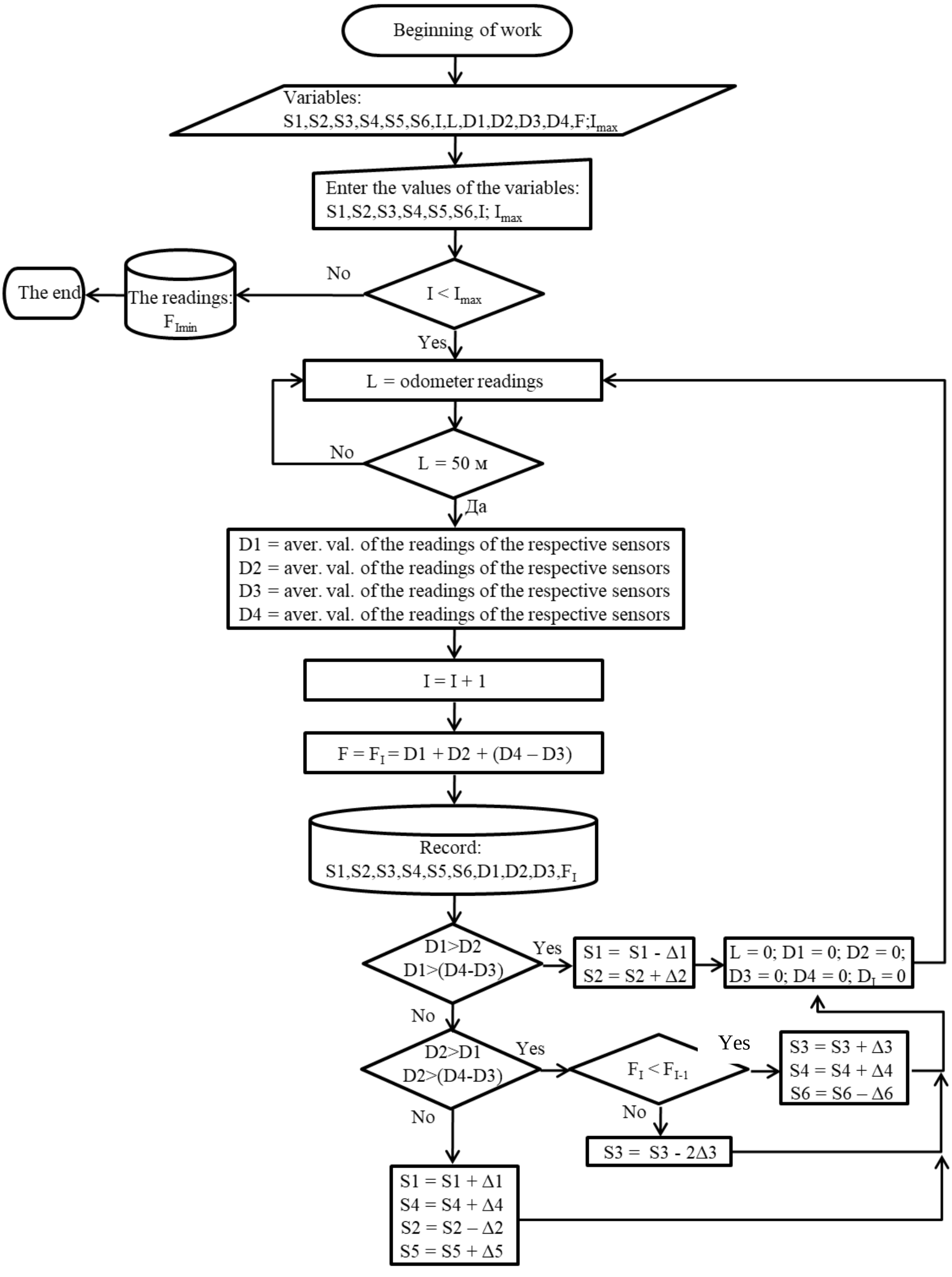

Fig. 4. Search algorithm for local minima of the objective function at optimizing technological adjustments of the combine harvester thresher.

Figure 4 shows the following notation:

$P_1 ... P_6$ – adjustable parameters of the TSD;
L – the route taken by the combine;
I – sequence number of the algorithm iteration;
$D_1 ... D_4$ – readings of the respective grain loss sensors;
F – value of the objective function;

F_I – the value of the objective function at each iteration of the algorithm I;

I_{max} – a given number of iterations of the algorithm for completion;

$\Delta 1 ... \Delta 6$ – the working step for the corresponding.

In accordance with the presented algorithm, the search for local minima of the objective function is carried out according to the feedback principle. The direction of the search for the minimum of the objective function is determined on the basis of recommendations for adjusting the technological settings of the TSD.

4 Conclusions

1. The integration of the methods for optimizing the functions of many variables and expert knowledge about the subject area allow us to reduce the number of iterations of the algorithm and increase its efficiency in the conditions of harvesting.

2. The use of automatic means of continuous monitoring of quality indicators of agricultural machinery technological parameters gives the possibility for improving the methods of setting and adjusting technological parameters.

3. The use of sensor signals characterizing the level of various losses will allow optimizing the operating modes of agricultural machines in accordance with the objectives of technological operations, on the basis of feedback.

4. The implementation of the algorithm presented in this article will reduce downtime for technological reasons and minimize operator involvement, and as a result, the number of possible errors in the process of adjusting the technological parameters of various agricultural equipment, be it the combine harvester or the precision seeder [15].

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