УДК 681.5+631.354.2 DOI: https://doi.org/10.32515/2664-262X.2024.9(40).1.55-63

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Combined system of automatic flow stabilization bread mass at the entry of the thresher of the grain harvester

The research conducted in this article is devoted to solving the actual problem of loading the grain harvester with bread mass at the entrance of the thresher. It is possible to achieve the minimum level of fluctuations in the flow of bread mass at the entrance of the threshing-separating device only in appropriately designed optimal multidimensional stabilization systems. At the same time, the methods of dynamic design and analytical design should be used for the construction of similar systems.

We proposed to extend the experimental and analytical approach to the design of optimal stabilization systems to the case when minimal fluctuations in the flow of bread mass occur at the entrance to the thresher of the grain harvester. As a result, we developed and implemented an optimal combined system of automatic stabilization with feedback on the deviation from the average value of the flow of bread mass and correction according to the change in output.

To carry out the above studies, the method of analyzing the quality of stabilization under random steady-state effects was used, and this made it possible to calculate normalized indicators of the quality of stabilization.

grain mass flow stabilization, automatic stabilization system, standardized quality indicators, hydraulic transmission, average yield, control signal vector

Formulation of the problem. The search for ways to increase the efficiency of grain cultivation in the world and in Ukraine led to the emergence of a system of precision agriculture. This system [6], on the one hand, provides maximum yields on certain agricultural areas, and on the other hand, it is aimed at maintaining the fertility of land.

Harvesting is the crown of production of any agricultural crop production. It is difficult to overestimate its importance and significance. This is the most costly technological operation. It accounts for 25 to 40% of total direct technical costs spent on technology as a whole. Non-performance or poor performance for one reason or another of the technological assembly operation turns the costs of all previous operations into direct losses. The quality of the performance of this technological operation is determined by many factors that characterize the design, condition and reliability of grain harvesting equipment, the degree of training of personnel, technology and harvesting conditions.

Analysis of recent research and publications. As we can see from the analysis of the design features of grain harvesting equipment [3], there are several ways to improve the quality of grain harvesting. Work on the development of new designs of elements of grain-harvesting equipment and grain-threshing technologies is constantly underway. But in order to achieve the maximum quality of grain collection, both for new developments and for existing grain harvesting equipment, it is necessary to provide optimal operating modes. One of the problems, the solution of which coincides with the trends in the development of grain harvesting equipment, is the stabilization of the flow of bread mass at the entrance to the thresher of the combine. Since any new developments in the designs of elements of grain harvesting equipment and grain threshing technologies are nullified by significant fluctuations in the flow of bread mass, and on the other hand, ensuring a stable flow makes it possible to maximize the quality of harvest for a given design and technology of grain collection.

Achieving the minimum level of fluctuations in the bread mass flow at the entrance of the threshing-separating device is possible [4,7], only in appropriately designed optimal stabilization systems. Therefore, the design and implementation of optimal grain flow stabilization systems is an important factor in maximizing the quality of the harvesting process.

Setting objectives. A characteristic feature of the modern development of automation systems for controlling technological processes on domestic and foreign harvesters [1,2,5] is the use of the latest methods, techniques and means of developing on-board control systems. The latest methodologies for creating control systems allow you to take into account the real stochastic nature of the change in signals acting in the control loops and to determine the structure, and not only the parameters, of the on-board controller that deliver the extremes of the selected quality criterion. Therefore, the development and implementation of a new method of automated synthesis of the optimal system for stabilizing the flow of bread mass at the entrance of the thresher of the grain harvester will allow to ensure the most complete use of achievements in the field of improving the design of threshing-separating devices and threshing technology.

A necessary condition for justifying the choice of a method of creating a particular automation system is the study of information about useful signals, disturbances and interferences acting on the system in the real conditions of its operation.

Presenting main material. In order to achieve the maximum quality of stabilization of the flow of bread mass at the entrance to the thresher of the grain harvester, it is necessary to apply the methods of dynamic design and analytical construction in the construction of the optimal system. Before developing the system, it is necessary to analyze the factors, the consideration of which will make it possible to achieve the required quality. These factors can be divided into three groups: dynamic characteristics of the elements of the automatic stabilization system; dynamic characteristics of disturbances acting in the system; meter noises.

From the point of view of dynamic characteristics, the most complex element of the system is the control object, the input of which is the angle of inclination of the washer of the hydraulic pump cylinder block, and the output is the flow of bread mass at the entrance to the thresher. A combine harvester is a rather complex object that includes non-linear elements, non-stationary elements and complex relationships between elements.

In the literature [2,5,8], a large number of mathematical models of both individual nodes and large aggregates and even the entire combine are described. These models are designed to solve various problems. From the point of view of the problem of stabilization of the grain mass flow, it is necessary to obtain a model of the generalized control object "the angle of inclination of the washer of the cylinder block - the flow of grain mass at the entrance to the thresher" (Fig. 1), which includes a hydraulic transmission that changes the frequency of revolutions of the hydraulic motor shaft ω depending on from the angle of inclination of the washer of the cylinder block of the hydraulic pump γ, the transmission of the combine, which converts the rotation of the hydraulic motor shaft into the translational movement of the combine, and the mathematical relationship connecting the flow of bread mass Q with the translational speed of the combine V

$$Q = VBУ(1+\varepsilon), \tag{1}$$

where Q is the flow of bread mass at the entrance to the combine thresher, kg/s;
V is the speed of the combine, m/s;
B – harvesting width, m;
$У$ – crop productivity, kg/m^2;
ε – is the ratio of grain to the non-grain part of the bread mass.

The first bread mass flow stabilization systems were built using mechanical, pneumatic, and hydraulic engine operating modes control links [3]. These systems could not give high accuracy of flow stabilization because they implemented simple control laws, so their implementation was hampered by a small gain in the quality of harvesting.

The relevance of the issue of stabilizing the flow of bread mass caused the further development of methods, techniques and means of developing systems of this class. New sensors of non-electric quantities for grain harvesters, circuit solutions and regulation principles were developed. A review of literary sources [3,6] showed a wide variety of methods and devices for regulating the loading of a grain harvester.

The analysis of the considered methods and devices for regulating the flow of bread mass showed that a common drawback is that they do not take into account the real dynamic properties of the control object and disturbances acting in the system.

A new impetus for the development of grain mass flow stabilization systems was given by the use of hydraulic transmission to regulate the speed of movement of the grain harvester. This made it possible to adjust the speed without affecting the operation of all other units of the grain harvester.

Taking into account the significant change in the average yield of fields in different regions of Ukraine, which is associated with the imperfection of grain growing technologies, the main drawback of the considered automatic systems for stabilizing the loading of the combine thresher is that they lack the adaptation of the parameters of the regulation laws to the change in the average yield. The consequence of this is the deterioration of the quality of harvesting with a decrease in the average yield of the field. Therefore, there is a need to create a system of automatic stabilization of the grain mass flow adapted to the conditions of domestic fields and adapted to the average yield of the field.

The development of modern technologies for managing technological operations in agriculture makes it possible to combine precision farming systems with the global positioning system and the capabilities of aerospace photography, therefore there is an opportunity to improve the quality of harvesting due to the construction based on the functional scheme of the system of the combined system of stabilizing the flow of bread mass at the entrance of the thresher (Fig. 1).

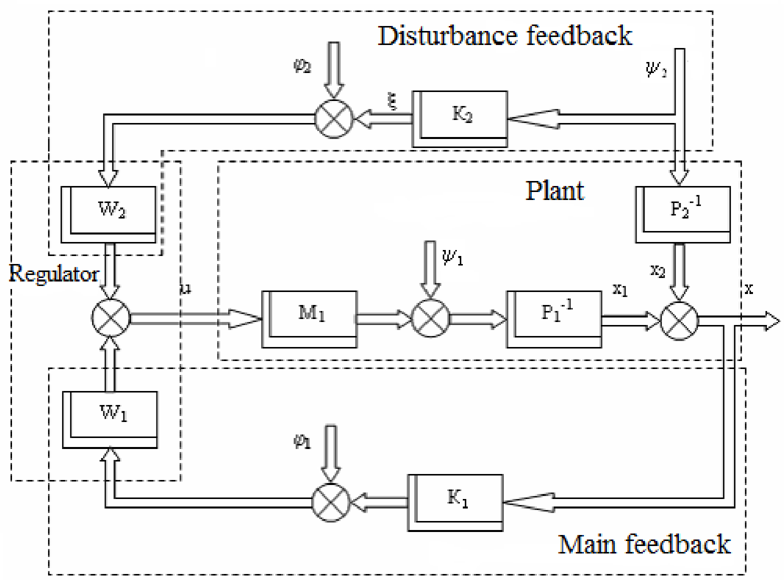

Figure 1 – Structural diagram of the combined automation system
Source: developed by the author Osadchyj, S. I., Miroshnichenko M. S.

The structural scheme of such a combined, moreover, multidimensional stabilization system (Fig. 1.) proposed by us consists of a number of elements. First of all, it is a control object, the dynamics of which is described by a system of equations

$$\begin{cases} P_1 x_1 = M_1 u + \psi_1 \\ P_2 x_2 = \psi_2 \\ x = x_1 + x_2 \end{cases}, \quad (2)$$

where x, x_1, x_2 – n -dimensional vectors of the initial coordinates of the control object;

u – m - dimensional vector of control signals;

P_1, P_2 – polynomial matrices from the differentiation operator $s=d/dt$ size $n\times n$, which determine the change in the initial coordinates of the object when the disturbance vectors ψ_1, ψ_2 change and are equal to

$$P_1 = (s+1.2)(s+0.206),\ P_2 = 3{,}85\cdot 10^{-2}, \quad (3)$$

M_1 – polynomial matrix from the differentiation operator s of size $n\times m$

$$M_1 = 144, \quad (4)$$

which characterizes the sensitivity of the control object to changes in the components of the vector u.

The deviation feedback consists of a sensor system, the dynamics of which is characterized by the transfer function matrix *K1*, and the measurement errors by the noise vector *φ1*, and the first channel of the regulator with the transfer function matrix *W1*

$$W_1 = -\frac{12.3(s+319)(s+3.91)(s+0.2063)}{(s+332)(s+0.4108)(s^2+25s+318)}. \quad (5)$$

The disturbance correction includes sensors with a matrix of transfer functions *K2* and a vector of measurement disturbances *φ2* and the second channel of the regulator, the dynamics of which is described by the matrix *W2*

$$W_2 = -\frac{12.33(s+0.2063)(s^2-2.44s+0.993)}{(s+332)(s+0.4108)(s^2+25s+318)}. \quad (6)$$

Since the sources of disturbances acting on the generalized object do not coincide (Fig. 1.), the structure of the combined system differs from the standard one [2]. The main distinguishing feature of the structural diagram in Fig. 1. there is the presence of a circle of correction for only one disturbance - field yield fluctuations.

In order to ensure the possibility of implementing this principle of regulation, work should be carried out aimed not only at the development of field yield assessment systems and the construction of yield maps even before grain harvesting, but also at the creation of new methods, principles and means of synthesis of optimal combined stabilization systems with correction for disturbance, which act on their output.[8,9]

To ensure the maximum quality when harvesting grain, it is worth creating an optimal combined system of stabilization of the volume of bread mass at the entrance to the thresher. The structure and parameters of the specified systems must be chosen taking into account the dynamics model of the stabilization object (polynomials *M1, P1*, Fig. 1.), primary measuring transducers in the feedback circuits for the deviation *K1* and in the correction circuit for the disturbance *K2*, disturbances *ψ1, ψ2* and interference *φ1, φ2*, which corresponds to the real operating conditions of the harvester, taking into account the latest effective methods of automated creation of control systems.

This approach to the design of automatic control systems is based on the fact that, as a result of finding a solution to the problem of analytical design, even before starting the main design of the system, it is necessary to assess the limits of improving its quality, as well as to create an optimal structure, not only the parameters of the regulator, but also establish the expediency of starting work that will lead to the creation of a new system. At the same time, the main material and time costs for the design, manufacture and testing of the product arise only after a positive decision has been made regarding the feasibility and quality of the system.

Such an experimental and analytical way makes it possible to significantly reduce costs for the development of an automatic control (stabilization) system by reducing the terms of testing and debugging work, determining the maximum limits of maximizing the quality of control even when a technical proposal was created, formalizing the methods of synthesizing the stabilization system and analyzing its quality, carrying out the final design to reproduction of optimal control laws invented analytically.

Studying the features of the procedures for the creation and construction of modern existing systems for stabilizing the flow of bread mass according to literary sources [1,3,6] allows us to identify a number of reasons that do not allow to dramatically increase the competitive capabilities of this agricultural technique. First, the differential equations of the grain harvester do not take into account the dynamic properties and design features of hydraulic transmissions operating in the mode of constant load changes. Secondly, traditional approaches to determining the structure and parameters, which are used for the development of control systems for technological processes on the harvester, are designed for the action of only regular external influences, while real disturbances and disturbances are of a stochastic nature [2]. Thirdly, the existing methods of synthesis of optimal combined stabilization systems allow to successfully determine the structure and parameters of a two-channel controller, if the system has only one controlled source of disturbances at the input of the stabilization object.

To overcome the identified shortcomings, we propose to spread the effect of the experimental and analytical approach [2,5] to the development of optimal stabilization systems in case of minimization of fluctuations in the flow of bread mass at the entrance of the thresher of the grain harvester through the development and implementation of the optimal combined stabilization system with feedback based on the deviation of the bread mass mass from the average value and correction for changes in yield.

In accordance with the design plan of the optimal combined system of stabilization of the volume of bread mass before entering the thresher of the grain harvester, a study was conducted of changes in the dispersion of the flow of bread mass e_x, the angle of inclination of the washer of the hydraulic pump cylinder block e_u and the stabilization quality indicator e, which arise in the adaptive optimal combined stabilization system when changing constant ratios μ, μ_1, μ_2, which characterize the operating conditions of the system and when the average yield of the field $У_0$ changes.

The ratio μ, μ1, μ2 determine the operating conditions in which the system should function. They can vary widely when the characteristics of the field surface and the noise intensity of the sensors change. μ is the "relief-yield" ratio. [4,7]

To carry out the study, the method of analyzing the quality of stabilization under random steady-state effects [2] was used, which made it possible to calculate normalized indicators of the quality of stabilization:

$$\bar{e} = \frac{e}{\sigma_б^2},\ \bar{e}_x = \frac{e_x}{\sigma_{Q0}^2},\ \bar{e}_u = \frac{e_u^2}{\sigma_{\gamma 0}^2}, \qquad (7)$$

where $\sigma_б$ is a coefficient equal to $\sigma_б = \sqrt{e_0}$, and the variable e_0 is equal to the quality indicator of the adaptive stabilization system, synthesized at the value of the weight coefficient C = 1, the average yield $У_0$ = 0.35 kg/m2 and the ratios $\mu = 1{,}06 \cdot 10^4$, μ_1 = 0,5, μ_2 = 0,5, $e_0 = 1 \cdot 10^{-3}$, are summarized by one value as an example in Table 1.

Table 1 –Standard indicators of the quality of stabilization at μ_1=μ_2=1

			$У_0$, кг/м^2						
			0.2	0.25	0.3	0.35	0.4	0.45	0.5
μ	1.06 10^3	$\bar{e}_x$	1.59	1.28	1.11	1.02	0.97	0.93	0.92
		$\bar{e}_u$	1.68	1.32	1.14	1.01	0.96	0.92	0.91
		$\bar{e}$	3.27	2.6	2.25	2.03	1.93	1.85	1.83
	1.06 10^4	$\bar{e}_x$	1.72	1.39	1.21	1.1	1.05	1.01	1
		$\bar{e}_u$	1.82	1.43	1.23	1.1	1.04	1	0.98
		$\bar{e}$	3.54	2.82	2.44	2.2	2.09	2.01	1.98
	1.06 10^5	$\bar{e}_x$	1.89	1.53	1.36	1.22	1.15	1.11	1.09
		$\bar{e}_u$	2.01	1.59	1.39	1.23	1.15	1.1	1.07
		$\bar{e}$	3.9	3.12	2.75	2.45	2.3	2.21	2.16

Source: developed by the author Osadchyj, S. I., Miroshnichenko M. S.

Consideration of the quality change surfaces of fig. 2, constructed according to the data of table 1, allows us to draw several conclusions.

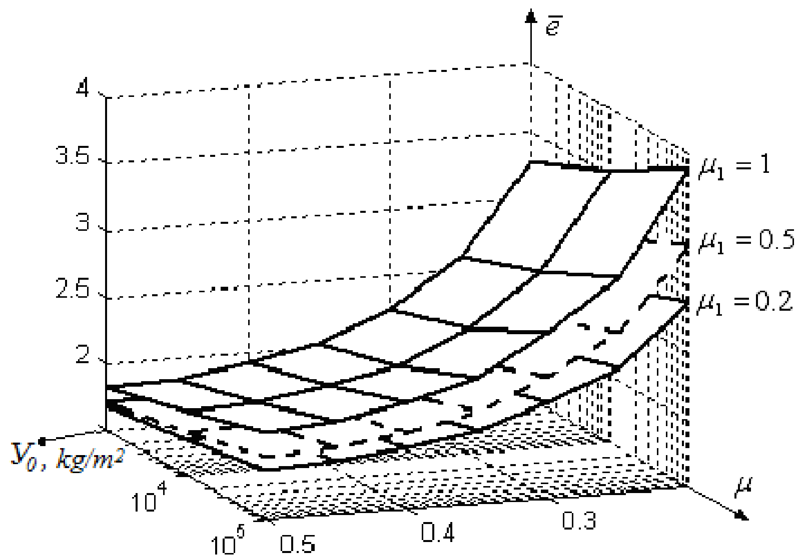

Figure 2 – Surface changes of the standardized system quality criterion
Source: developed by the author Osadchyj, S. I., Miroshnichenko M. S.

Conclusions. The main influence on the quality of maintenance of the set value of the flow of bread mass by the optimal combined system with adaptation is exerted by the change in the average yield of the field. When it changes from 20 to 50 c/ha, the change in normalized root mean square deviations of the flow of bread mass is almost 80%. A change in the driving conditions of the harvester during harvesting within very wide limits (the coefficient μ is ten times) causes a change in the normalized root mean square deviation of the bread mass flow by a maximum of 15%.

The inclusion of an optimal two-channel regulator in the feedback circuit, the parameters of which are adapted to the average yield of the field, ensures the stability of the closed control system and limits the root mean square deviation of the flow of bread mass at the entrance to the thresher in the amount of $5.2 \cdot 10^{-2}$ kg/s at the root mean square deviation of the control signal - the angle of inclination of the washer of the cylinder block of the hydraulic pump, which is 3.48°, in the worst conditions of minimum yield and maximum intensity of sensor noise.

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Комбінована система автоматичної стабілізації потоку хлібної маси на вході молотарки зернозбирального комбайну

Проведені у даній статі дослідження присвячені вирішенню актуальної проблеми завантаження зернозбирального комбайну хлібною масою на вході молотарки. Досягти мінімального рівня коливань потоку хлібної маси на вході молотильно-сепаруючого пристрою можна тільки у відповідним чином спроектованих оптимальних багатовимірних системах стабілізації. При

цьому слід застосовувати методи динамічного проектування та аналітичного конструювання за побудови подібних систем.

Ми запропонували поширити експериментально-аналітичний підхід до проектування оптимальних систем стабілізації до випадку, коли на вході до молотарки зернозбирального комбайну відбуваються мінімальні коливання потоку хлібної маси. У результаті розробили та впровадили оптимальну комбіновану систему автоматичної стабілізації зі зворотним зв'язком по відхиленню від середнього значення потоку хлібної маси та корекцією відповідно до зміни виходу.

Для виконання наведених досліджень використали метод аналізу якості стабілізації при випадкових стаціонарних впливах, а це дозволило розрахувати нормовані показники якості стабілізації.

З метою мінімізації коливань потоку хлібної маси необхідна розробка якісно нових комбінованих систем автоматичної стабілізації на базі поєднання систем точного землеробства з системами глобального позиціонування рухомих об’єктів, враховуючи можливості аерокосмічної фотозйомки.

Структура та параметри багатовимірних систем стабілізації мають бути знайдені у результаті виконання синтезу оптимальних систем автоматизації, враховуючи при цьому особливості динаміки гідротрансмісії зернозбирального комбайну, змінний характер рельєфу поля, точність та інерцію датчиків, урожайність у реальних умовах збирання урожаю.

стабілізація потоку зернової маси, система автоматичної стабілізації, нормовані показники якості, гідротрансмісія, середня урожайність, вектор сигналів керування

Одержано (Received) 25.01.2024

Прорецензовано (Reviewed) 15.03.2024
Прийнято до друку (Approved) 25.03.2024