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аграрний університет****УДК 631.363:636.22/28****DOI: 10.37128/2306-8744-2021-2-12****INVESTIGATION OF  
TRANSITIONAL PROCESSES IN  
THE ADAPTIVE SYSTEM OF  
HYDRAULIC DRIVES OF THE  
MECHANISM FOR CUTTING AND  
UNLOADING STALK FODDER**

*The problem of creating an energy-efficient and competitive mechanism for cutting and unloading stalk fodder from trench storage, by developing and justifying the parameters and modes of operation of the adaptive system of hydraulic drives of the mechanism is researched. The principal implementation of the adaptive system of hydraulic drive of the mechanism for cutting and unloading is proposed, in which a spool flow divider is placed between two executive hydraulic motors, which allows to regulate the supply of a U-shaped frame according to the load change which affects the cutting mechanism. The adaptive system of the hydraulic drive of the mechanism allows to stabilize energy consumption for separation of a portion of a stalk fodder under the condition of change and fluctuation of parameters which essentially influence the process of separation and unloading of a stalk fodder from the monolith.*

*The transients in the adaptive systems of hydraulic drives of the mechanism for cutting and unloading of stalk fodder are received and analyzed.*

*As a result of the study, it was found that by changing the operating widths of the slide valve of the separator in the direction of reduction, a significant increase in the responsiveness of the hydraulic drive system of the mechanism for cutting and unloading to the changes in the loading on the cutting apparatus. As a result, the range of the adjustment of the feeding of the hydraulic cylinder of the U-shaped frame, which increases the efficiency of stabilizing the separation process from the monolith of block-portion of stalk fodder with a minimum power of the hydraulic drive system, is substantially expanded.*

*It is noted that the dynamic characteristics of the hydraulic drive of the mechanism for cutting and unloading stalk fodder adaptive to the load are influenced by the design parameters of the spool flow divider which implements feedback. On the basis of the conducted experimental research recommendations on the choice of constructive parameters of the spool flow divider are given.*

**Key words:** mechanism for cutting stalk fodder, hydraulic drive, mathematical model, transients, flow divider, hydraulic motor, hydraulic cylinder, energy consumption.

**Introduction.** Today, in the context of the global economic and food crisis, the issue of agricultural production is one of the priorities. To achieve positive dynamics in the development of this industry, it is necessary to provide farms with convenient, mobile equipment that would

automate the process of loading and unloading stalk fodder from trench storage, thereby saving time and money [1, 2].

**Formulation of the problem.** In the system of machines recommended for unloading stalk fodder from trench storage facilities, block-



batch separators based on frontal (wheel) loaders have become widespread [3,4]. Given the existing range of variable working bodies, such machines are effectively used throughout the year to perform a variety of works.

The hydraulic drives of these machines must operate in a wide range of speed modes of movement of the working bodies and have an adaptive control system that is sensitive to changes in the load on the working body. However, the recommended modes of operation of block-batch stalk feed separators provide fixed values of cutting speed and feed rate, in fact, without anticipating a possible significant increase in cutting forces when internodes of corn and other inclusions of high hardness fall under the knife. It is obvious that such circumstances are the reason why foreign manufacturers have increased the power of the drive of the cutting mechanism and the drive of the U-shaped frame. Their total capacity in the machines produced by leading European companies is from 20 to 25 kW [4].

This fact of significant excess of the drive power of the separator of the block portion of stalk fodder over the theoretically and experimentally confirmed values of the required drive power indicates the need to improve the hydraulic drive system of the separator. The direction of improvement should include coordination of regulation of cutting speed and feed rate in order to stabilize the total power of these drives, which will provide a significant energy-saving effect.

Therefore, the development of a new generation of hydraulic drives based on hydraulic units with an adaptive control system which significantly increase the accuracy and efficiency of such machines is timely and important for the development of mechanical engineering.

**The aim of the study.** The aim of the work is to increase the accuracy of the mechanism for cutting and unloading stalk fodder, reducing unproductive power losses and dynamic loads in the hydraulic drive of the mechanism for cutting and separation by creating a scientific basis for their development based on nonlinear mathematical models and adaptive hydraulic drive system.

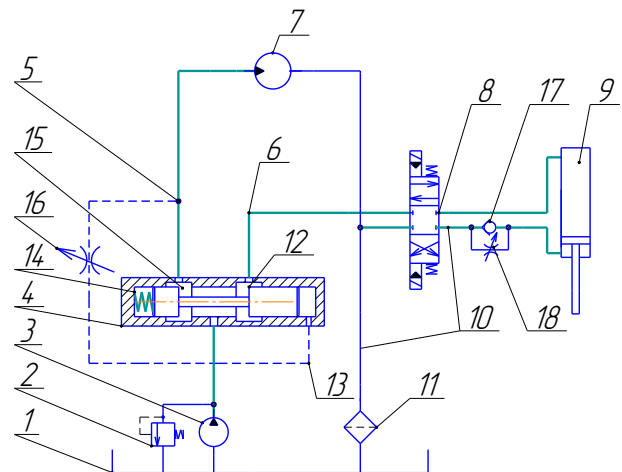
**The main results of the research.** To reduce the energy consumption of the hydraulic drive system for cutting and unloading stalk fodder, Vinnytsia National Agrarian University has developed a new structure and principle of building a hydraulic drive system which allows to significantly reduce the power of drive hydraulic

motors by adapting their modes to the technological system [5,6].

The hydraulic drive system of the mechanism for cutting and unloading stalk fodder (fig. 1) contains hydraulic tank 1, safety valve 2, hydraulic pump 3, spool flow divider 4 with control line 13, controlled spool 12, hydraulic motor 7, hydraulic lines 5,6, four-line three-position distributor with electro-hydraulic control 8, hydraulic cylinder 9, drain hydraulic lines 10, filter 11, non-return valve 17, throttles 16, 18 and spring 14.

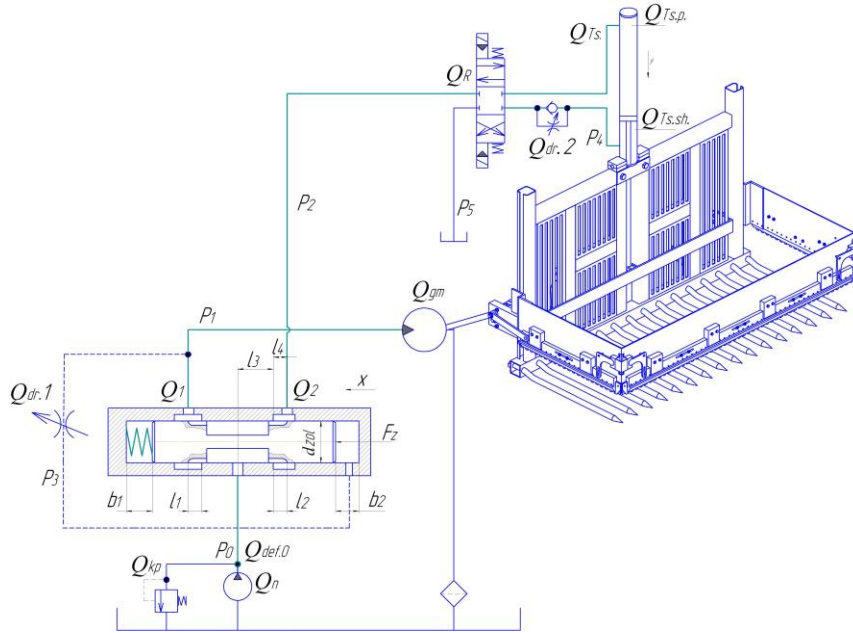
The adaptive system of hydraulic drives of the mechanism for cutting and unloading of stalk fodder provides regulation of speed of cutting and feed rate of the U-shaped frame. The result of this coordination of the speeds of the hydraulic drives of this system is to ensure constant total power of the drives when changing the conditions of separation of the feed unit from the monolith.

The study of the stability of the adaptive hydraulic drive system of the mechanism for cutting and unloading stalk fodder is performed on the basis of a mathematical model containing the equation of continuity of flows and the equation of forces [7].



**Fig.1. Hydraulic scheme of the hydraulic drive system of the mechanism for cutting and unloading of stalk fodder**

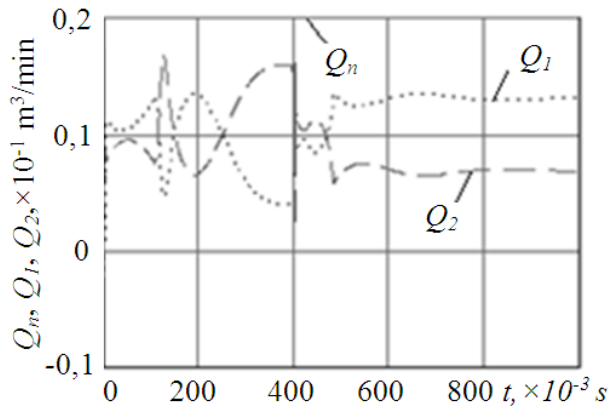
The mathematical model is developed using the software package MathCad, which is an interactive tool for modeling, simulation and analysis of dynamic systems. The design scheme of the hydraulic drive of the mechanism for cutting and unloading of stalk fodder is shown in fig. 2.



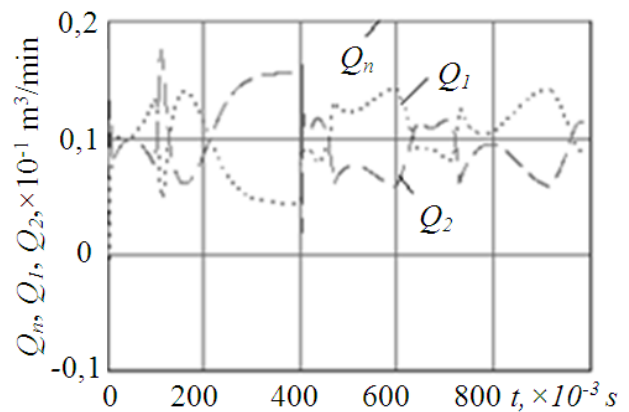
**Fig.2. Calculation scheme of the hydraulic drive of the mechanism for cutting and unloading of stalk fodder**

As a result of the study of the mathematical model, the transients (fig. 3-6) of the system of hydraulic drives of the mechanism for cutting and unloading for different ratios of parameters were obtained.

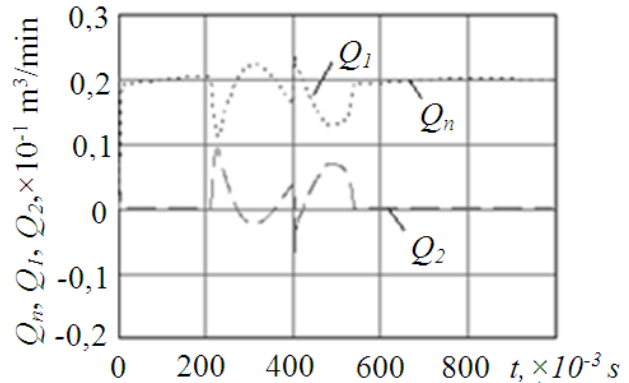
The transients shown in figures 3-6 are calculated at the following initial values of the parameters of the hydraulic drive system of the mechanism for cutting and unloading of stalk fodder:  $Q_n = 2,38 \cdot 10^{-4} \text{ m}^3/\text{s}$ ;  $a = 1 \text{ mm}$ ;  $l_1 = 6 \text{ mm}$ ;  $l_2 = 2 \text{ mm}$ ;  $\mu = 0,62$ ;  $p_0 = 10,0 \text{ MPa}$ ;  $\rho = 850 \text{ kg/m}^3$ ;  $K = 0,6 \cdot 10^{-9} \text{ m}^2/\text{N}$ ;  $d_{zol} = 25 \text{ mm}$ ;  $C_{pr} = 0,5 \text{ N/mm}$ ;  $m_{pr} = 45 \text{ kg}$ ;  $\beta = 2,5 \cdot 10^3 \text{ N} \cdot \text{s}$ ;  $D_{ts} = 63 \text{ mm}$ ;  $W_1 = W_2 = W_4 = 100 \text{ cm}^3$ ;  $W_3 = 25 \text{ cm}^3$ ;  $b_1 = 1 \text{ mm}$ ,  $b_2 = 2 \text{ mm}$ ;  $m_{zol} = 0,2 \text{ kg}$ .



**Fig. 3. The transient process in the hydraulic system of the mechanism for cutting and unloading at the value of the adjustment of the stop  $b_2 = 4 \text{ mm}$**



**Fig. 4. The transient process in the system when adjusting the stop  $b_2 = 4 \text{ mm}$ , the diameter of the spool  $d_{zol} = 19,5 \text{ mm}$ , the spring stiffness  $C_{pr} = 0,3 \text{ N/mm}$**



**Fig.5. The transition process in the system when adjusting the stop  $b_1 = 3 \text{ mm}$ , the diameter of the spool  $d_{zol} = 32 \text{ mm}$ , the spring stiffness  $C_{pr} = 0,5 \text{ N/mm}$**



The transients obtained at different combinations of parameters testified to the presence of different modes of operation of the hydraulic drive system of the mechanism for cutting and unloading of stalk fodder. Figure 3 shows the transient in the hydraulic system of the mechanism for cutting and unloading, which confirms the possibility of adjusting the range of changes in the speed of the hydraulic motor and the feed of the rod by appropriate choice of rational values of some system parameters. The start of the hydraulic drive system of the mechanism for cutting and unloading stalk fodder occurs at zero load on the executive hydraulic motors, which generally corresponds to the process of bringing the U-shaped frame to the surface of the preserved monolith, when the load on the output links of executive hydraulic motors is minimal or absent. At 400 ms from the beginning of the work, the load on the output links of the executive hydraulic motors is increased to a value that corresponds to the real value of the load moment on the hydraulic motor shaft  $M_{gm} = 100 \text{ N} \cdot \text{m}$  and the force  $F_{rez} = 1200 \text{ N}$  on the hydraulic cylinder rod. The volumetric supply of the working fluid  $Q_1$ , which is consumed by the hydraulic motor, increases from  $0,088 \times 10^{-1} \text{ m}^3/\text{min}$  to  $0,136 \times 10^{-1} \text{ m}^3/\text{min}$ , which corresponds to an increase in the cutting speed of the silage monolith by 57 %. At the same time, the supply of working fluid  $Q_2$  which is consumed by the hydraulic cylinder is reduced from  $0,113 \times 10^{-1} \text{ m}^3/\text{min}$  to  $0,075 \times 10^{-1} \text{ m}^3/\text{min}$ , which corresponds to a reduction in the feed rate of the U-shaped frame by 43 %.

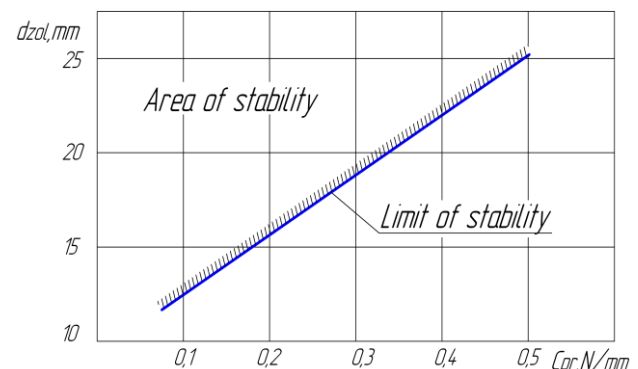
In the process of studying the transient processes of the hydraulic drive system of the mechanism for cutting and unloading stalk fodder it was found that with certain combinations of system parameters there are unstable operating modes (fig. 4). They are characterized by the occurrence of fluctuations in speed and pressure with an amplitude that reaches the limit values, in terms of system power, and the nature of these processes does not correspond to the specified control signals [8]. This mode of operation is unacceptable from the point of view of the efficiency of the hydraulic drive system of the mechanism for cutting and unloading stalk fodder. In this regard, an important point of study of this system of hydraulic drives is to determine the range of values of parameters at which this system will work stably, which will allow further research to identify rational parameters that ensure high efficiency of the proposed hydraulic system [9,10].

The results of the calculation of transients in the hydraulic drive system of the mechanism for cutting and unloading stalk fodder indicate that the stability condition significantly depends on the values of parameters as components of hydraulic units of the hydraulic drive mechanism for cutting and unloading (hydraulic motor, hydraulic cylinder, etc.), as well as the parameters of the spool flow divider. These include the following parameters:  $d_{zol}$  is the diameter of the spool of the flow divider,  $C_{pr}$  is the stiffness of

the spring of the spool of the flow divider,  $a$  is the width of the working edge of the spool,  $f_{dr}$  is the area of the control throttle,  $W_3$  is the volume of the control line cavity,  $l_1, l_2$  are the initial opening of the working window of the flow divider and  $b_1, b_2$  are the distance to the stops that limit the movement of the spool.

Determining the conditions of stability of the adaptive hydraulic system of the mechanism for cutting and unloading is necessary to ensure its efficiency in dynamic modes of operation. For this purpose, the area of stability of this hydraulic drive is determined in the plane of values of its parameters - diameter  $d_{zol}$  spool flow distributor and stiffness  $C_{pr}$  its springs which largely determine its design and functional characteristics (fig.7).

The stability limit divides the plane of parameters into the area of stability and instability of the hydraulic drive adaptable to changes in the load on the working bodies[11]. In figures 7-13, the stability limit is shown by a solid line with hatching. The hatching is turned towards the area of stability.



**Fig. 7. Area of stability of the hydraulic drive system of the mechanism for cutting and unloading of stem forages**

It should be noted that the parameters of the structural elements of the spool flow divider have an ambiguous effect on the characteristics of the hydraulic system of the mechanism for cutting and unloading. Thus, increasing the diameter of the spool  $d_{zol}$  has a positive effect on the dynamic characteristics, while significantly expanding the area of stability, facilitating the task of developers of such a hydraulic drive when choosing the dimensions of hydraulic equipment and its mass.

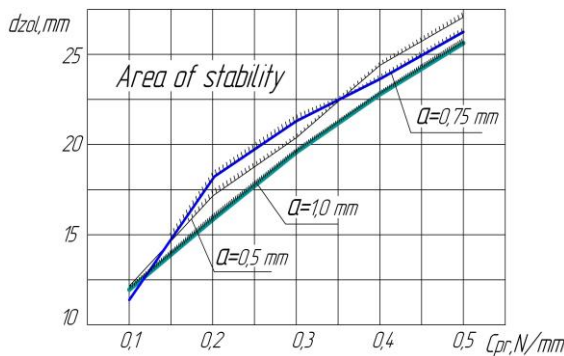
Increasing the stiffness of the spring  $C_{pr}$  also significantly affects the dynamic characteristics of this hydraulic drive, reducing the area of stability. Thus, to ensure the stability of the spool flow divider when using a spring with high rigidity it is necessary to increase the diameter of the spool, which can lead to an undesirable increase in the dimensions of the flow divider.

In a further study of the influence of the parameters of the hydraulic drive system of the mechanism for cutting and unloading on its stability, the results of calculations of the stability limit were compared with the calculation results, which are



shown in fig. 7.

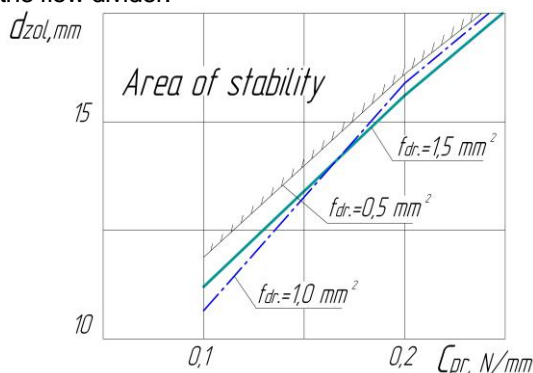
Fig. 8 shows the areas of stability defined in the plane of the parameters "diameter of the spool of the flow divider  $d_{zol}$ , the stiffness of the spring  $C_{pr}$ " at different values of the width of the edges  $a$  of the spool of the flow divider.



**Fig. 8. Influence on the position of the stability limit of the width  $a$  of the flow divider edges**

The limits of stability, which are shown in fig. 8 are calculated for the following values of the width of the working edges of the spool of the flow divider -  $a = 0,5; 0,75; 1,0$  mm. Increasing the width of the working edges of the flow divider shifts the stability limit to reduce the allowable values of the diameter of the spool  $d_{zol}$  and increase the allowable values of the stiffness spring  $C_{pr}$  flow divider, thus expanding the range of values  $d_{zol}$  and  $C_{pr}$ , which provides a stable mode of operation unloading of stalk fodder. It should be noted that increasing the width of the edges of the spool of the flow divider does not significantly expand the range of values of the diameter of the spool  $d_{zol}$  and the stiffness of the spring  $C_{pr}$ , which provides a stable mode of operation of this hydraulic system.

Fig. 9 shows the limits of the stability of the hydraulic drive system of the mechanism for cutting and unloading calculated at different values of the cross-sectional area of the control throttle 16 (fig. 1) installed at the entrance of the right end-to-end cavity of the flow divider.



**Fig. 9. Influence on the position of the stability limit of the throttle area  $f_{dr}$**

The limits of stability which are shown in fig. 9 are calculated at the following values of the throttle

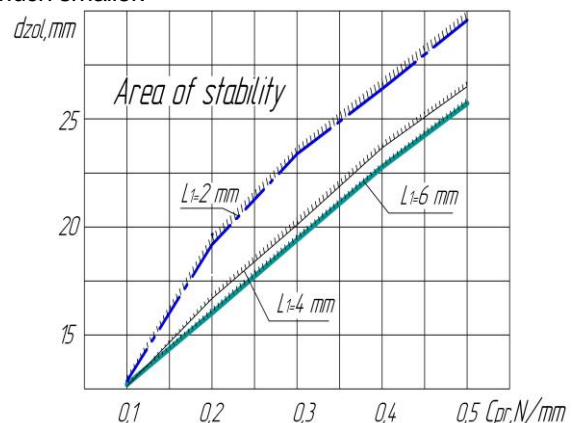
area  $f_{dr} = 1,5; 1,0; 0,5$  mm<sup>2</sup>.

Reducing the cross-sectional area of the throttle slightly increases the area of stability due to the shift of the stability limit towards smaller values of the diameters of the spool.

This usually reduces the oscillation of the control process, but reduces the speed of the spool flow divider. Therefore, in this case, it is advisable to recommend a value of the cross-sectional area of the throttle which is equal to  $f_{dr} = 1,0$  mm<sup>2</sup>. Based on the considerations of manufacturability of the throttle hole of small diameter and taking into account the limited influence of this parameter on the position of the stability limit, it is permissible to increase the cross-sectional area to  $f_{dr} = 2,0$  mm<sup>2</sup> [12].

Studying the influence of the parameters of the hydraulic drive system of the mechanism for cutting and unloading stem fodder on the stability of its work revealed a significant impact on the stability of the values of the initial openings of the working windows of the distributor spool through which the working fluid enters the hydraulic motor 7 and the distributor 8 of the hydraulic cylinder 9 (fig. 1). Fig. 10 shows the limits of stability of this hydraulic drive calculated at different values of the initial opening  $l_1$  of the left working window. The magnitude of the opening  $l_1$  varied from 2 mm to 6 mm. The smallest size of the stability area for this case was obtained at  $l_1 = 2$  mm. The limit of stability is shifted towards larger values of the diameter of the spool of the divider. Increasing the initial opening of this working window to  $l_1 = 4$  mm leads to a significant decrease ( $\approx 20\%$ ) of the critical value of the spool diameter, at which there is an unstable mode of operation.

A further increase in the value of the initial opening of this working window to the value  $l_1 = 6$  mm moves the limit of stability also in the direction of smaller values of the diameter of the spool, but the effect of increasing the area of stability in this case is much smaller.

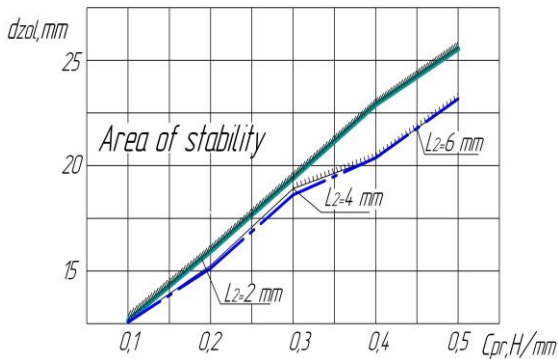


**Fig. 10. Influence on the position of the stability limit of the value of the initial opening  $l_1$  of the first working window of the spool of the flow divider**

To a lesser extent, the position of the limit of stability of the hydraulic drive of the mechanism for



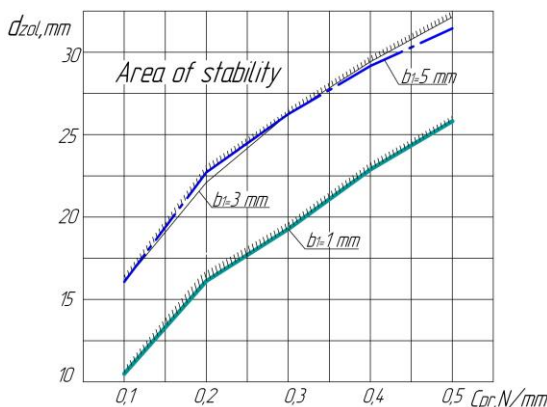
cutting and unloading (fig. 11) is influenced by the initial opening of the right working window of the spool flow divider.



**Fig. 11. Influence on the position of the stability limit of the value of the initial opening  $l_2$  of the second working window of the spool of the flow divider**

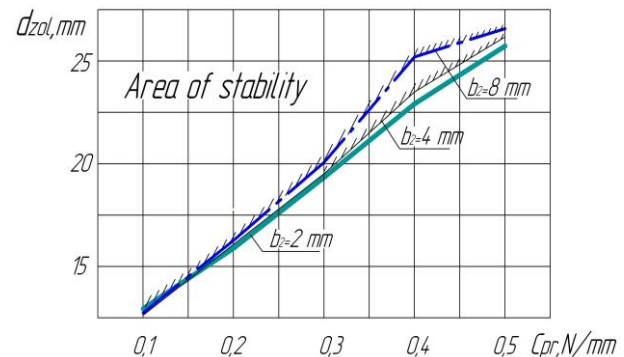
Only with increasing spring stiffness  $C_{pr}$ . (up to 0,5 N/mm) increasing the initial opening of this working window to the value  $l_2 = 6$  mm significantly reduces the critical value of the spool diameter ( $\approx 10$  %), which corresponds to the limit of stability.

The distances  $b_1$  and  $b_2$  to the stops which limit the movement of the spool of the flow divider have a significant influence on the stability of the hydraulic drive system of the mechanism for cutting and unloading. Fig. 12 shows the boundaries of the stability area determined by changing the distance  $b_1$  to the stop, which limits the movement of the spool when moving it to the left, in the range from 1 to 5 mm. According to the calculation, the best result is possible at the minimum of the specified values,  $b_1 = 1,0$  mm. When increasing the value of the spool stroke in the specified direction ( $b_1 = 3$  mm, 5 mm), the critical value of the spool diameter increases significantly - up to 40 %, which worsens the possible operating conditions of this hydraulic drive and significantly increases the dimensions of hydraulic equipment.



**Fig. 12. Influence on the position of the boundary of the stability area of the distance  $b_1$  to the stop which limits the movement of the spool when it moves to the left**

To a much lesser extent, the stability of the hydraulic system of the mechanism for cutting and unloading is affected by the setting  $b_2$  of the second stop which limits the movement of the spool to the right. The boundaries of the area of stability, which are shown in fig. 13, calculated by changing the specified distance from 2 to 8 mm, show that the size of the stability area and the position of the stability limit changes insignificantly.



**Fig. 13. Influence on the position of the boundary of the stability area of the distance  $b_2$  to the stop, which limits the movement of the spool when it moves to the right**

As a result of the analysis of transients in the adaptive system of hydraulic drives of the mechanism for cutting and unloading stem fodder the design and technological parameters of the spool flow divider were substantiated, which allows to monitor and respond to changes in load on the hydraulic motor by changing the flow rate of the working fluid through the throttle slots.

**Conclusion:**

The offered adaptive system of hydraulic drives of the mechanism for cutting and unloading of stalk fodder under the condition of steady work provides the performance of the formulated principle of the coordinated change of speeds of initial links of hydraulic motors at the change of loading on the cutting mechanism. The change of speeds is proportional to the magnitude of the moment of loading on the shaft of the hydraulic motor of the cutting mechanism, which allows to implement the principle of adaptation of the hydraulic drive system to the change of loading modes.

The characteristics of the adaptive system of hydraulic drives of the mechanism for cutting and unloading of stalk fodder at different operating modes are investigated. The influence of its parameters on ensuring the stability of work is analyzed. A significant influence on the fulfillment of the conditions of stable operation of the system of hydraulic actuators of the spool diameter and the stiffness of the spring of the flow divider is revealed.

Possibilities of expansion of the stability area due to the width of the working edges  $a$ , the cross-sectional area of the throttle  $f_{dr}$ , the magnitude of the initial opening of the first working window of the spool



$l_1$ , and the magnitude of the adjustment of the left stop  $b_1$  are revealed. Effective expansion of the stability area is possible by increasing the initial opening of the second window of the spool  $l_2$  and the right stop limiting the stroke of the spool.

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### ДОСЛІДЖЕННЯ ПЕРЕХІДНИХ ПРОЦЕСІВ В АДАПТИВНІ СИСТЕМІ ГІДРОПРИВОДІВ МЕХАНІЗМУ ДЛЯ ВІДРІЗАННЯ ТА ВИВАНТАЖЕННЯ СТЕБЛОВИХ КОРМІВ

Розглядається проблема створення енергоефективного та конкурентоздатного механізму для відрізання та вивантаження стеблових кормів з траншейних сховищ, шляхом розробки та обґрунтування параметрів і режимів роботи адаптивної системи гідравлічних приводів механізму. Запропоновано принципове виконання адаптивної системи гідравлічного привода механізму для відрізання та вивантаження, в якій між двома виконавчими гідродвигунами розміщено золотниковий роздільник потоку, що дозволяє регулювати подачу П-подібної рамки відповідно зміни навантаження, яке діє на різальний механізм. Адаптивна система гідравлічного привода механізму дозволяє стабілізувати енерговитрати на відокремлення порції стеблових кормів при умові зміни і коливанні



параметрів, які суттєво впливають на процес відокремлення та вивантаження стеблових кормів від моноліту.

Отримані та проаналізовані перехідні процеси в адаптивній системі гідроприводів механізму для відрізання та вивантаження стеблових кормів.

В результаті проведеного дослідження виявлено, що зміною ширини робочих кромок золотника роздільника потоку в бік зменшення можливе значне підвищення чутливості системи гідроприводів механізму для відрізання та вивантаження до зміни навантаження на різальному апараті. В результаті цього також суттєво розширюється діапазон регулювання подачі штоком гідроциліндра П-подібної рамки, що підвищує ефективність стабілізації процесу відділення від моноліту блок-порції стеблових кормів при мінімальній потужності системи гідроприводів.

Зазначено, що на динамічні характеристики гідропривода механізму для відрізання та вивантаження стеблових кормів, адаптивного до навантаження, впливають конструктивні параметри золотникового роздільника потоку, який реалізує зворотний зв'язок. На основі проведених експериментальних досліджень дано рекомендації з вибору конструктивних параметрів золотникового роздільника потоку.

**Ключові слова:** механізм для відрізання стеблових кормів, гідравлічний привод, математична модель, перехідні процеси, роздільник потоку, гідродвигун, гідроциліндр, енергоємність.

#### **ИССЛЕДОВАНИЕ ПЕРЕХОДНЫХ ПРОЦЕССОВ В АДАПТИВНОЙ СИСТЕМЕ ГИДРОПРИВОДОВ МЕХАНИЗМА ДЛЯ ОТРЕЗАНИЯ И ВЫГРУЗКЕ СТЕБЕЛЬНЫХ КОРМОВ**

Рассматривается проблема создания энергоэффективного и конкурентоспособного механизма для резки и выгрузки стеблевых кормов с траншейных хранилищ, путем разработки и обоснования параметров и режимов работы адаптивной системы гидравлических приводов механизма. Предложено принципиальное выполнения

адаптивной системы гидравлического привода механизма для резки и выгрузки, в которой между двумя исполнительными гидродвигателями размещен золотниковый разделитель потока, что позволяет регулировать подачу П-образной рамки соответственно из изменения нагрузки, которые действуют на режущий механизм. Адаптивная система гидравлического привода механизма позволяет стабилизировать энергозатраты на отделение порции стеблевого корма при условии изменения и колебании параметров, которые существенно влияют на процесс отделения и выгрузки стеблевого корма от монолита.

Получены и проанализированы переходные процессы в адаптивной системе гидроприводов механизма для резки и выгрузки стеблевых кормов.

В результате проведенного исследования выявлено, что изменением ширины рабочих кромок золотника разделителя потока в сторону уменьшения, возможно значительное повышение чувствительности системы гидроприводов механизма для резки и выгрузки к изменению нагрузки на режущем аппарате. В результате этого также существенно расширяется диапазон регулирования подачи штоком гидроцилиндра П-образной рамки, повышается эффективность стабилизации процесса отделения от монолита блок-порции стеблевых кормов при минимальной мощности системы гидроприводов.

Отмечено, что на динамические характеристики гидропривода механизма для резки и выгрузки стеблевого корма, адаптивного к нагрузке, влияют конструктивные параметры золотникового разделителя потока, который реализует обратную связь. На основе проведенных экспериментальных исследований сделаны рекомендации по выбору конструктивных параметров золотникового разделителя потока.

**Ключевые слова:** механизм для отрезания стеблевого корма, гидравлический привод, математическая модель, переходные процессы, разделитель потока, гідродвигатель, гідроциліндр, енергоємність.

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