Trends in the implementation of non-assured structural mechanisms in technological machines modules

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Abstract The results of the analysis of scientific research in the field of non-assure mechanisms are presented, on the basis of which the conclusion is made about the need for further development of the theory of mechanism structures and methodological approaches to the synthesis of machines with special properties of kinematic structure, allowing to reduce energy consumption and improve technical performance. The results of experimental studies have confirmed the existence of a relationship between the magnitude of the pre-voltage of the closed kinematic circuit and the energy intensity of the grinding and pressing process. The revealed patterns make it possible to minimize energy consumption and adapt the technological machine to the properties of the processed material. Experimental studies of a gear-grinding mill on sandstone, quartz, marble samples have confirmed that with the same energy consumption, the maximum grinding efficiency (an increase in the proportion of fine particles) is achieved only in a certain loading range of a closed kinematic contour corresponding to the strength of the crushed material.

1 Introduction

Modern technical innovations, the variety of technological processes and the machines corresponding to them, the expansion of the scope and functional purpose of mechatronic devices, robots and automatic machines presuppose the constant complication of not only control systems, but also utilized mechanisms, their structures and designs. Among the main trends, one can note multifunctionality, the ability to automatically rebuild its work (parameters or modes) or change its structure depending on external conditions, loads or changes in the input signal, independently replace elements that have lost their performance, use their design features to save and accumulate energy.

Such tendencies determine the use of previously unexplored or insufficiently studied structural groups and mechanisms in modern technical objects, set a number of questions for designers related to the analysis of the structure, power and kinematic calculations, ensuring the reliability and accuracy of movements, and optimization of functional properties. Mechanisms that have been studied quite well, having an assured structure, are mainly

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supported by calculation methods, recommendations, etc. However, as practice shows, assured structural mechanisms do not always meet the goals and objectives set in the terms of reference, which leads to the use of parallel structure mechanisms [1], mechanisms with closed tense kinematic circuits [2], mechanisms with variable structure [3]. The widespread use of automated machines and unmanned technologies required the introduction of adaptive and indifferent mechanisms [4]. Without considering in the framework of this article the problems of terminology and a unified classification, we note that all the mechanisms listed above have their own unique properties, functional technical effect, area of rational application, that requires their further study and scientific substantiation.

2 General combinatorial-logical approach to the synthesis of structural mechanisms for the technological machines modules

In order to obtain systematized, relatively complete information about the structure and design features of an innovative technical object, it is desirable to obtain its generalized model, which makes it possible to take into account all the variable elements and their morphology. i.e. a model that includes all classification features, possible options for changing the elemental, functional and parametric base, a system of restrictions and search algorithms for the required option. At the same time, such a model makes it possible to identify new, not yet developed structures, to substantiate the possibility of combining two or more structures in one module, etc.

As an apparatus for the development and substantiation of such a model, in our opinion, the combinatorial-logical method of structural synthesis can be used, which is described in the literature in sufficient details [5]. The method allows to establish a logical relationship between the structural elements of a technical object, a system of structural, parametric and logical constraints, create a search field for rational structures, formalize the synthesis process and identify promising schematic diagrams. Catalogs of ready-made technical solutions can be created on the basis of combinatorial-logical approach both for the entire object as a whole and for individual elements.

Some of the first catalogs [6] were developed by K. Roth, who created a notation system that differs from the generally accepted one in the theory of mechanisms and machines. This made it possible to create tables of ready-made structural solutions, for example, for mechanisms with zero and negative degrees of mobility: lock joints, self-braking mechanisms, etc. With certain assumptions, the method can be classified as morphological. Common to the methods is the identification of the elemental (modular) base, the creation of a generalized logical scheme or model, a system of algorithms for the search (selection) of a technical solution, the presence of rules (methods) and a system of restrictions. The use of such techniques has been sufficiently tested and made it possible to obtain new designs of machines, mechanisms and their elements, including in the field of drilling cutting tools, energy storage traction and brake drives, grinding machines, transport-feeding carts, etc., which is confirmed by a number of works [7,8,9].

For formalized tasks, the most characteristic feature is the search for a structure, since it is independent of the function and may not take into account the entire range of parameters, which in this case are constraints or boundary conditions. Today, structural synthesis can be implemented at the subject level or irrespective of a specific application.

The main conditions or assumptions of using the method are:

- the presence of structure and structural features in the object of consideration;

- the presence of many analogs, prototypes, elements, connections, etc., creating a combinatorial space sufficient for the synthesis of many options;

- variable elements allow structural and constructive compatibility, while maintaining technical and technological feasibility;

- the object of consideration belongs to a group with the same functional purpose;

- the constraints and conditions of the enumeration algorithm allow combinations of elements in a volume sufficient for the purposes of consideration.

In this regard, the creation of a complete model of an arbitrary module of a technological machine is difficult and at the initial stage can be limited by: the peculiarities of the structure of the basic mechanism; functional requirements of an innovative solution; the peculiarities of the module interaction with the environment or other modules; technological requirements. Thus, such a model can reflect a local set of technical solutions for a certain class, type or group of machines.
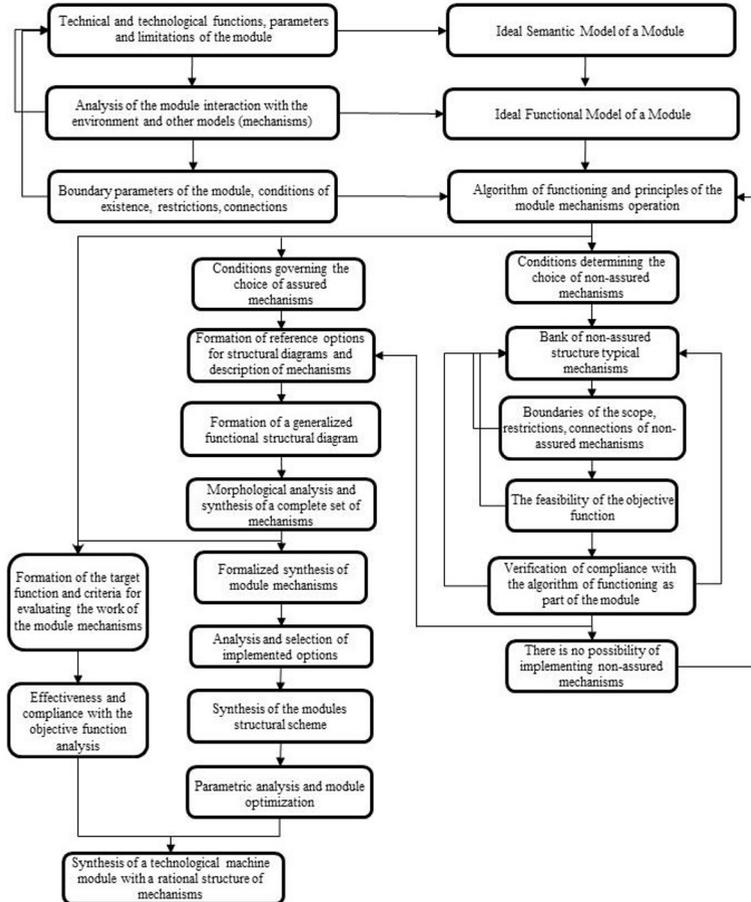

Fig. 1. General algorithm of technological machines modules mechanisms structural synthesis.

Constraint analysis makes it possible to present the required amount of generalizations for a given module. Moreover, each of the factors causes an increase in the number of options. However, the method of combinatorial-logical synthesis allows obtaining a complete classification and a set of technical solutions, creating more perfect and innovative modules for various technological machines. The general mechanisms structural synthesis algorithm for modules of technological machines is shown in Fig. 1.

The technical and economic feasibility of the transition to the layout of a module or machine with a non-standard structure of mechanisms is determined on the basis of a step-by-step analysis of the production subject, technological functions, intra-system parameters

and constraints, the interaction of the module with the environment and other modules, external parameters and restrictions, conditions of existence, restrictions and connections.

The result of the first stage is an ideal module model, which describes the algorithm of functioning and the principle of mechanisms operation. The scheme of the initial stages can be supplemented and adjusted for specific conditions, technological tasks and environmental parameters. The general result of the analysis and the formation of ideal models is the development of the desired algorithm of functioning and the principle of module mechanisms operation, which determines the conditions for choosing an assured or non-assured mechanism.

The choice of the structure in conditions of uncertainty in the values of the designed system indicators can be made according to the mathematical expectations of the indicators. In this case, the criterion for choosing the optimal structure can be either the mathematical expectation of the system indicators values built on the given structure, or the probability that the values of these indicators will satisfy the algorithm of functioning.

So, for example, for functional modules of technological machines with a constant pre-stress of a closed kinematic loop as an indicator, it is fair to introduce the utilization factor of the loop, which is justified and confirmed experimentally in [2]. The coefficient can be represented as:

$$k_{\mu} = \frac{\Delta N_0}{\Delta N_{in.}} \qquad (1)$$

where ΔN_0 - is relative power consumption in a technological process without voltage of a closed kinematic loop;

$\Delta N_{in.}$ - is relative power consumption during the technological process when loading a closed kinematic loop

For adaptive and indifferent mechanisms, it's possible to use the indicators and the bank of typical structures presented in the works [4, 10]. The system of restrictions in a number of cases can be reduced to formalized structural and parametric indicators, which are more convenient in form for further elaboration and comparison of alternative options.

An important point is the formation of the target function and criteria for evaluating the work of the module mechanisms. With regard to the synthesis of structures, these criteria are mainly of a qualitative nature, reflecting the compliance with the functioning algorithm.

Thus, having the principle of choice *F* and a set of options *{K}*, we can write:

$$\{\{K\}, F\} \rightarrow K^* \qquad (2)$$

where K^* - is a set of selected alternatives.

In these circumstances, the most common case is when the boundaries of the set {K} are not fixed, and the principle of choosing *F* is not formalized, which corresponds to the solution of design problems (especially at the level of structural schemes) with an unlimited matrix of possible solutions. If the possibility of choosing the auxiliary principle *Φ* is impossible, then some initial set of alternatives {K0} is established by expert means and they are compared by known methods. If none of the selected alternatives answers $\{\{K\}, \{K'\}\}$, then the choice of the next initial set, or the type of non-assured mechanisms is made, or a conclusion that there is no possibility of implementing non-assured mechanisms is drawn.

The next stage is the formation of reference options, their analysis and construction of a generalized functional-structural model, which allows to formulate a complete set of module mechanisms using the morphological method.

Based on the morphology of the object, depending on the tasks set, a matrix of variables is formed: functions, elements, possible movements, etc. The procedure for the formation and work with morphological matrices is quite fully described in the literature [11,12].

When analyzing and selecting the implemented variants of the functional model, one should pay attention to the following aspects:

- control functions can be transferred to the structure itself, that is, self-regulation, energy redistribution along the branches of the kinematic chain, etc are carried out.;

- in the structure of mechanisms with non-assured mechanisms, there is a number of additional elements in the form of load devices, additional closing pairs, etc., the functions of which can be structurally combined;

- the nature of the movement, the number of parallel kinematic chains, etc. have a significant impact on the design of the functional mechanism, that is, they can, for example, combine transport and technological functions;

- the change in variables is determined by the limits of variation, established in accordance with the structural and parametric constraints of the technological machine as a whole.

The synthesis of possible structures is carried out for each reference variant and can be formalized.

It is assumed that the generalized functional-structural diagram is considered at one of the n levels, which includes the developed functional mechanisms (or a group of mechanisms) with connections going to the level $n+1$ and $n-1$, and horizontally to subsystems of the same rank. The useful effect of each subsystem determines the cost vector S, which imposes additional restrictions on the choice of parameters P^n. Then, through the structural diagram of the functional mechanism, they can be given the form of a restriction function for each level:

$$Q_{n-1}^n(P^n) \geq S_{n-1}^n$$
$$Q_n^n(P^n) \geq S_n^n \qquad (3)$$
$$Q_{n+1}^n(P^n) \geq S_{n+1}^n$$

If at each level of the system there are additional autonomous constraints B^n that are not related to the cost vector S, then

$$Q_n^n(P^n) \leq B^n(S_n^n) \qquad (4)$$

For the options selected above, a brief description is given with diagrams and sketches, similar to patent descriptions. After drawing up preliminary sketches, a more detailed design study is carried out, taking into account additional requirements. In this case, individual elements can be considered and worked out in full.

Structural optimization is reduced to a combinatorial problem of synthesis, construction of structural and systemic technical and economic models. The choice of optimal or rational parameters provides the identification of patterns change in performance indicators from certain parameters to their totality. The problem of choosing criteria is solved unambiguously at the level of parametric optimization. The method of choice in the given general methodology is not specified.

In the case of several criteria, any alternative can be compared to a point in the n-dimensional criterion space, which requires additional introduction of significance coefficients. The preference condition is given to the alternative with the highest score. A more typical case is when the scores differ by the value of the criterion calculation error, that is, a number of alternatives will not be improved. The question of further choice formalization depends on the specifics and requirements of a particular task: the introduction of additional criteria, ranking by the method of expert assessments or group ordering.

In general, the parametric optimization procedure is reduced to:

- the substantiation of the variable parameters main system and highlighting the most significant ones for the purposes of consideration;

- the formulation of constraints, a system of assumptions and variability of operational (including emergency) loads;

- the development of a mathematical model with a given level of adequacy and completeness;

- the substantiation of performance criteria and comparison methods;

- the choice of the method of parameters and modes optimization;

- the establishment of rational or optimal parameters and modes.

Establishing connections between the required function, structure and parameters allows you to synthesize functional mechanisms for specific mining, construction and hoisting-and-transport machines, systematize them and identify technical solutions that have "dropped out" from the general matrix. This approach takes into account not only the final indicators (productivity, degree of crushing or deformation, etc.), but also the physical essence of mining, construction, transport processes as the basis laid down in the design development, which allows you to create technical solutions in the field of functional mechanisms and modules technological machines using special properties of non-assured mechanisms.

3 Features of the adaptive mechanisms synthesis on the example of cutting drill bits

The existing classifications of adaptive systems mainly reflect the "management" side of the process, i.e. related to the amount and quality of information required to ensure the normal operation of the system. For example, in terms of transmitted information volume, the systems can be self-adjusting and self-organizing. The first ones provide stabilization of the functional criterion set value by changing the parameters of the control action. Self-organizing ones imply changes not only in the numerical values of parameters, but also in structural diagrams and control algorithms. In this case adaptive mechanisms presuppose structural changes [4] due to the presence of an adaptive connection, which makes it possible for the technological process to influence the driven links law of motion. Self-regulation processes, in their turn, raise the problem of energy saving, not only parametric but also structural restructuring, adaptability or immunity to certain signals.

Adaptive mechanisms are structures with the number of mobility degrees greater than the number of leading links per the number of adaptive links. "An adaptive connection is a condition for interaction of two moving links on their relative displacement, in which their movement is not determined by either the kinematic or dynamic parameters of the mechanism, but depends only on the parameters of technological (working) process" [4]. Due to the presence of such connection and an additional mobility degree, these mechanisms provide automatic regulation of the operating mode depending on the environmental conditions or the state of the executive body, the redistribution of energy flows between the modules of the machine.

Non-assured chains of positive orders, in contrast to adaptive ones, provide immunity to the magnitude of the closing connection reaction, i.e. they are able to ensure the impossibility of transmitting motion in any direction, the accuracy of a given motion regardless of the existing technological loads, etc. Such structures are called indifferent [4].

The peculiarities of the adaptive mechanisms synthesis lie in identifying the conditions and nature of technological processes, in the formation of additional adaptive connections that allow the mechanism to adapt to environmental conditions or changes in the technological process, to difficulties of mathematical description of the adaptive connection type, since in general case, the latter can be represented by functions of displacements, speeds, accelerations, time, and environmental parameters. At the same time, the adaptation mechanism should be triggered after overcoming the maximum permissible deviation, the "threshold" - the criterion value by which the external influence is assessed.

When drilling blastholes in open pits, changing external conditions are caused by layering, strength, direction of rocks bedding and a number of other factors. The strength of individual layers can range from 2 to 7 on the scale of Professor M.M. Protodyakonov. Analysis of research in the field of cutting drilling tools improvement showed that in this range, cutting bits are the most effective. However, the parameters of cutting bits for soft formations differ significantly from those required for drilling hard formations.

Modern bits, depending on the external environment, have different design solutions and parameters: the shape and size of the cut, the geometry of the cutting edge, the size and shape of the bearing surface, positive and negative rake angles of the cutters, cutters of different strength, etc. It follows that the issue of their adaptation requires elaboration from various points of view: the validity of the adaptable parameters, the identification of their boundary and optimal values, the determination of rational balance of the structures variability, the possibility and feasibility of constructive implementation, the establishment of economic feasibility balance and technical efficiency.

The general diagram of technical and technological functions, variability of parameters and limitations is shown in Fig. 2.
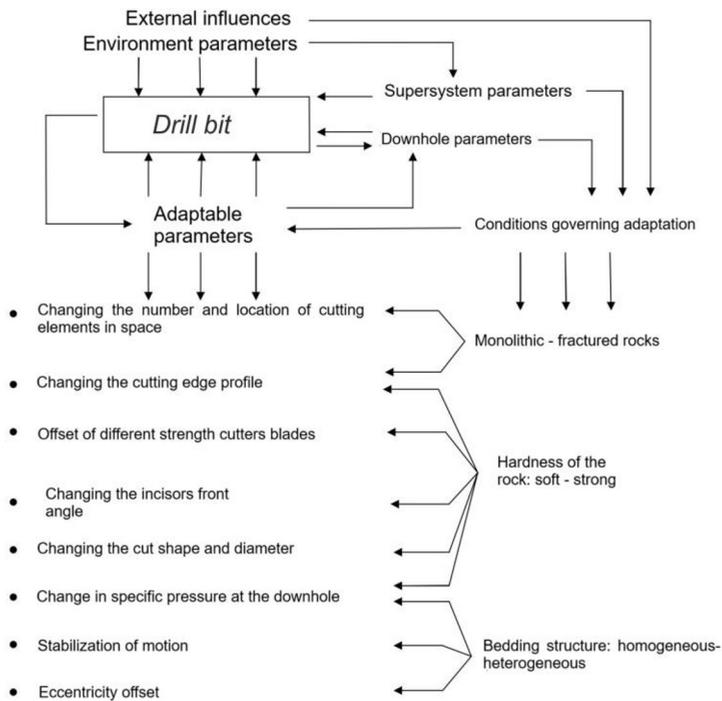

Fig. 2 General diagram of technical and technological functions, variability of parameters and restrictions.

The change in the size, number and location of cutting elements (supporting surface) during drilling of fractured rocks is highlighted in [13, 14] and many others and is implemented due to three or four feather structures, screw-shaped bits, facilitating the removal of drill fines, or other structures, assuming the distribution of cutting elements over the face volume. The multi-support contact of the bit cutting edges with the borehole face provides stable operation in fractured formations, eliminating the tool jamming, and the shape of the body ensures good removal of drill fines from the bottom hole to the auger spiral, good centering of the bit in the downhole.

Recommendations on the choice of the end angle (taper angle) of the cutting tool are ambiguously presented in the literature. In particular, theoretical and experimental studies have confirmed that a decrease in the end angle increases the drilling speed and wear resistance of the tool blades, and the limiting factors are the strength characteristics of the body and the conditions for removing drilling fines. In a number of other works, it is substantiated that on soft rocks it is necessary to have a minimum crown height, i.e. bring the auger as close as possible to the destruction zone, which requires an increase in the end angle. Thus, the end angle can vary depending on the hardness of the rocks and the drilling regime parameters.

The issue for discussion is the presence of a solid or discontinuous cutting edge. Essentially the design of an adaptive bit can provide a change from a solid cutting edge when drilling in soft, especially abrasive formations, which protects the bit body from wear, to discrete placement of cutters, with an intermittent cutting edge, which allows to reduce the consumption of hard alloy, to reduce the contact area of the blades with the bottom, to provide an increase in the specific pressure on the bottomhole for drilling in hard rocks, as well as to use replaceable unified cutters.

As you know, most designs of drill bits provide for the presence of a cut in the central part. The resulting core is destroyed under the action of bit vibration, friction forces, etc. Self-destruction of the core is determined by the strength of the rock, its fracturing, heterogeneity of the structure, which determines the choice of the cut size and shape. General recommendations provide for a cylindrical shape and relatively smaller cutting diameters for hard rocks, for soft, loose and fractured rocks - a conical shape and increased cutting diameters. For drilling layered rocks, the diameter and shape of the cut are selected on the basis of calculation of drilling hard rocks, therefore, on soft and fractured rocks, the maximum drilling efficiency is not achieved.

As a result of the adaptive functions formation basic principles analysis of the cutting drill bit elements and using the bank of mechanisms structures[4], it is possible to proceed to the formation of reference variants, which allow to generalize functional-structural diagrams and synthesize a set of module mechanisms with given properties.

Structural diagram of a bit with an adaptive cut can be presented in the form (Fig. 3-A). The blades 4 of the bits are made rotary relative to the axis 3, fixed on the body 1 of the bits, and are held by an elastic element 2 when drilling in soft formations in a position, providing a tapered shape and a large cutting diameter. With an increase in the rock hardness, the drilling resistance increases, the elastic element 2 is compressed, the blades 4 of the bits rotate about the axis 3. The shape of the cut (see Fig. 3-A) is transformed into a cylindrical one, small in diameter. The bit design is protected by a patent [15].

Structural diagram of a bit with adaptable cutter pressure on the bottomhole is shown in Fig. 2B. One of the blades 7 is made movable relative to the hull 5 and rests on an elastic element 9. The blade is kept from falling out by a locking pin 10. When drilling soft rocks, destruction is carried out by a bit 8 and a movable blade 7 extended towards the bottom. This structure reduces the length of the cutting blade contact with the bottom and provides an increase in specific pressure at the bottom. When the bit encounters stronger interlayers, the drilling resistance increases. The elastic element 9 is compressed, the movable blade moves until it stops in the locking pin 10 (Fig. 3-B, C). Both blades are located at the same level in the face plane. The specific loads acting on the cutting blades are reduced, which contributes to their reliability. The bit design is also protected by a patent [16] and has passed production tests.
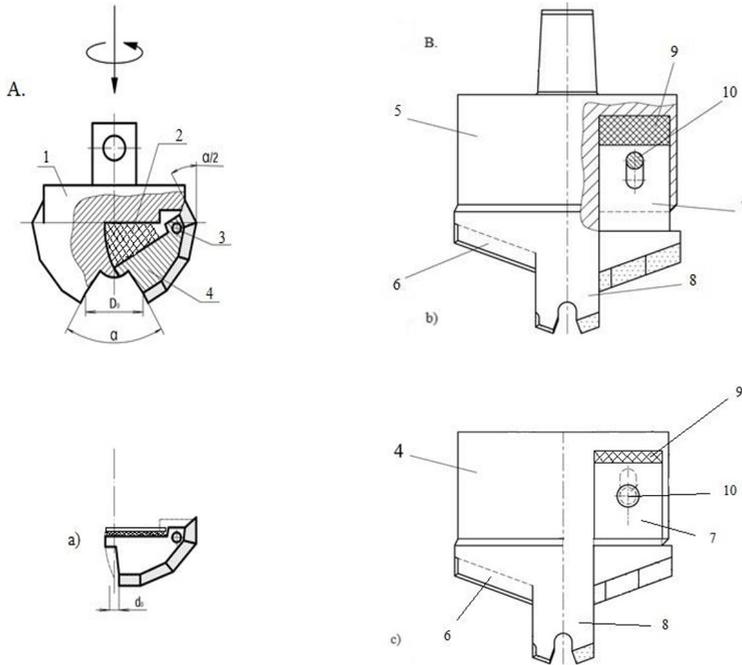
Fig. 3 Adaptive bit designs with variable parameters and structure. A- diagram of a bit with an adaptable cut; B - bit pattern with adaptable cutter pressure on the bottomhole. a - a diagram of the limiting blades rotation with the decrease in the cut diameter; b - bit diagram for drilling soft rocks; c - bit diagram for drilling hard rocks; 1 - case; 2 - elastic element; 3 - axis of blade rotation; 4 - movable blade; 5 - case; 6 - fixed blade; 7 - movable blade; 8 - leading borehole; 9 - elastic element; 10 - locking pin.

Other adaptable parameters and functions can be implemented in a similar way, and their morphology can be analyzed. The study of the structural-morphological model makes it possible to create a catalog of the adaptive elements and adaptive mechanisms system element base, taking into account the hierarchical levels of specification, allowing to synthesize both general functional and structural and constructive schemes of mechanisms, taking into account the diverse characteristics of technical objects and environmental conditions.

4 Features of the tense closed loop mechanisms synthesis on the example of grinding machines

The expediency of using "stressed cycles" in "paired connections" in the design of technological machines was previously indicated in the works of Kutzbach [18], Hein [19] and many other authors. The meaningful use of tense closed kinematic circuits (contours) is realized in test stands for wear, in mechanisms for sampling gaps, etc. The works [3,9] present the results of a systematic consideration of machine mechanisms using tense closed circuits. A number of original mechanisms were developed and implemented by A.N. Drovnikov, S.A. Kuznetsov, V.S. Isakov, V.B. Balashov in machines for grinding and cutting various materials, pressing equipment, energy-saving and energy storage drives of construction, lifting and mining machines, etc. According to the proposed classification, mechanisms with preliminary and variable loading of closed kinematic circuits were investigated.

Grinding of various natural and man-made materials is a mandatory, most common and energy-consuming process in almost all industries: mining, coal, chemical, etc. In agriculture and woodworking industry, about 100 million tons of biological waste are left annually, which are also shredded during subsequent processing. Thus, the physical properties, chemical compositions of materials are characterized by a variety and a wide range of values. At the same time, some physical properties, for example, the strength of particles, change with an increase in the thickness of grinding. The structure of new composite materials is characterized by the heterogeneity of the individual inclusions properties: strong, brittle, viscous, etc.

In this regard, the ideal shredder structure should be one that matches the physical properties of the starting material. Let's say that in this case we mean the introduction of certain changes into the design (by reconfiguring, replacing individual elements, changing the structure or in another way) in order to increase the efficiency and reduce the energy intensity of the process. Such changes can be made through the use of adaptive, indifferent and other structures of the mechanisms discussed in section 1 of this article. Existing mechanical grinders with toothed working bodies, ensuring the use of the tense closed loop effect, to the greatest extent, in our opinion, are suitable for these requirements [17].

The general scheme of variable parameters is shown in Fig. 4.

As it can be seen from the presented diagram, the parameters of the initial and final product determine the design features of the grinder working body, determine the need for changes, and also directly affect the optimized parameters. In less detail, the conditions that determine the design parameters of the working body can be represented by three groups: changes in the size of the original product, changes in the physical properties of the original product, changes in the requirements for the final product. Each group requires adequate changes in one or a set of variable parameters.

An increase in the size of the initial product determines the size of the mill inlet, the size of the teeth, and possibly the center-to-center distance in order to organize a certain degree of pre-grinding. The requirements for the final product, as an ideal functional model, determine the profile and shape of the teeth, the center-to-center distance, the organization of the recycle, and the amount of prestressing for mills with a closed kinematic loop. Changes in the physical properties of the initial product correspond to changes in size, profile and shape of the teeth, center-to-center distance, addition of special (for example, cutting) elements, etc. Each change presupposes the presence of dominant methods of destruction. Shredders with a toothed working body are capable of implementing various methods of destruction: crushing, breaking, impact, abrasion, cutting, etc. It is advisable to choose the dominant methods depending on requirements for the final product and the type of material.

Singling out (Fig. 4) the strength of the destroyed material from the whole variety of physical properties, it can be assumed that the main variable parameter will be the magnitude of the preliminary stressed closed kinematic circuit compression, which determines the choice of the non-assured mechanism. By determining the correct stress value for different materials, the efficiency of the mill can be maximized.
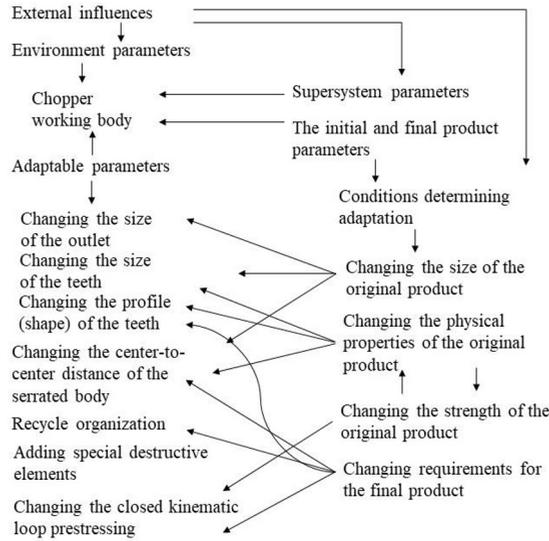
Fig. 4. Formation of variable parameters

Based on this, reference variants of structural diagrams corresponding to the implementation of variable parameters can be formed. Omitting the above procedures, let us consider the accepted schematic diagram of the mill working body with a tense closed kinematic circuit (Fig. 5)
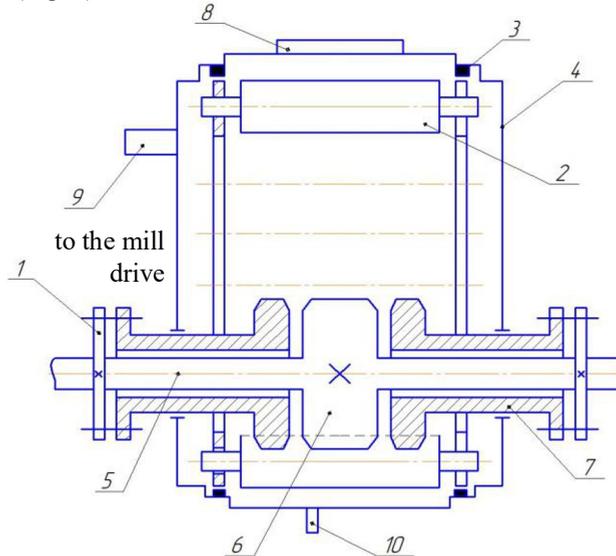

Fig. 5 Schematic diagram of the gear-pin mill working body with a stressed closed kinematic circuit. 1 - differential clutch, 2 - pinwheel, 3 - pinwheel supports, 4 - body, 5 - elastic shaft, 6 - working body, 7 - hollow shaft, 8 - loading port, 9 - unloading port, 10 - purge valve.

The working body of the mill is a combined arrangement of gears, made as follows. The working body (6), which is the leading and driven by the engine, is made in the form of a gear with elongated teeth and is fixed on an elastic shaft (5). An elastic shaft (5) is housed in a hollow shaft (7), which in turn is divided into two parts. Each part of the hollow shaft (7) in the working area of the mill is made in the form of a gear wheel. The components are interconnected by means of a differential clutch (1). This structure is located in the body (4)

and engaged with the pinwheel (2), which is movable and rests on the body with the help of supports (3). The raw material is crushed when it enters the crushing chamber through the loading window (8) into the space between the spindles and the toothed working body. The prestress between the spindle and the gears is created when the elastic shaft 5 is twisted and is fixed using differential couplings (1). The crushed material is removed from the zone of working bodies action through the unloading window (9). The use of this working body arrangement makes it possible to implement a tense closed kinematic loop in the design of a gear-pin mill, which allows to regulate the voltage value in a static mode.

5 The results of using non-assured structural mechanisms in technological machines modules

The main difficulty in the implementation of adaptive drill bits is the choice of an elastic element (or in the general case of an adapting element). A separate study is devoted to this issue, the results of which are published in [20]. The results of studies of the constructive extension influence of the movable blade and the feed forces of the machine tool on the well drilling speed are shown in Fig. 6.

The graph shows that when the flow rate is increased to points 2,4,6, the bit destroys the bottom of the well according to the "movable blade + rammer" pattern. Starting from these points, a stationary blade gradually comes into contact with the bottom of the well. Drilling speed up to points 3,5,7 practically does not increase.
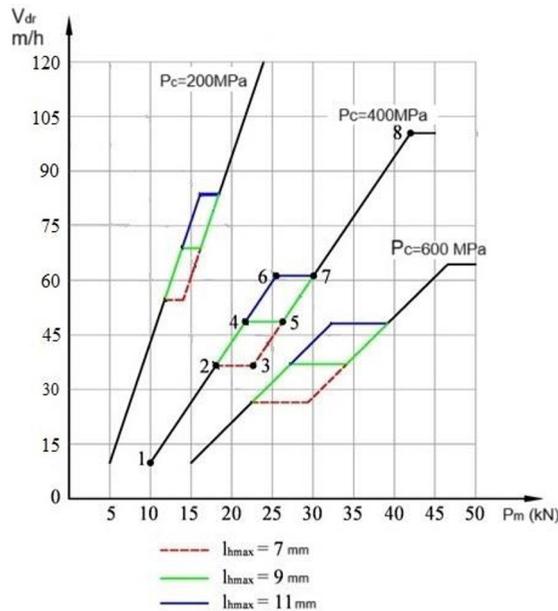

Fig. 6. Dependence of the drilling speed on the feed force of the machine tool and the structural extension of the movable blade for different values of the rock contact strength. Vdr - drilling speed; Pm - machine feed force; lhmax - constructive blade extension; Pc - contact strength of the rock.

When the cutting edge of the movable blade aligns with the fixed one (points 3,5,7), the drilling speed begins to increase. Point 8 corresponds to the limitation on the rated power of the rotator motor, the drilling speed does not increase.

Thus, depending on the design features and strength characteristics of the bit, it is possible to determine the required amount of shrinkage of the elastic element to obtain the maximum

drilling speed at a given level of reliability. The recommended way of the movable blade is 11 mm for the AD-160 bit with interlayers with a contact strength of up to 600 MPa. The experimental sample (Fig. 7) passed production tests, which showed an increase in the drilling speed by 1.2 - 1.5 times than when drilling with non-adaptive bits, for various modes and initial conditions. The change in the structure of the bit (single-blade - two-blade) occurs automatically without a special control system.

AD-160 drill bit.

Fig 7. Production test of the drill bit.

The main problem in the design of mechanisms with a tense closed kinematic contour is to determine the rational parameters of a toothed working body and the magnitude of prestressing.

The results of the effect study of loading the closed kinematic contour of the mill on the change in the granulometric composition of the material are presented in the graphs (Fig. 8). The volume of larger fractions particles decreases, and the volume of particles less than 0.315 and 0.15 mm increases with the same energy consumption for grinding. The maximum increase in the percentage of particles of size 0.15-0.315 mm is 7.8% for quartz. In crushed stone and marble, the main increase in the mass of small particles occurs in the range> 0.15: 8% and 4.52%, respectively.
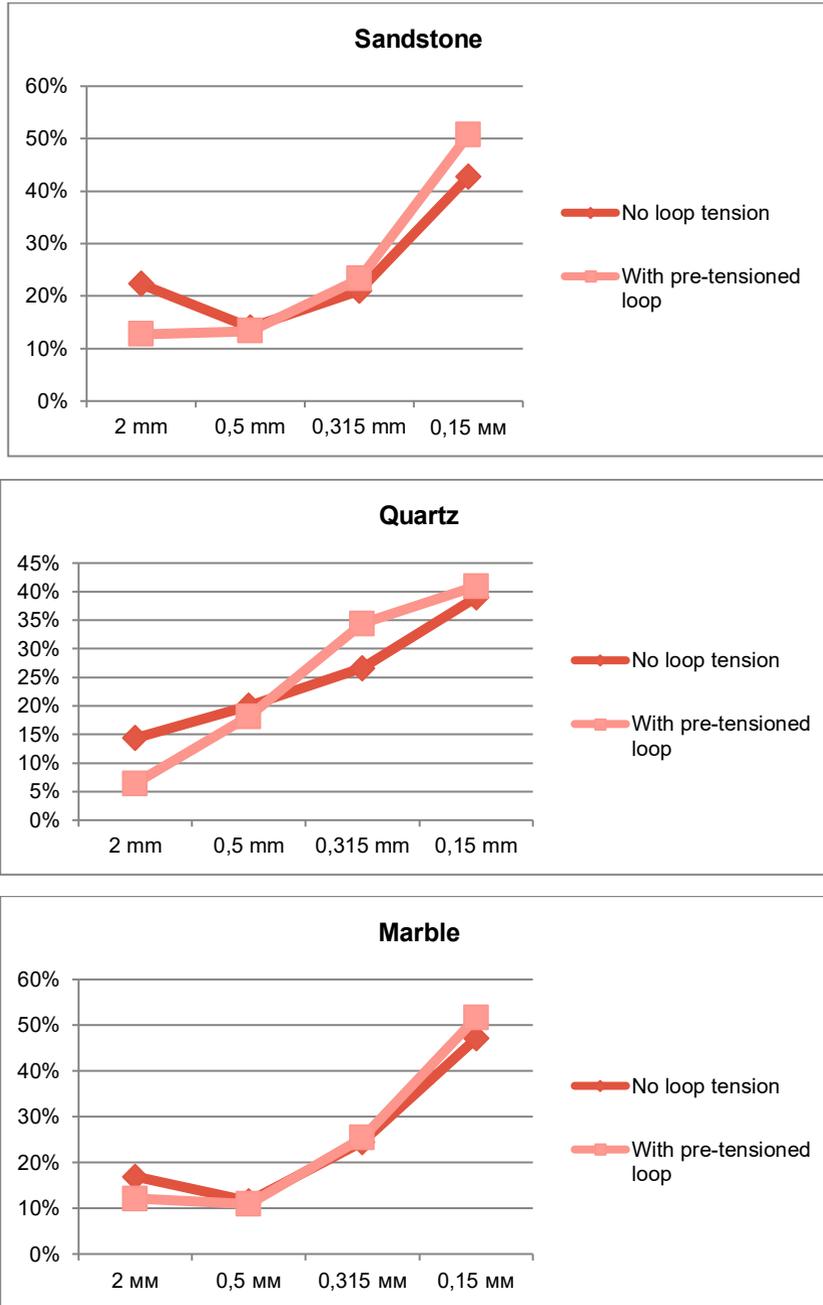
Fig. 8. Granulometric distribution diagrams after grinding in a mill

The rational forces of loading a closed kinematic loop in mills equipped with a toothed (toothed-like) working body in relation to different strength ranges of crushed materials and the working body of the mill are shown in Fig. 9.
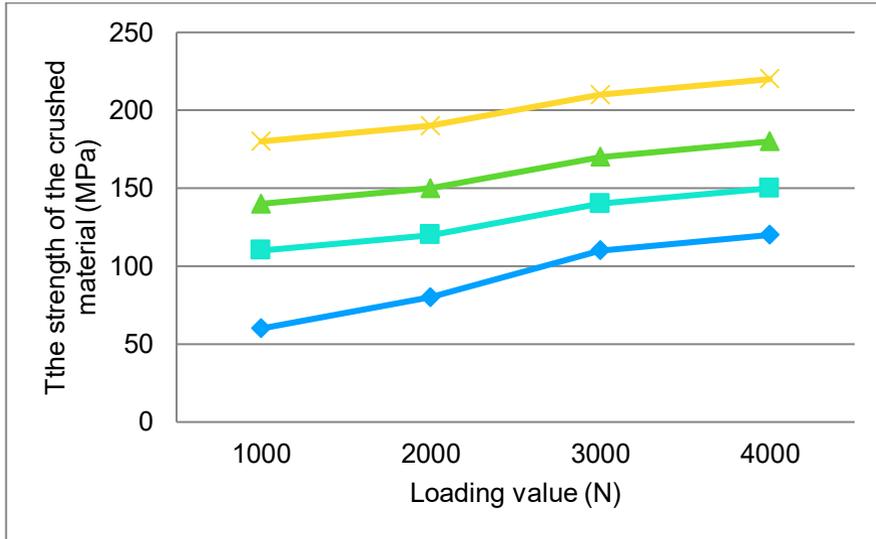
Fig. 9. Dependence of the contour rational loading value on the strength of the crushed material

The experimental model of the mill passed production tests, which showed that the highest grinding efficiency for sandstone is achieved at a preload of 1600 - 1700 N, for quartz - 1800 - 1900 N, for marble 2000 - 2500 N.

6 Conclusion

The use of non-assured structural mechanisms with special properties in the practice of modern mechanical engineering is an integral development pattern and requires deep scientific substantiation and research, since the entire volume of non-assured structures and possible implementations based on them is many times greater than the assured mechanisms. General principles of classification, substantiated by L.V. Assur and developed in the works of numerous researchers, make it possible to use the accumulated knowledge and experience in solving the issues of systematizing non-assured mechanisms, their analysis and synthesis.

However, for practical application, it seems promising to use ready-made or modular solutions, systematized on the basis of a functional combinatorial-logical (morphological) approach. The approach itself, in particular for the systematization of mechanisms, was used in the works of K. Roth, I.I. Artobolevsky, S.N. Kozhevnikov and other authors. The method has been successfully applied in the works of L.A. Khmara, G.Sh. Khazanovich, Yu.M. Lyashenko, A.S. Nosenko, V.P. Bykov and others in the field of applied developments, in particular for the construction of building functional modules, hoisting-and-transport and mining machines. They formed general approaches and proposed structural, functional and constructive tables of individual modules and variable execution schemes.

New approaches to the structural synthesis of adaptive and indifferent mechanisms, mechanisms with a tense closed loop, mechanisms of variable structure have made it possible to obtain a significant number of fundamentally new technical solutions, in practice to confirm the advantages of non-assured mechanisms, to prove their efficiency and effectiveness.

However, many design issues are still insufficiently studied, which limits their application in engineering. Thus, adaptive mechanisms are very diverse both in their structure and principle of the adaptive connection operation. For the definiteness of the mechanism links movement it is necessary to include such connections in the structural, kinematic and

dynamic analysis, taking into account the possibility of the influence of the working process on the law of motion of the driven links and the possibility of changing the structure of the mechanism itself.

As noted above, adaptive forces can be represented as functions of displacement, speed, time, physical and mechanical properties of the interaction object, or a set of other properties. Existing techniques do not take into account the properties of adaptive elements that ensure the functioning of adaptive links. This question still requires deep research and generalizations. The use of elastic elements in the formation of an adaptive link, the system of substitute links, considered in this article, is apparently the initial stage of such studies.

For technological processes associated with deformation, destruction, change in material properties, the efficiency of the use of toothed (toothed-like) working bodies with a stressed closed kinematic contour has been confirmed. The carried out studies have shown that the efficiency of grinding and pressing is determined by the value of the circuit prestressing, set in accordance with the physical and mechanical properties of the material being processed. Determining the optimal load ranges for various technological processes and requirements for the final product also necessitates additional research.

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