УДК 621.7 doi.org/10.31498/2522-9990262023294135

Manoilov O.V., Kudinova K.V.

MODERN CONCEPTS OF IMPROVING THE TOOL RESISTANCE OF THE TOOL DURING DEVELOPMENT

It has been established that increasing the vibration resistance of cutting processing technological systems is one of the priority areas of intellectual activity in the field of technologies and technical methods of equipping the cutting processing process. It is noted that the level of intensity of self-oscillations of elastic technological systems significantly affects the stability of the tool, the productivity of processing and the quality of the processed surface of products (waviness, roughness, slander, residual stresses). For each technological process, there is a certain optimal level of oscillations, at which the maximum stability of the tool and the high quality of the machined surface are observed. Due to the control of the intensity of self-oscillations, it is possible to achieve a tenfold increase in the stability of the tool, a two- to fivefold increase in productivity and a significant improvement in the operational characteristics and quality of the machined surface. The impact of the design parameters of reamers with variable tooth inclination angles on vibration resistance, methods of improving the construction of reamers with the aim of increasing vibration resistance are analyzed. An improvement of the technological method of manufacturing reamers, which ensures a constant width of the rear surface along the cutting edge, is proposed. The principle of sequential execution of helical teeth with alternating their inclination in the proposed version, compared to their placement with an uneven angular step, provides significant advantages in reducing vibrations during processing, primarily due to the greater universality of distribution to different standard sizes of reamers and suitability for use in a wide range of modes. It was established that the maximum value of the difference in inclination of the teeth is limited by the convergence of two adjacent teeth at the end of the calibration part, depending on the length of the working part of the reamer, as well as the diameter, number and angle of inclination of the reamer teeth. A significant increase - by 1.5-2 times - was noted in the stability and reliability of sweeps with a variable inclination of the teeth.

Keywords: *vibration, reamer, multi-bladed tool, cutting edge, oscillations, disturbance force tooth inclination, hole reaming.*

Problem statement. Among the variety of ways to overcome vibrations when turning holes, the most attractive is the use of tools with reduced vibration activity. The rest of the currently existing methods, despite their originality and technical perfection of their implementation, in most cases have extremely limited versatility in application and require additional resources and time for technical preparation of production. Since most of the reamers used are tools for specialized purposes, the maximum adaptation of their design to specific application conditions justifies the feasibility of this particular method of solving the task of ensuring stable vibration-free operation — due to the concentration of the anti-vibration effect in the tool itself by an appropriate combination of its design and geometric parameters.

Analysis of recent research and publications. The presence of periodic oscillations that accompany the process of metal cutting in all types of processing and have a significant impact on this process has attracted the attention of researchers since the very beginning of the development of the science of metal cutting. Almost all machine vibration studies are based to one degree or another on the classical provisions of the theory of oscillations and stability of motion, elements of the theory of automatic regulation and materials of experimental research of machine tools. It should be noted that although until now there is no consensus on the issue of the occurrence and development of self-oscillations during cutting, the majority of scientific schools and scientists tend to consider the causes of self-oscillations of the elements of the technological system to be caused by not one, but several physical phenomena that can act simultaneously or separately from these phenomena can dominate. It depends on the specific conditions and state of the elastic system of the machine tool - device - tool - part (SID), first of all, the stiffness and damping ability of the system elements, the strength and plasticity of the processed material, the type of processing, cutting modes, etc. [2]. The level of intensity of self-oscillations of elastic technological systems significantly affects the stability of the tool, processing productivity and the quality of the processed surface of products (waviness, roughness, slander, residual stresses). For each technological process, there is a certain optimal level of oscillations, at which the maximum stability of the tool and the high quality of the machined surface are observed. By controlling the level of self-oscillation intensity, it is possible to achieve a tenfold increase in tool stability, a two- to fivefold increase in productivity, and a significant improvement in operational characteristics and the quality of the machined surface [2].

Goal (task) research. Improvement of the technique of designing tools with alternating inclination of the teeth.

Main text. Overview of ways to prevent vibrations during turning machining

To increase the dynamic stability of machining operations, a large number of advanced tools, special devices and equipment have been developed and are currently under development and research. The use of such tools, devices and equipment with increased coefficients η_0 and C allows almost always to change the amplitude of oscillations in the desired direction and to bring it closer to the optimal value of A_{om}, i.e. successfully complete the process of controlling the intensity of self-oscillations and significantly increase productivity, stability of the tool and the quality of the processed surface of the products. Some examples of such tools, devices and equipment are described below.

Increasing the vibration resistance and productivity of metal-cutting tools can be achieved as a result of increasing their rigidity or, with even greater success, increasing their damping capacity.

The damping capacity of the tool can be increased by the so-called constructive damping, i.e. by increasing the resistance in the joints, in the places where the cutting plates are connected to the cutting block and the Block to the tool holder, as well as by active damping, i.e. by introducing special vibration dampening devices into the design of the tools .

The development of tools with active damping is also promising. Active damping is achieved through the use of disturbing devices with an additional energy source. The force of resistance (damping) is proportional to the speed of vibration, so it is advisable to apply an additional force proportional to the speed to the tool to increase the damping.

The intensity of self-oscillations of the technological system can be controlled by tools with adjustable stiffness.

Overview of reamer designs and prospects for improving their designs and use as part of technological systems to increase vibration resistance.

Purpose and types of sweeps . The reamer is designed for making precise holes. Depending on the technological requirements, with the help of reamers, holes can be obtained with an accuracy of 10 to 6 qualities for the roughness of the treated surface Ra = (6.3-0.4). The reamer is used after preliminary processing of the holes with a countersink, boring cutter or drill, it can be used as a finishing or roughing tool. The correct operation of the reamer depends on the design and quality of its manufacture, operating conditions (cutting mode, cooling, size of allowance, quality of sharpening and sharpening of cutting edges).

Domestic manufacturers of cutting tools supply the market with reamers of the following types: cylindrical; conical (for instrumental , boiler (rivet) and other cones); stepped for processing holes of tolerance classes G6, H6, Js6, K6, G7, H7, Js7, K7, M7, N7, P7, E8, U8, F8, H8, D9, E9, F9, H9, H10, H11, as well as complete reamers No. 1...No. 6 for processing holes for proofing. The majority of this assortment consists of reamers made of tool steels, which ensure the stability of the declared accuracy and quality indicators of the processed holes when they are processed with extremely low (6...8 m/min) cutting speeds. Such tools no longer correspond to the current state of metalworking technologies.

Leading foreign manufacturing companies, such as Sandvik Coromant, Kennametal, and Korean, Chinese and Israeli companies Korloy, ZCC, ISCAR, which are widely represented in Ukraine, have recently focused their efforts on the production and saturation of the market with reamers made of hard alloys. The use of reamers with a cutting part made of hard alloys, capable of processing at cutting speeds of more than 200 m/min, allows you to radically increase the productivity of reaming when implementing modern concepts of High Speed Cutting/Multi Task Cutting processing technology [3-8].

As an example, the characteristics of carbide reamers of the CoroReamer 435 series are given [3-8]. CoroReamer 435 is a series of universal high-performance reamers for processing a wide range of materials - steels, cast irons, non-ferrous metals. It provides tight hole tolerances and high surface quality due to the internal alignment of the MOR, the geometry of the cutting edge and the maximum uneven arrangement of the teeth. The maximally uneven arrangement of teeth implies a different angular pitch for all teeth without exception. With this step distribution, none of the teeth is located diametrically opposite the other, thanks to which the reamer forms holes with much smaller deviations from roundness than after processing with reamers of a cross-sectional design (Fig. 1).

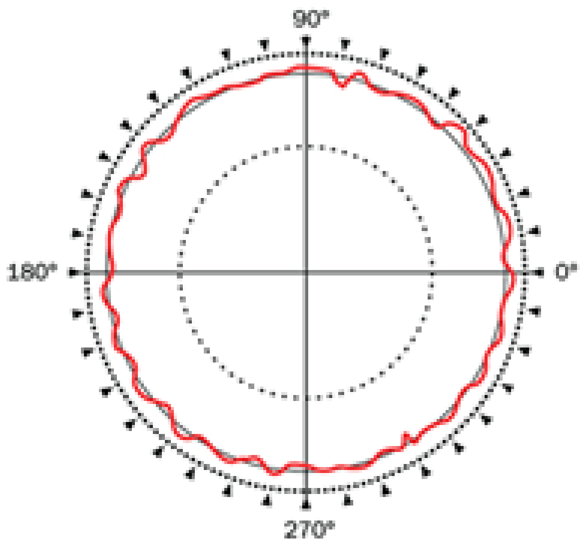

Fig. 1 – Circular pattern of a hole machined with CoroReamer™ 435 Sandvik Coromant reamer [3-8]

In addition to the specified effect, when using reamers with the most uneven angular arrangement of the teeth, a significant reduction in vibrations is observed when processing at high cutting speeds. A characteristic feature of the tools of this series is their adaptability to processing with an internal supply of MOR. The internal supply of MOR is carried out through nozzles (axial for reamers with straight chip grooves and lateral for reamers with helical chip grooves) ensures the supply of MOR exactly to the cutting zone, which contributes to increasing the stability of the tool and the efficiency of chip removal (Fig. 2).

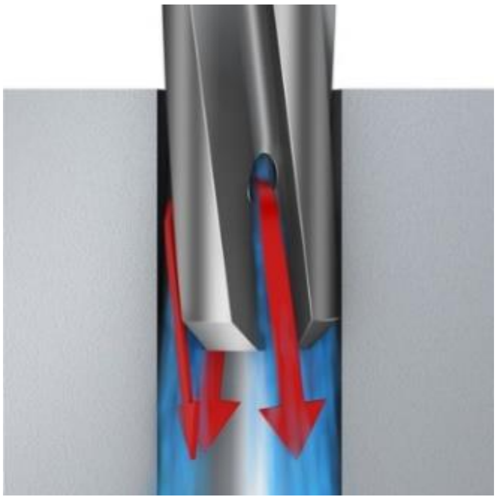

Fig. 2 – Hole machining with CoroReamer™ 435 Sandvik Coromant series reamers [3-8]

The above features make it attractive to use reamers of the considered design in various branches of mechanical engineering, such as general mechanical engineering, processing of molds and stamps, automotive, energy, aerospace industries, etc. [3-8].

Innovative developments of prefab constructions of reamers and modular instrument systems for reaming are gaining some popularity.

According to the design of the replaceable cutting part, assembled reamers are divided into reamers with replaceable heads and reamers with replaceable plates. For examples of similar designs in fig. 3 and 5 show, respectively, Kennametal's RMR™ Reamers, Kennametal's RHM E™ Interchangeable Reamer Modular Tooling System, and Korloy's IRT and IRB Series Prefabricated Adjustable Reamers with Mechanical Interchangeable Inserts.-

Fig. 3 – RHM E™ modular tooling system with interchangeable heads -for Kennametal turning

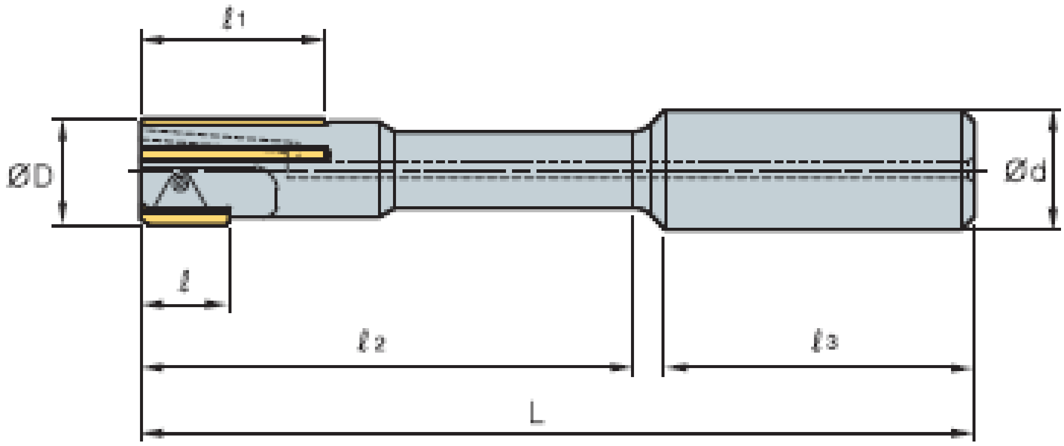

Fig. 4 – Assembled adjustable sweeper of the IRT and IRB series with mechanical attachment of replaceable plates of the company Korloy

Among the original design improvements of the working part of the reamers, it is worth mentioning the design of the so-called "pulling" reamer HBRE of the Korloy company. The main difference of this design is the large inclination of the helical teeth in the left direction — $\omega = 45°$ — uncharacteristic of most scanners. According to the developer, this solution provides a significant increase in the accuracy and quality of processing of through holes with a diameter of 3 mm to 20 mm, favorable conditions for the removal of chips without the involvement of forced removal of its MOR, a more even distribution of the load on the cutting edges and an increase in the stability of the tool. The increased total length of the cutting edges in this case contributes to the improvement of dynamic characteristics and has a positive effect on the vibration resistance of the technological system.

Analysis of the influence of the design parameters of reamers with alternating inclination of helical teeth on vibration resistance and substantiation of the conceptual features of their structure

According to [1], a rational choice of cutting modes and, especially, cutting speed contributes to damping of oscillations during multi-blade processing; optimal sharpening of tool blades; arrangement of teeth, which achieves stability in the system; taking into account the directional characteristics of the oscillating properties of multi-blade tools.

One of the effective ways to reduce vibrations during reaming processing with constructive measures is the implementation of reamer teeth with their arrangement with an uneven angular step. However [1], the use of tools with an uneven tooth pitch is not universal and is largely determined by a combination of certain technological processing conditions and the state of the technological system. The ambiguity of the manifestation of the anti-vibration effect when reaming holes with reamers with different angular steps of the teeth arrangement is clearly manifested in the works of various authors, in which there is a certain discrepancy in the conclusions regarding the optimal values of the difference in the angular steps of the teeth. The use of additional damping elements to reduce vibration in the designs of an axial tool for processing holes is not always advisable primarily due to design limitations and, in addition, leads to its increase in price, a certain decrease in reliability, and an increase in the cost of time and resources for production preparation. Therefore, the improvement of sweeps in this direction can be expedient only under the conditions of sustainable production and under justified serial production.

Vibrations during multi-blade processing have their own specificity due to the fact that several blades are involved in cutting, so the dynamic system of the machine simultaneously receives a significant number of disturbing influences, different in magnitude and direction.

The back reaction of the elastic system is manifested on each individual blade in the form of elastic movements and increases in cutting force. Stability in the system is achieved when the forces of disturbance and damping are equal, the magnitude of which largely depends on the design and current technical condition of the machine tool, the tool, the stiffness of their individual elements and connections, the speed of movement of the elements of the technological system, the degree of damping in them, as well as on the design parameters of the multi-blade tool: shape, size, number and mutual arrangement of teeth, geometric parameters of cutting blades, rigidity of the body of the tool and the frequency of its own oscillations.

To a large extent, dynamic processes in the technological system are influenced by variable technological factors — the mechanical properties of the surface layer of the processed workpiece and the uniformity of their distribution over the processed surface, the uniformity of the allowance to be cut, the actual dimensions of the tool used at the time of use, which in turn are caused by primary technological errors its manufacture, technological errors in the restoration of the tool and its current wear and tear. All of the above factors can be a source of fluctuations, while their ambiguity and randomness of occurrence affect the magnitude and direction of disturbing forces. Reduction of tool vibrations can in principle be achieved by controlling the cutting modes in the machining process when using machines with stepless adjustment with adaptive CNC systems. However, with regard to reaming, as with other types of hole processing with an axial multi-blade tool, this method has not become widespread today due to the complexity of technical implementation and limited application, primarily due to the fact that it allows you to control the magnitude and direction of the vector of disturbing forces.

The use of reamers with alternating inclination of helical teeth allows to increase the vibration resistance of the reaming process due to the large angle of inclination of the teeth ($\omega \approx 30°$) and the difference in the angles of inclination of adjacent teeth. At the same time, the uniform arrangement of the teeth on the end of the reamer (section A—A in fig. 5) ensures the constancy of the section of the sheared layer, which eliminates one of the main causes of the disturbance force, and the large angle of inclination of the teeth increases the damping of the tool from the side of the calibration part (section C— C in fig. 5).

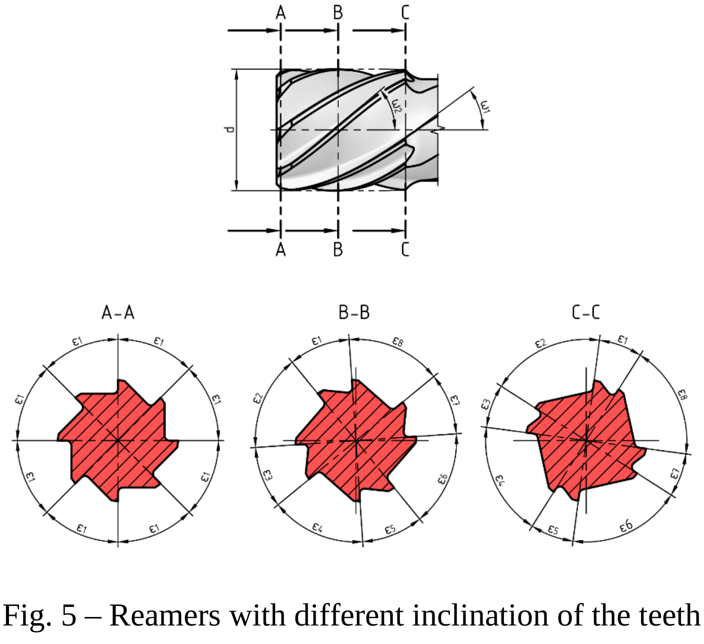

Fig. 5 – Reamers with different inclination of the teeth

The change in the value of the central angle as it moves away from the end of the reamer (sections B—B, C—C in Fig. 5) ensures the manifestation of the effect of the unevenness of the angular steps, which vary from 0° to 6-8°; which is explained by the provision of self-intersection of waves that are formed by teeth with a constant angle of inclination of the teeth and the phase shift of these waves. At the same time, it is noted that the greater the angle of inclination of the sweep teeth, the smaller the difference in the inclination of adjacent teeth ensures vibration-free operation.

The cutting edges of the reamer blades of the considered design are symmetrical curves of different inclinations (ω = 40°± 4°...6°), which provide favorable working conditions for the teeth when the reamer is withdrawn from the treated hole.

It was established that the maximum value of the difference in the inclination of the teeth $\Delta \omega_{max}$ is limited by the convergence of two adjacent teeth at the end of the calibration part depending on the length of the working part of the reamer l_p, as well as the diameter d , the number z and the angle of inclination ω of the reamer teeth.

The limitation of the angle of inclination difference $\Delta \omega$ to no more than 8° can be explained by ensuring the vibration-free operation of reamers at $\Delta \omega \leq 6^\circ$, as well as by reducing the penetration of MOR into the chip grooves when adjacent teeth converge with a large value of $\Delta \omega$ over 8° and the technological difficulties associated with chip groove machining between these teeth.

The principle of sequential execution of helical teeth with alternating their inclination in the proposed version, in comparison with their placement with an uneven angular step, provides significant advantages in terms of reducing vibrations during processing, primarily due to greater versatility in spreading to different standard sizes of reamers and in suitability for use in a wide range of cutting modes.

In this way, the design of the working part of the reamers according to the specified principle allows to significantly reduce the manifestation of the factor of secondary excitation of vibrations in the cutting process. This can be explained by the fact that when cutting with a multi-bladed tool with successive changes in the shape of the cutting edges, the marks on the cutting surfaces from the movements of successively located teeth do not coincide. The intersection of these traces eliminates slipping of the teeth and copying of the contact relief, which occurs when processing tools with different angular steps of the teeth. During reaming, the change in the width of the sheared layer and the length of contact with the machined surface of the calibration areas of the teeth affect the value of the slope difference $\Delta \omega$, namely: the increase in both of these values corresponds to the decrease in the difference in the slope of adjacent reamer teeth.

CONCLUSIONS

In the presented work, the solution to the problem of overcoming vibration during hole reaming was considered. Modern concepts of the development of metalworking technologies provide for an increase in the efficiency of the use of cutting tools primarily due to an increase in processing productivity with a significant increase in cutting modes. Under the conditions of growth of speed and power characteristics of cutting processing, the occurrence of vibrations very often turns out to be a restraining factor, which in production conditions forces to impose regime restrictions on processing processes and not to fully use the potential capabilities of the available tools and equipment. Therefore, increasing the vibration resistance of cutting processing technological systems is one of the priority directions of intellectual activity in the field of technologies and technical means of equipping cutting processing processes.

It is proposed to improve the methodology of designing tools with alternating inclination of the teeth, namely: the methodology of verifiable geometric calculations of such tools has been clarified and the technological method of their manufacture has been improved, which ensures a constant width along the cutting edge of the back surface of the reamer teeth of this design. A significant increase - up to 1.5-2 times - in the stability and reliability of sweeps with alternating inclination of the teeth was revealed.

List of sources used

1. А. С. 348309 СССР. МКИ Е23F 21/16. Червячная фреза.
2. *Жарков, И. Г.* Вибрации при обработке лезвийным инструментом / *И. Г. Жарков*. - Л. : Машиностроение. Ленингр. отд-ние, 1986. — 184 с.: ил.
3. https://www.sandvik.coromant.com/ru-ru/pages/default.aspx?country=ru
4. https://www.kennametal.com/ru/ru/home.html
5. https://www.iscar.com.ua/Products.aspx/countryid/46/ProductId/67
6. http://www.korloy.com/ru/main/main.do
7. https://www.walter-tools.com/ru-ru/tools/standard_products/holemaking/overview/reaming/Pages/default.aspx
8. https://www.widia.com/ru/ru/products/holemaking/reaming-tools.html
9. *Кудинов, В. А.* Динамика станков / *В. А. Кудинов*. – М. : Машиностроение, 1967. - 359 с. - Для инженерно-технических работников машиностроительных заводов и научно-исследовательских институтов.
10. *Кудинов, В. А.* Поузловой анализ динамических характеристик упругой системы станка / *В. А. Кудинов, В. М. Чуприна* // Станки и инструмент. - 1989.- № 11. - С. 8-11.
11. *Крепак, А. С.* Анализ результатов исследований при работе инструментами пониженной виброактивности / *А. С. Крепак, С. А. Крепак* // Университетская наука - 2007 : в 2 т. : тез. докл. междунар. науч.-техн. конф. (Мариуполь, 2007 г.) / ГВУЗ «ПГТУ». – Мариуполь, 2007. – Т. 2. – С. 28-29.

Манойлов О.В., Кудінова К.М.

СУЧАСНІ КОНЦЕПЦІЇ ПІДВИЩЕННЯ СТІЙКОСТІ ІНСТРУМЕНТУ ПІД ЧАС РОЗРОБКИ

Встановлено, що підвищення вібростійкості технологічних систем обробки різанням є одним із пріоритетних напрямів інтелектуальної діяльності в галузі технологій і технічних прийомів оснащення процесу обробки різанням. Відзначено, що рівень інтенсивності автоколивань пружних технологічних систем істотно впливає на стійкість інструменту, продуктивність обробки та якість обробленої поверхні виробів (хвилястість, шорсткість, наклепи, залишкові напруги). Для кожного технологічного процесу існує певний оптимальний рівень коливань, при якому спостерігається максимальна стабільність інструменту і висока якість обробленої поверхні. Завдяки регулюванню інтенсивності автоколивань вдається досягти десятикратного підвищення стійкості інструменту, 2-5-кратного підвищення продуктивності та значного поліпшення експлуатаційних характеристик і якості обробленої поверхні. Проаналізовано вплив конструктивних параметрів розгорток зі змінними кутами нахилу зуба на вібростійкість, методи вдосконалення конструкції розгорток з метою підвищення вібростійкості. Запропоновано удосконалення технологічного способу виготовлення розгорток, що забезпечує постійну ширину тильної поверхні по ріжучій кромці. Принцип послідовного виконання гвинтових зубів із змінним їх нахилом у пропонованому варіанті порівняно з розміщенням їх з нерівномірним кутовим кроком дає значні переваги у зниженні вібрацій під час обробки, насамперед за рахунок більшої універсальності розподілу на різні типорозміри розгорток. і придатність для використання в широкому діапазоні режимів. Встановлено, що максимальне значення різниці нахилу зубів обмежується зближенням двох сусідніх зубів у кінці калібрувальної частини в залежності від довжини робочої частини розгортки, а також діаметра, кількість і кут нахилу зубів розгортки.

Значне підвищення - в 1,5-2 рази - відзначено стійкості і надійності розгорток зі змінним нахилом зубів.

Ключові слова: *вібрація, розгортка, багатолезовий інструмент, ріжуча кромка, коливання, сила збурення нахил зуба, розсвердлювання отвору.*

Стаття надійшла 15.09.2023 р.

УДК 621.873.11 **doi.org/10.31498/2522-9990262023294136**

Суглобов В.В., Крупко В.Г., Крупко І.В.

ОБГРУНТУВАННЯ КОНСТРУКЦІЙ ПРИВОДІВ З ХВИЛЬОВИМИ ЛАНЦЮГОВИМИ ПЕРЕДАЧАМИ

У роботі розглянуто застосування сучасних будівельних, дорожніх, підйомно - транспортних, землерийних і інших типів машин, які відносяться до технологічних, у відбудові зруйнованих війною інфраструктури, промислових, цивільних будівель, шляхів і інших об'єктів Ефективна робота наведених машин в значній мірі залежить від конструкцій робочих органів їх виконавчих механізмів та одного із основних складових елементів технічних систем, а саме приводів та передатних механізмів. Передатні механізми забезпечують необхідний режим роботи, задані параметри і закони руху робочих органів,, або інших кінцевих елементів машин. У роботі наведено приклади удосконалення конструкцій приводів на основі сучасних досліджень механічних передач, пошуку нових фізичних ефектів, що дозволять підвищити ефективність застосування машин, зменшити енергетичні затрати на виконання технологічних операцій.

Запропоновано застосування приводів з нерівномірним «пульсуючим» рухом виконавчого органу, що забезпечує хвильова ланцюгова передача. Виконання провідного елементу ланцюгової передачі, що служить для підвісу та повороту барабана, у вигляді двох нерухомих зірок, забезпечених розміщеним між ними водилом з двома котками, забезпечує, автоматичний покроковий круговий рух барабана тільки за рахунок принципу дії механічної передачі «водило - нерухомі зірочки - барабан». Замість барабана може бути застосовано кінцевий ведений елемент (наприклад ківш, роторне колесо, стрічка конвеєра та інші робочі органи). Нерухомі зірочки гарантують зупинку багаторядного ланцюга, а отже, і механізму підйому вантажу в цілому, у момент зупинки електродвигуна, або при раптовому руйнуванні з'єднувальної муфти, що забезпечує безпеку роботи обладнання. При цьому, обертання водила з роликами з постійною кутовою швидкістю, забезпечує пульсуючу кутову швидкість обертання зірочки, а зміна кількості та геометричних параметрів складових елементів передачі дозволить досягти заданого закону руху кінцевих елементів виконавчих механізмів.

Ключові слова: *хвильові ланцюгові передачі, пульсуючий рух виконавчого органу, конструкції приводів процесів, забезпечення заданих законів руху кінцевих елементів обладнання*

Постановка проблеми. В сучасному господарському комплексі України значна увага буде приділятися технологічним процесам, пов'язаних з відбудовою зруйнованих війною інфраструктури , промислових, цивільних будівель, шляхів і інших об'єктів Названі процеси потребують застосування сучасних будівельних, дорожніх, підйомно - транспортних, землерийних і інших типів машин,які можна віднести до технологічних[1]. Ефективна робота наведених машин в значній мірі залежить від конструкцій робочих органів їх виконавчих механізмів та одного із основних складових елементів технічних систем, а саме приводів та