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PROCESSING OF HARDENED CYLINDRICAL GEAR WHEELS OF THE CUTTING GEARBOX OF THE COMBINE UKD 200-500

Abstract. *The article discusses the latest developments of unique technological methods of gear milling of cylindrical gears for preliminary blade gear processing of hardened cylindrical gears of the cutting reducer of the UKD200-500 coal mining harvester for the final gear grinding of gear teeth with modulus m = 16 mm, with hardness HRC 56 ... 62. The peculiarity of the design of special hob cutters is that a circle passing through the lower boundary points of the involute is used as the palloid of the machine gearing of the tool and part. Pre-cutting the teeth of hardened wheels with carbide milling cutters allows you to remove the main allowance for the final gear grinding.*

Keywords: *hardened wheels; preliminary blade gear machining; high-speed gear hobbing; technological methods.*

1. INTRODUCTION

Increasing the efficiency of industrial production is largely associated with the development of mining equipment, transport, energy systems of machines, the drives of which contain large-scale gear drives (m = 12 ... 30mm). The bearing capacity of gearwheels in terms of contact strength increases with the surface hardness of the teeth. Increasing the hardness of the surface of the teeth from HRC32 to HRC62 makes it possible to halve the dimensions of the gearbox and reduce the mass by 3 times.

The high requirements for reliability and strength are presented to the cylindrical gearwheels of the cutting reducer of the UKD200-500 combine harvester. However, the high labor intensity of manufacturing cemented hardened coarse-modular gears due to significant allowances assigned for gear grinding operations to eliminate defects after heat treatment, the possibility of burns and micro cracks that contribute to the formation of macro cracks and chipping of teeth requires a scientific approach in solving problems of processing hardened gears. A unique technology for the manufacture of hardened coarse-modular gears of a high degree of accuracy with preliminary cutting of teeth for carburizing and hardening with subsequent removal of the main allowance to 95% with a special blade tool and final gear grinding with a minimum allowance of 5% has been proposed.

2. PURPOSE AND OBJECTIVES

For processing coarse-modular gears with high wear resistance of the teeth, with high strength properties of the surface layer, it is advisable to study the technological directions of processing hardened coarse-modular gears to ensure the necessary parameters of surface roughness, gear hobbing quality with the achievement of high productivity, accuracy and quality of gear processing of hardened coarse-modular gears, due to improvement of technology and kinematics of gear milling, development of instrumental and technological equipment, which will ensure the predicted quality of the surface layer of the teeth and the performance properties of the gears. To achieve this goal, the following research objectives have been identified:

– to analyze and establish the main directions of increasing the productivity and quality of gear processing of hardened large-modular gear wheels in the conditions of small-scale production;

- to substantiate the application of technological methods of gear processing:

- to formulate the criteria for choosing the structure and parameters of the systems for blade processing of hardened coarse-modular gears in order to ensure the specified operational properties.

3. MATERIALS AND METHODS

Unique technological methods of preliminary blade gear processing of hardened spur gears of coal miners' reducers provide for preliminary blade gear cutting to remove the main allowance of 95%, followed by gear grinding when removing the final allowance of 5% gear wheels with modulus m = 16 mm, , with hardness HRC 56... 62. The complex of scientific research works with the development of original technological processes, prospective constructions of worm carbide cutters, special technological equipment was made. Technological regulations have been developed and implemented for the high-speed gear hobbing with blade carbide cutters with a final clean slash operation by applying effective grinding technologies.

The special worm cutters have been developed for pre-processing of cylindrical gears for grinding, in which a circle (Fig. 1) which passing through the lower boundary points of involutes B and B1 is used as a palloid of machine gearing of the tool and part. In this case, the active sections of the BE and B1E1 engagement lines are located symmetrically with respect to the axial perpendicular and at some distance from it [1, 4, 5, 6].

The angle of the teeth profile of a special cutter α_K depends on the number of teeth of the machined wheel Z_k and is determined by:

$$\alpha_{\kappa} = \alpha_{B} - \sigma_{B}, \tag{1}$$

Where α_B – is the pressure angle at the lowest point B of the involute; σ_B - is the half of the angle thickness of the tooth at the lower boundary points B and B 1 of the involute.

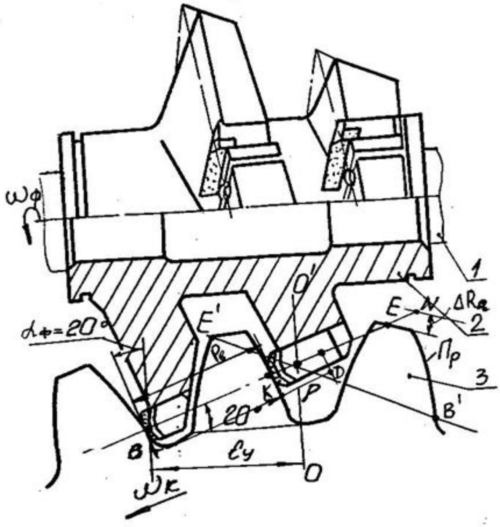

Figure 1 – Scheme of machine engagement of a special carbide cutter with a machined wheel

In the range of cut gear teeth $Z_к = 20...400$, the profile angle of the teeth of special cutters varies within the range of $\alpha_K=5^0$-19^0

Each mill can cut the teeth of the wheel in a certain range of teeth numbers: $Z_K = 33$-49, $Z_K = 46...66$, $Z_K = 60...88$, $Z_K = 88...134$, $Z_K = 134...204$

Technological installation of cutters is achieved by turning one cutter body relative to the other at a certain calculated angle and changing the thickness of the distance ring placed between the bodies. Several keyways are made in each of the cutter bodies.

Figure 2 shows the dependence of the profile angle of the teeth of a special cutter α_k on the number of teeth of the machined wheels Z_K and the displacement coefficient of the original contour of the gear rack X, as well as the range of teeth to be cut [3, 7, 9, 11].

The area of application of the cutters is illustrated in Figure 3. Uncorrected gearwheels with 33 ... 49 teeth could be cut with a milling cutter with a profile angle $\alpha_K = 9^0$ and setting the cutter bodies with a turn at an angle θ

$$\theta = 2z_K \beta_K,$$

where Z_K – is the number of teeth of the cut wheel;

$$\beta_K = \alpha_K - \alpha'_K,$$

where α'_K – is determined from the graph (Fig. 2)

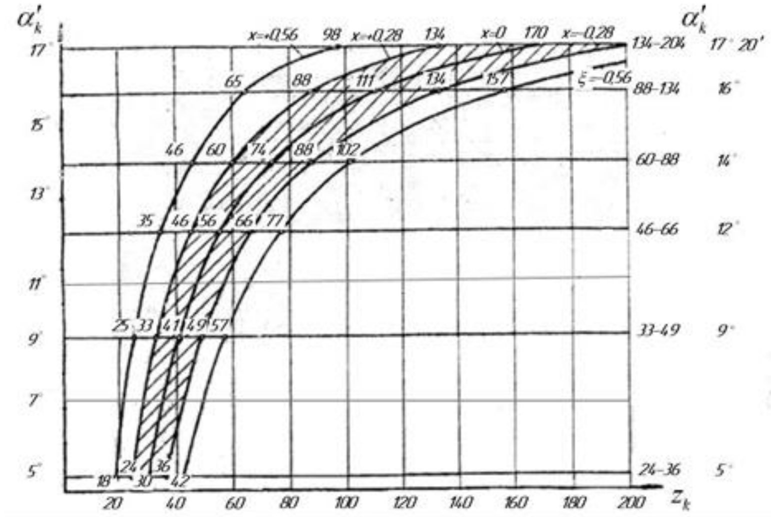

Figure 2 – A Graph for determining the applicability
of special carbide milling cutters

For corrected wheels, the range of numbers of teeth to be cut increases: at X = +0,56, using a cutter with $\alpha_K = 9^0$, gear wheels with 25 teeth are cut, and at X = –0,56, gear wheels with 57 teeth are cut

Technological installation of cutters is achieved by turning one cutter hulls relative to the other by a certain design angle (Fig. 3) and changing the thickness of the distance ring *Δ*, inserted between the cutters hulls. In each of the cutter hulls, several keyways are made [8, 10, 13, 15, 22].

Mills with a given angle $\alpha_к$ can be used for cutting wheels with a different number of teeth, if the axis of the tooth of the wheel deviates from the axis of the machine (Fig. 3) at an angle $\beta_к$ and $S_ф$ - the distance between the bodies is recalculated. With positive $\beta_к$, the right cutter body turns clockwise relative to the left one by the angle θ. With negative $\beta_к$ - the right cutter body turns counterclockwise and in this position both bodies are fixed to the mandrel.

The rotation of the cutter bodies by an angle θ is carried out by aligning the corresponding keyways in the bodies.

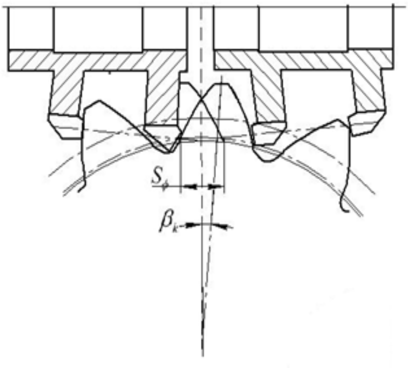

Figure 3 – Installing and adjusting the cutter when turning the wheel at an angle $\beta к$

While being installed on the machine, the bodies of the cutters, which are on the mandrel, are aligned with the first teeth in one plane and set at a distance $S_ф$ determined by the conical template (Figure 3, a). The inner distance between the ends of both cutter bodies is measured and a distance ring is selected from it. Then the cutter bodies are installed on the corresponding keyways and fixed on the mandrel. A milling cutter with a mandrel is installed in the machine support with subsequent adjustment relative to the axis of the wheel tooth.

The advantage of the considered design of special hob cutters considered is that both bodies simultaneously treat both lateral surfaces of the wheel teeth. The cutting forces from both bodies are directed towards each other, i.e. there is a force closure inside the tool. This helps to reduce vibrations and oscillations of the machine table together with the processed wheel.

The most rational area of using the considered special mills is the serial and large-scale production of gear wheels, for example, used in coal and ore mills, excavators, rolling mills, lifting mechanisms [1, 12, 14, 17, 20, 21].

Figure 4 shows a special hob cutter m =12 mm. The cutter consists of 2 bodies, separated by a distal ring with tapered threads of one direction.

The development and modeling of the technological process of shaping using universal m = 16 mm single-sided and double-sided cutting mills (Fig. 4) equipped with alloy plates ВК10-ОМ; ВК10-ХОМ. Single-sided cutters (Fig. 4) consist of two bodies: left and right with conical screw threading of turns of the same direction. On the lateral surfaces of the turns in the tangential grooves, hard-alloy non-overlapping rotary plates made of alloys are installed ВК10-ОМ; ВК10- ХОМ with dimensions 20x16x6 mm, which are fixed in the sockets with eccentric screws.

Carbide cutting elements are placed only along the lines of machine engagement of the tool and the workpiece, which makes such a milling cutter more economical in comparison with known designs of similar tools.

The fundamental difference between cutters in comparison with well-known foreign designs (coarse-modular cutters of the company "Azumi", Japan, the company "Fete", [15, 16, 18, 19]) is that with an increased in 1.5-2 times the amount of its teeth over the length of one cutting turn, the above dimensions of the cutting carbide plates are the same for the entire used range of modules m = 16 mm and this, for the first time, a constructive solution reduces the consumption of hard alloy in the manufacture of the tool by 2-5 times, but most importantly, the cutting process is significantly improved with increasing the durability of cutting inserts.

The tangential arrangement of carbide cutting inserts with wear-resistant coatings also contributes to the increase in tool life.

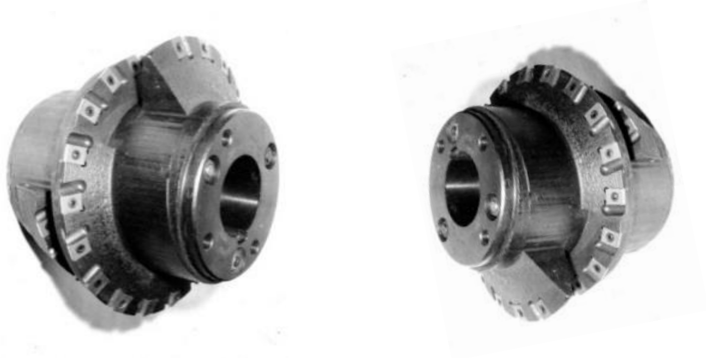

Figure 4 – Special worm-and-carbide double-body cutter
m=16 mm, ($a_u=9^0$; $Z_к$=19…57)

The technological disadvantage of special carbide milling cutters is the impossibility of processing gear wheels with the same tool, which differ significantly from each other in the number of teeth [15]. Meanwhile, in the practice of heavy engineering, gears are widely used, including a small-toothed gear, for exampl, $z_к$=12÷40 and a multi-toothed wheel, for example $z_к$=180÷316. These are gear drives of coal and ore grinding mills, excavators, etc.

When processing such wheels with different worm cutters, the identity of the main pitch and the profile of the teeth will not be ensured, which will undoubtedly affect the quality of the engagement and the durability of the gear transmission. Of particular importance for the quality of the engagement is the machining of a mating pair of hardened (HRC56…62) gearwheels with the same tool, the operational running-in of which is practically excluded.

In order to improve the accuracy of engagement of mating, predominantly hardened, gears with a different number of teeth, and to reduce the range of tools used, the design of universal coarse-modular solid carbide hob mills m=10-65 mm has been developed. The pitch circle of the wheel is used as the palloid of the machine gearing of such cutters with the machined wheel, and the profile angle of the tool teeth is equal to $\alpha_и = 20^0$.

The two-body design of single-sided cutters is designed to process wheel teeth in two passes. The milling cutter (Fig. 5) consists of a left 1 and right 2 bodies with a conical screw thread in one direction, in the grooves of which are installed hard-alloy non-overlapping rotary plates.

According to the gear processing technology developed for this design [1, 2], each of the cutter bodies is installed separately on the gear hobbing mandrel with an offset relative to the center perpendicular $00^/$ tool-part pair by a distance l_y (Fig. 5, a, b), determined point B ($B^/$) of intersection of the circle of the lower boundary point of the involute of the teeth and the line of machine gearing BE ($B^/$ $E^/$). The setting distance does not depend on the number of teeth of the wheel being machined. The value l_y (Figure 5) is determined by the profiled angle of the initial contour of the rack α 0, the tooth base height h_f and the radius of curvature of the tool head for the preliminary tooth cutting $r_Ф$. These parameters only depend on the modulus and the offset ratio of the original toothed rack contour.

The installation distance is determined by the formula:

$$l_y = \frac{h_f - xm - r_ф(1 - sin\alpha_0)}{tg\alpha_0}, \qquad (2)$$

where x – is the coefficient of displacement of the original contour of the gear rack; m is the module of the teeth of the wheel.

For the wheels with toothed rack source circuit in accordance with GOST 13755-81, where $\alpha_o = 20^0$, $h = 1{,}25 \cdot m$ and $r_Ф. = 0{,}3 \cdot m$, the formula (2.10) is simplified:

$$l_y = \frac{m*(1.052 - x)}{0.36397}. \qquad (3)$$

Thus, by alternately installing each of the bodies with an offset on the gear-cutting mandrel, one cutter can process gears with any number of teeth in two passes. The displacement of the cutter body from the center perpendicular to the calculated distance l_y is carried out by using a special template installed in the machine center finder, which is located on the milling head in the axis of rotation of the machine table.

For convenience of practical definition, Figure 6 shows a graph of the dependence of the installation distance l_y on the modulus of the cut teeth of the wheel and the displacement coefficient of the original contour of the gear rack - x. With the values of the displacement coefficient of the original contour x>1.0, the value of the installation distance l_y, calculated according to (2) and (3), may turn out to be negative. It means that the tool must be moved on the machine during installation, so that, the very first tooth with the largest radius of rotation would not intersect the center perpendicular when displaced.

In practice, setting the tool to the calculated distance l_y does not require high accuracy and can be performed either by using a special template or by using a ruler mounted on the machine support.

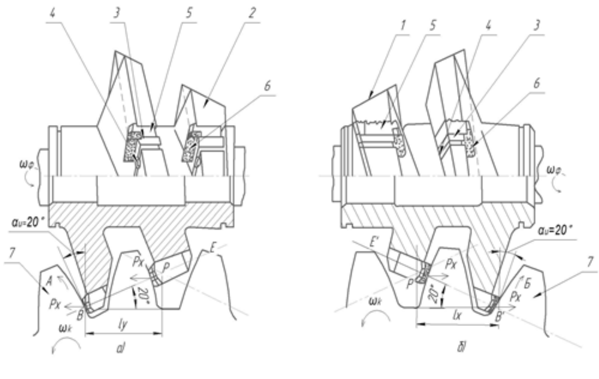

Figure 5 – Two-body, one-sided universal cutter:
a – is the right body; *б* – is the left body
(1 – a tapered thread of the left body; 2 – a tapered thread of the right body;
3 – a pressure plate; 4 – a split slot; 5 – a cutting plate; 6 – an adjustable pin)

The analysis of cutting patterns and kinematics of gear processing with universal double-body cutters [1, 5, 9] shows that when the right-hand housing is in operation (Fig. 5, a), the axial cutting forces P_x coincide with the direction of rotation of the machined wheel ωк (with the direction of rotation of the indexing worm wheel of the machine), and the stock removal proceeds sequentially from the base of the tooth to the top of the same tooth (arrow B).

If the directions of action P_x and ωк coincide, the axial force tends to "separate" the teeth of the pitch worm wheel from the turns of the pitch worm, and this can lead to the disruption in the smooth operation of the pitch worm pair of the machine, vibrations of the processed wheel and decrease in the quality of the processing.

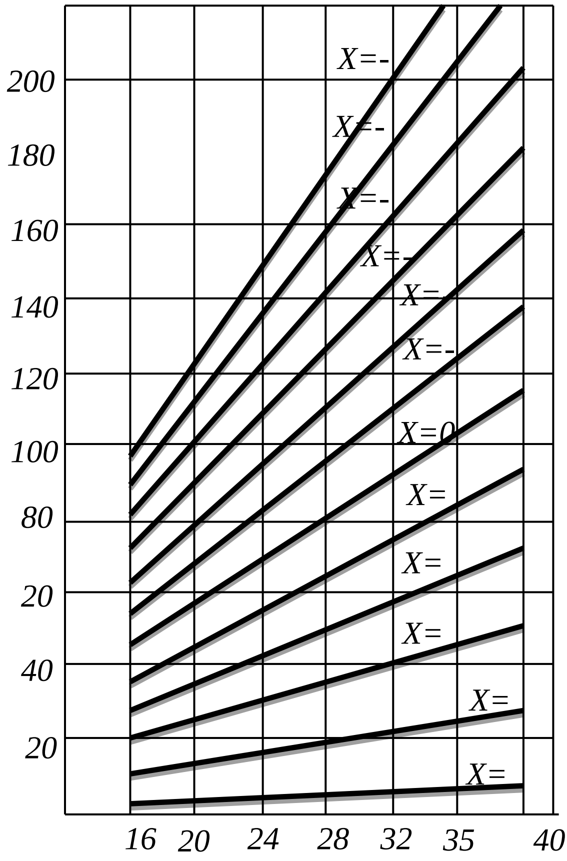

Figure 6 – Graph for determining the installation distance l_y

While removing the allowance in the direction of arrow B (Fig. 5, b), the width of the layers (cut by the teeth of the left housing) is still 2 - 2.5 times greater than that of the teeth of the right housing [1, 4, 7, 9], even it does not exceed the nominal length of the cutting edge of 20 mm.

4. RESULTS AND DISCUSSION

In order to ensure the same processing conditions in terms of cutting dynamics and according to the stock cutting pattern, the cutter bodies can be made with screw threads in different directions. For example: the left-hand cutter body (Fig. 7) has a right-hand screw thread, and the right-hand cutter body has a left-hand thread. In this case, during machining, the axial components of the cutting force are directed towards the rotation of the wheel $\omega_к$, and the stock removal, carried out by both bodies, goes in the same direction along arrow A - from the base of the tooth to the apex.

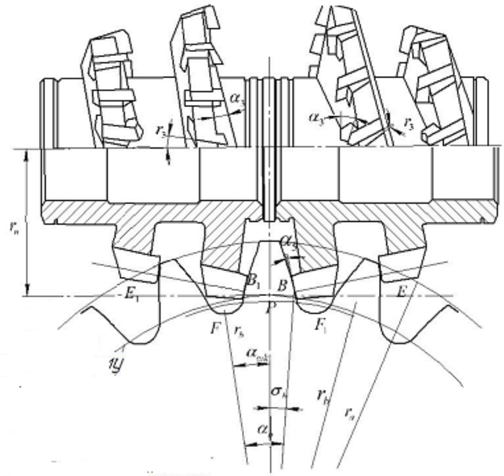

Figure 7 – A scheme of machining the wheel with cutter bodies with different directions of turns

In order to increase the efficiency of using the tool, the processing of both lateral surfaces of the teeth of the wheel could be carried out with only one (either right or left cutter hull), for example, the right cutter body, alternately shifting it to the left and right on the gear-cutting mandrel. In this case (Fig. 8), while processing the left side surfaces, it is necessary to reverse the direction of rotation of the tool $\omega_ф$ and the wheel $\omega_к$ and this processing would be carried out with the accompanying milling [2, 10, 14, 15, 21].

Figure 9 shows a preliminary gear grinding blade processing of the hardened gear wheel m=16 mm; z_k=20; b=155 mm, steel 20Х2Н4А-Ш, HRC≥55 in the production conditions at the gear shop of the factory "Svet Shahtyora". The gear hobbing process is carried out with a carbide-tipped hob cutters (Fig. 10) without using the lubricating liquids. The direction of milling is reversed. The cutting conditions for processing hardened teeth are: the depth of the cut t=0.5-0.8 mm per passage; the cutter feed S=1.5-3 mm/rev; the cutter speed: n=40-60 min^{-1}; the cutting speed V=1.0-1.2 m/s.

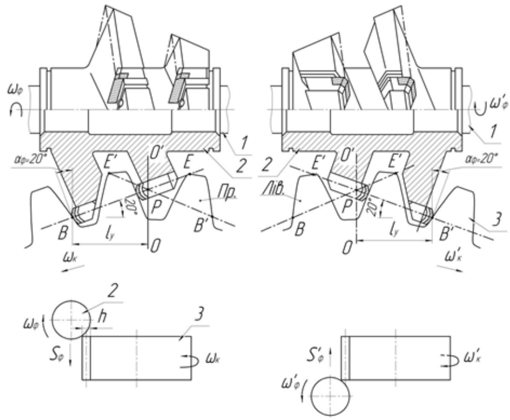

Figure 8 – A scheme of processing wheel teeth with one right-hand cutter body:
a, *c* –is a right - hand body during counter milling; *б*, *d* – is the right body during passing milling with a reversible direction of rotation of the cutter and the gear which is being cut

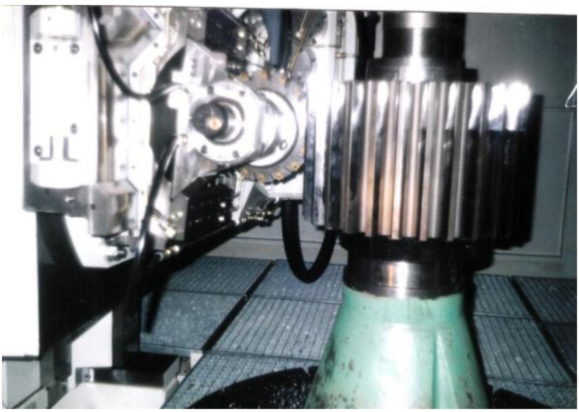

Figure 9 – The pre-treatment with a gear blade for a hardened gear wheel
m=16mm; z=20; β = 0º; b=155 mm; steel 20Х2Н4А-Ш, HRC56…62 at the gear shop
of the factory "Svet Shahtyora"

The time of the machine to remove the preliminary allowance for the gear grinding is 35 min. The maximum wear out of the individual cutter teeth, after the specified continuous running time, did not exceed 0.15 mm.

SUMMARY

The use of the developed technological methods of preliminary blade processing of the teeth of hardened wheels with carbide milling cutters makes it possible to reduce the labor intensity of low-performance gear grinding operations, depending on the wheel module, by 3-4 times due to the removal of the main allowance for gear grinding by the method of high-speed gear milling with a special blade tool, in which the allowance is removed according to the line of engagement and does not require the manufacture of the cutting part of the cutter along the height of the entire tooth.

The peculiarity of the design of special hob cutters is that a circle passing through the lower boundary points of the involute is used as the palloid of the machine gearing of the tool and part.

Carbide cutting elements are placed only along the lines of machine engagement of the tool and the workpiece, which makes such a milling cutter more economical in comparison with known designs of similar tools. In order to improve the accuracy of engagement of mating gears with a different number of teeth, and to reduce the range of tools used, the design of universal large-module solid carbide hob cutters m = 16mm has been developed.

A certain cutting section of the cutter tooth is involved in cutting, which ensures economical use of cutting inserts, simplifies the design of cutters, and increases the reliability of the cutting process of hardened cylindrical gears.

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ОБРОБКА ЗАГАРТОВАНИХ ЦИЛІНДРИЧНИХ ЗУБЧАСТИХ КОЛІС РЕДУКТОРА РІЗАННЯ КОМБАЙНА УКД 200-500

Анотація. *У статті розглянуті останні розробки унікальних технологічних прийомів зубофрезерування циліндричних зубчастих коліс для попередньої лезової зубообробки загартованих циліндричних зубчастих коліс редуктора різання вугледобувного комбайна УКД200-500 для остаточного зубошліфування зубів зубчастих коліс з модулем 16. Для швидкісної лезової зубообробки розроблено, виготовлено та впроваджено в виробництво перспективні конструкції черв'ячних твердосплавних фрез. Для експлуатації кожного з конструктивних рішень твердосплавних черв'ячних фрез розроблені технологічні регламенти лезової зубообробки. Розроблено конструкцію спеціальної двокорпусної черв'ячної фрези двостороннього різання. Особливість проектування спеціальних черв'ячних фрез полягає в тому, що як палоїда верстатного зачеплення інструменту і деталі використовується коло, що проходить через нижні граничні точки евольвенти. Твердосплавні різальні елементи розміщені тільки по лініях верстатного зачеплення інструменту та заготовки, що робить таку фрезу економічнішою порівняно з відомими конструкціями аналогічних інструментів. З метою підвищення точності зачеплення сполучних, зубчастих коліс з різним числом зубів, і скорочення номенклатури інструменту розроблена конструкція універсальних великомодульних твердосплавних черв'ячних фрез m=16мм. Застосування розроблених технологічних прийомів попередньої лезової обробки зубів загартованих коліс твердосплавними фрезами дозволяє знизити трудомісткість малопродуктивних зубошліфувальних операцій, залежно від модуля коліс, у 3-4 рази за рахунок зменшення припуску з 1,5-2,5 мм на бік зуба до 0,3 -0,5 мм, а також дозволяє забезпечити економічність процесу зубообробки за рахунок зменшення витрат твердосплавних пластин.*

Ключові слова*: технологічні прийоми; крупномодульні циліндричні загартовані зубчасті колеса; швидкісна лезова зубообробка*.