Сучасний стан наукових досліджень та технологій в промисловості. 2018. № 1 (3) *ISSN 2522-9818 (print)*
ISSN 2524-2296 (online)

UDC 621.923 DOI: https://doi.org/10.30837/2522-9818.2018.3.059

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OPTIMIZING THE TECHNOLOGY OF RECONDITIONING LARGE HIGH PRECISION GEAR RIMS

The **subject** matter of the research is issues related to the optimization of the technology for reconditioning large-size high precision gear rims of the drives of mining complexes, mine lifting equipment, heavy vehicles; these issues are a perspective trend for reducing the cost of reconditioning and operation of expensive unique equipment. The **goal** is to ensure intensifying production processes, increasing workloads and speeds, reducing the deterioration of high precision gear rims. The **objective** is to develop a new technology to optimize reconditioning large high precision gear rims. To achieve this, the following **method** is suggested – to machine gear rims after they have been surfaced by pre-milling with special hob cutters with a prominence and by final machining the teeth with special cutters equipped with hardmetal inserts that process teeth along the line of engagement, which does not require making full-length cutting teeth and increases the quality of machining, the durability of hardmetal milling cutters. The process of reconditioning of large high precision gear rims is a resource-saving technology, as compared with manufacturing new parts, this technology considerably reduces the cost of materials for manufacturing, decreases a number of process steps, reduces the cost of machining equipment, tools, cutting and measuring instruments. The smooth operation of a gear train can be ensured only at a constant gear ratio but due to manufacturing and operational errors, the gear ratio is not constant at every time, which intensify the deterioration of large high precision gear rims. The following **results** are obtained. The possibility and practicability of using hob cutters with a prominence (m = 20-28 mm) while rough cutting the worn and reconditioned large gear rims was proved. To obtain the necessary durability of rough milling cutters, it is recommended that the prominence angle be set within 8-10°. The use of hardmetal hob cutters for finishing makes it possible to increase the performance rate by 2 to 3 times as compared to high-speed cutters of other designs and to obtain the necessary quality and precision of manufacturing worn and reconditioned large gear rims. **Conclusions.** The technology for the optimization of reconditioning large high precision gear rims with the use of special and universal hardmetal single- and double-flute cutters that have both re-sharpened cutting elements and disposable rotary tools was developed and introduced.

Keywords: new optimization technology, reconditioning large gear rims, high precision, hob cutters with a protuberance, special cutters, machining tooth along the line of engagement, improving the quality of machining.

Introduction

The performance of mining complexes, mine lifting equipment, heavy vehicles is gradually getting worse due to the deterioration of their equipment in the process of operation. Among them, there are large high precision gear rims. Such large gears can have failures and malfunctions that are fixed in the course of various types of reconditioning and repairing activities. To ensure high-quality recovery, a new technology for the optimization of reconditioning large high precision gear rims is suggested.

The service life of fast-wearing large gear trains determines the prove-in performance of expensive machines. Stopping equipment to replace worn large gear trains with new ones leads to a significant decrease in labour productivity, disrupts the rhythm of the production process, causes non-productive metal costs to manufacture new parts and results in the need for special maintenance teams.

Analysis of literary sources and problem statement

Modern trends in intensifying of production processes, increasing workloads, speeds, temperatures lead to faster deterioration of parts, and along with the need for production automation, give points to the problem of increasing the service life of quickly deteriorated machine parts [1, 4, 7, 9], so most of the parts that are connected with other parts wear out fast. This process results in material damage when the material scales off the solid surface and its friction strain accumulates. These phenomena lead to a gradual change in the size and shape of a part. The techniques for reconditioning the parts and joint connections are resource-saving, as compared to the manufacture of new parts, the costs for materials in manufacturing are significantly reduced, a number of technological operations is decreased, the costs for machine tools, devices, cutting and measuring equipment as well as for labour remuneration of workers are reduced [2, 3, 5, 10]. A part that has toothed surfaces is known to be under cyclic and dynamic loads while operating, which leads to the damage of working surfaces. The smooth operation of the gear train can be ensured only at a constant gear ratio but due to manufacturing and operation errors, for example, the deformation of teeth, the gear ratio does not remain constant at every time [6, 8, 11]. Moreover, dynamic loads or interference generate an additional negative impact. The deformation of gear wheels, as well as manufacturing errors lead to uneven distribution of the load across the width of the gear rim.

When the worn-out teeth are repaired by surfacing, the worn side of each tooth is surfaced when the gear wheels are of a large diameter (up to 15 m) and a module is of more than 10 mm. High wear resistance and durability of the faced surfaces of teeth can be ensured by using the alloys of sormite and stalinite types. A thin coat of sormite is spread on the surface firstly faced with a filler material and roughed up (fig. 1). After surfacing with sormite, the teeth are firstly milled with special hob cutters with a prominence and finally machined with special cutters with hardmetal inserts [1, 2, 3].

a) b)

Fig. 1. Worn large gear wheels: a) a worn cylindrical gear wheel; b) a worn cylindrical gear wheel surfacing

When operating large cylindrical gear trains, the following types of tooth fracture occur: fatigue spalling of the teeth working surfaces, chipping of the teeth, deterioration, binding of teeth, crushing of the teeth working surfaces. Fatigue spalling of the teeth working surfaces which usually occurs near the operating pitch circle on a tooth root fillet is the main type of destruction of enclosed gears. The cause is variable contact pressures on the surface of the teeth σH; these stresses cause primary cracks, extending cracks, chipping, shelling, slivering of metal from the tooth surface (fig. 2) [7]. A crack at the tooth root often causes chips which results in the increase in the contact pressure and the disruption in the tooth gearing [4, 5, 6, 7, 12]. Surface layers in open gears abrade before fatigue cracks appear in them, so spalling happens very rarely.

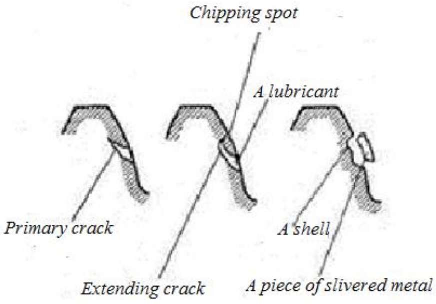
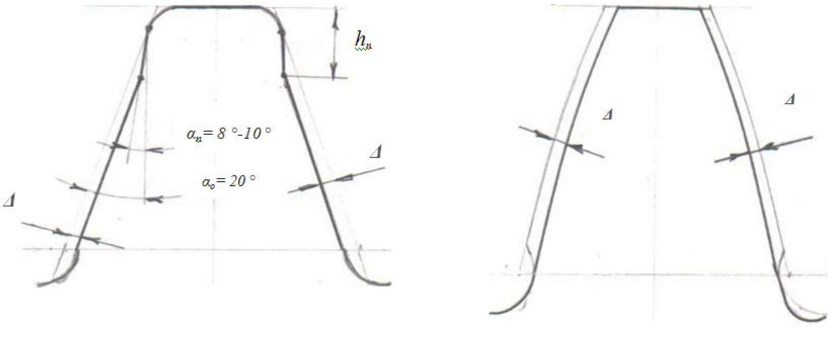


Fig. 2. Fracturing on the involute flank of the teeth of large gear rims

The goal and objectives of the research

The goal and objectives of the research are to ensure intensifying production processes, increasing workloads, speeds, reducing the deterioration of high precision gear rims and developing a new technology to optimize the recovery of large high precision gear rims. To achieve this, a method for machining teeth after surfacing by pre-milling with special hob cutters with a protuberance and by final machining the teeth with special cutters equipped with hardmetal inserts that machine teeth along the line of engagement, which does not require that cutting teeth of milling cutters be manufactured along the full length and which significantly improves the quality of machining, increases the durability of hardmetal milling cutters. A new technology for reconditioning large high precision cylindrical gears is suggested, where primary rough milling cutters with a modified face of a tooth with a prominence are used at the stage of pre-machining of the wheel teeth for strengthening and final speedy edge cutting machining of the tooth [7, 8].

For this purpose, the tip of a milling cutter (fig. 3, a) has a tooth angle that differs from the standard one which is αo= 20° near the tooth tip and the tooth thickness is reduced by the allowance amount Δ which is necessary for further final machining (fig.1, b).



(a) (b)

Fig. 3. Wheel teeth precutting: *a* – a tooth of hob cutter with a prominence; *b* – a wheel tooth machined with Δ allowance: h_n – the prominence height, a_0 – the angle of original profile, a_n – the angle of prominence profile

The required allowance Δ is left on the wheel teeth flanks after machining by this milling cutter (fig. 3, b), while teeth inverts are machined adequately. The fact that the tips of a finishing tool, for example, tips of a grinding wheel, do not participate in cutting the inverts improves the process of cutting. Radial forces of cutting are reduced, vibration and springing of a tool decrease and, subsequently, its durability increases as well as the quality of the machined teeth.

The drawback of milling cutters with a prominence is the lowered angle (α3= 1,5°-2°) on the tooth flank due to relieving work.

The developed technique of pre-machining on the teeth of a large module (m =20- 25 mm) was successfully tested for the first time while gear cutting the worn bur reconditioned large gear rim with the following dimensions – Da=8058,4mm, m =28 mm; zk= 284; β0= 6°25'; bz=1000mm, produced of 35ХМЛ steel; 220-260 HB; the precision rate is 8-В GOST1643-81, which is used in the ore-pulverizing mill (fig. 4) of МБ 90х30 model.

Gear hobbing was dome by a special heavy vertical gear hobbing machine of КУ-306 model (fig. 5) with the diameter of the operating face plate equal to 8000mm. The fast-cutting hob cutter “Progress” was used for rough teeth cutting [7, 8, 9]. This cutter has an elongated starting taper (lk=350 mm) and an expanded tool bore – ф100Н7. According to the diagram given in fig. 1(a), a prominence is made on the teeth of a milling cutter (fig. 4); the teeth have complete profile heightwise. There are chip control flutes on the teeth of the starting taper, which enables separating box chips, i.e. escaping the space-limited cutting. This improves the tool durability.

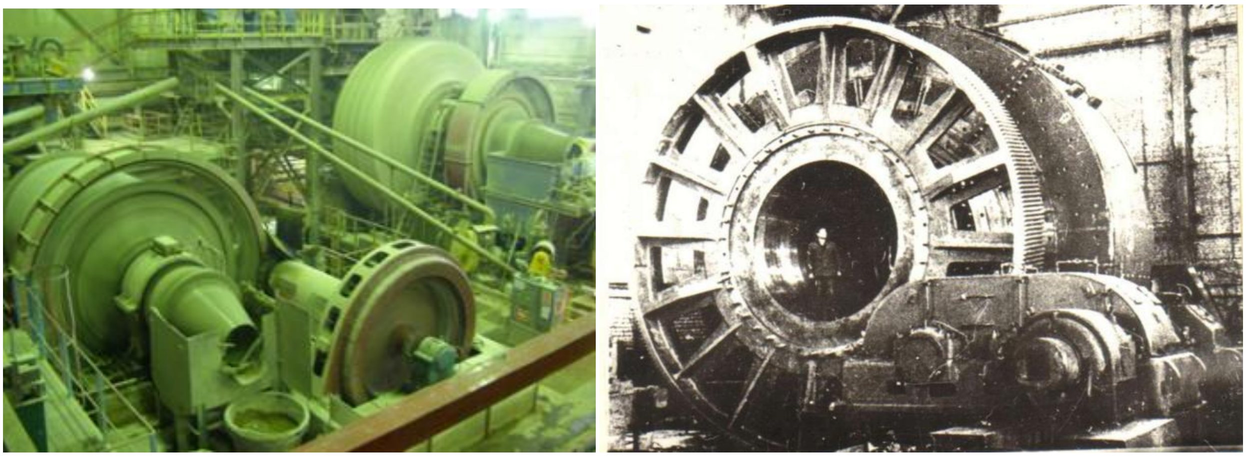


Fig. 4. The general view of the ore-pulverizing mill of МБ 90х30 model with the reconditioned gear rim with the following dimensions m = 28 mm; z_k = 284, D_a = 8058,4 mm

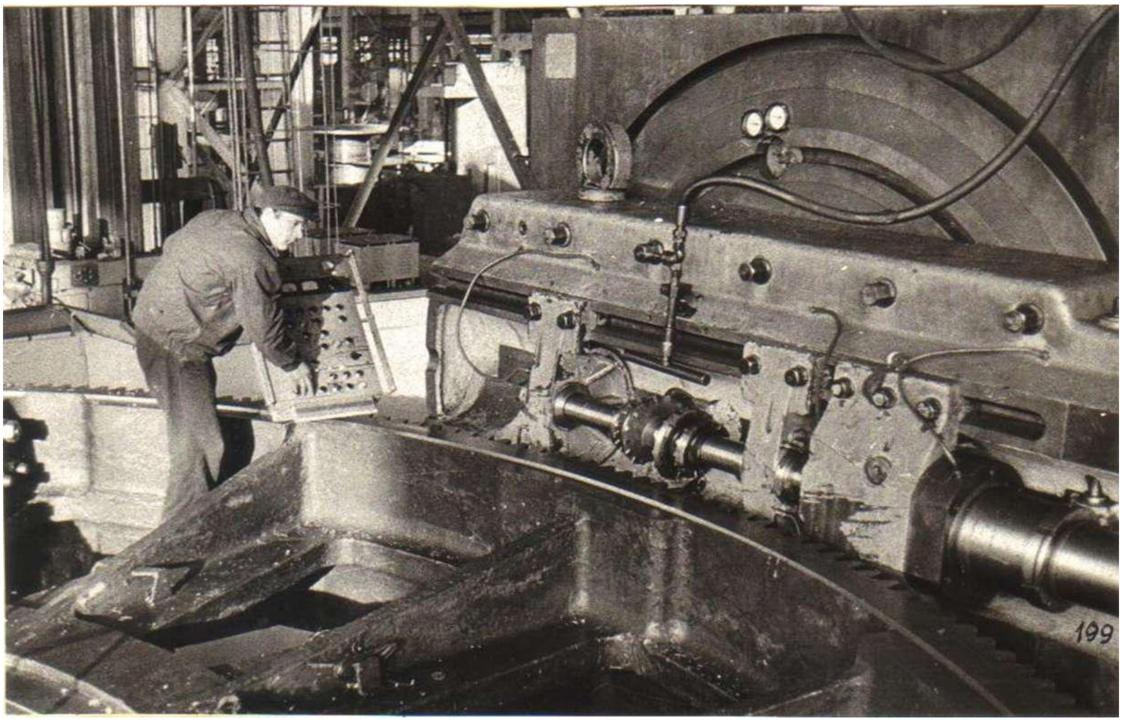


Fig. 5. Finish cutting the worn and reconditioned large gear rim (m= 28; z_k =284) with the use of the gear hobbing machine of КУ-306 model

The rough cutting modes were as follows: cutter feed Sf=2,5 mm/r; rotary velocity nf= 0,2 sec-1; the cutting direction is counter, metal cutting oil is “Industrial-20”. The machining time of rim cutting in one operation was 110 hours.

For reference: the time for machining this rim by other cutters, for example, by the “Frezer” plant is 350 hours.

The special hob cutter m= 28 (fig. 6) was used for teeth finish machining in one operation, this cutter has hardmetal inserts made of ВК 10-ХОМ alloy [7, 9, 10].

The cutting direction was counter, the cutting modes – $t = 0{,}6$ mm, $S_f = 3{,}86$ mm/r; $n_f = 0{,}33$ sec-1.

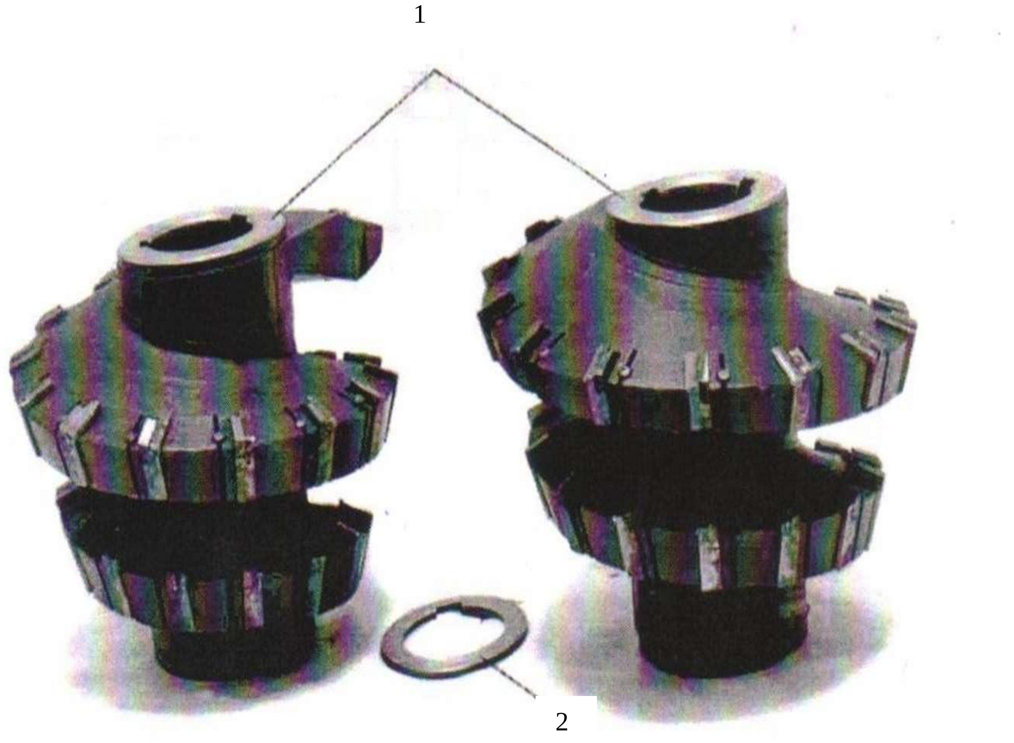


Fig. 6. Special double hob cutter for two-way cutting (m= 28 mm); αf=19°20'
1- cutter housing; 2 - distance ring

The machining time for finishing the rim was 65 hours. The maximum wear of the individual teeth of the milling cutter after this continuous working time did not exceed 0.3 mm, which is 4-5 times less than in the case of similar machining with high-speed cutters. The fact that the difference in the thickness of the teeth of the machined rim at the upper and lower ends (l3 = 1000 mm) did not exceed 0.06 mm indicates the high durability of the cutter. The measurement of the precision parameters of the cut teeth with attachable devices showed that the gear corresponds to the 8th degree of precision in accordance with GOST 1643-81 in the context of the deviation of the circumferential pitch of the teeth and the pitch of the engagement.

Materials and methods of the research

The technique of rough and finishing teeth machining after the teeth (fig. 5) of large rims were reconditioned by rough cutters “Progress” with a prominence and a hardmetal finishing cutters (fig. 6) of a special design was introduced at PrAT “NKMZ”.

The vertical gear hobbing machine of HHA-750A model manufactured by the firm “Shibaura” (Japan) (fig. 7) was used for machining by counter milling with the use of metal cutting oil is “Industrial-20”. The rim with the following parameters m = 20 mm; Zk = 268; βz= 5°15'; b= 700 mm; 35L steel; 140-160 HB was finished in one operation under the following modes of cutting – t=0,9 mm; Sf= 4,72 mm/r; nf= 0,5 sec-1; Vr.=32m/min.

The machining time for finishing one rim is 24 hours, which is by 1.8 times less than while machining by a high-speed cutter (fig. 8) (STP 4-15-70).

Fig. 9 shows chips cut during finishing of teeth with a high-speed cutter without rough cutting by a cutter with a prominence. Most of the teeth of a finishing milling cutter cut the box chips; there is the space-limited cutting. In this case, the perimeter of the chips is approximately equal to half the perimeter of the wheel tooth which is 45-48 mm when the tooth module m = 20 mm. The tips of the individual teeth of the milling cutter cut thickened chips from the bottom of the tooth groove (fig. 9, the upright row), which raises the radial cutting forces and leads to vibrations and springing of the tool, increases the wear of the teeth (fig. 10).

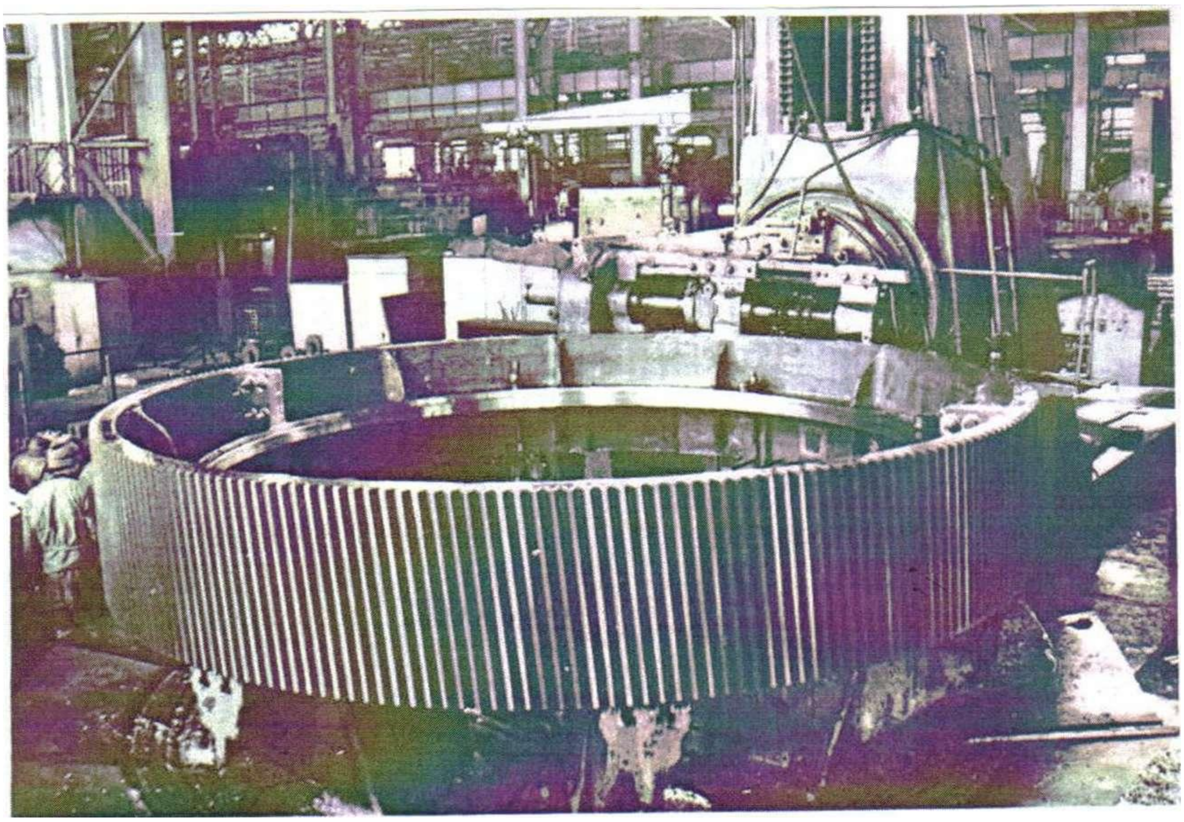


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Fig. 7. Finish cutting the rim teeth (т=20 mm; Zк=268; βz= 5°15'; b=700mm; 140... 160 HB) using the machine of HHA-750 model (Japan)

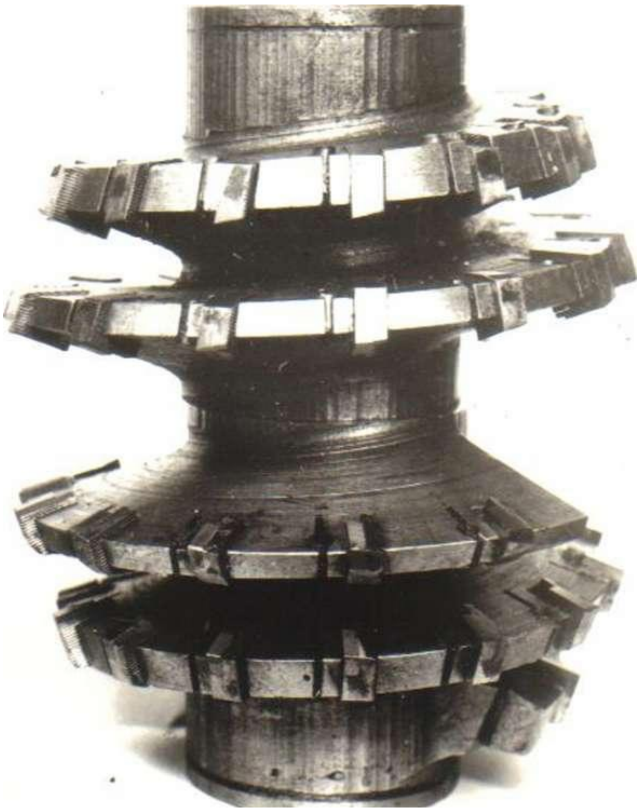


Fig. 8. Finishing hardmetal hob cutter (т=20 mm)

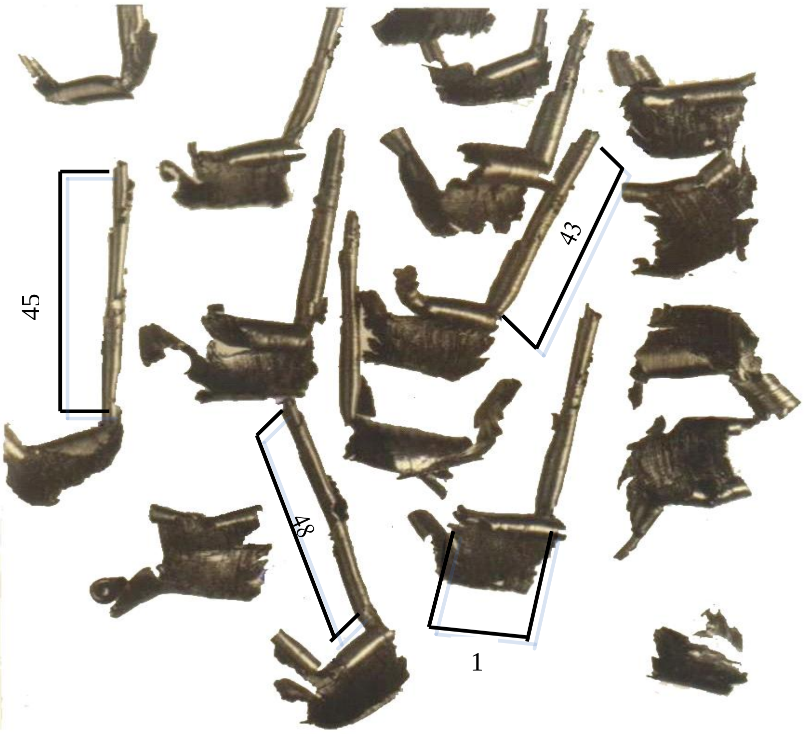


Fig. 9. Chips cut by the finishing cutter (т=20 mm) without teeth cutting by a cutter with a prominence

Fig. 10. Increased wear of the teeth of a finishing high-speed cutter of a pre-fabricated welded design

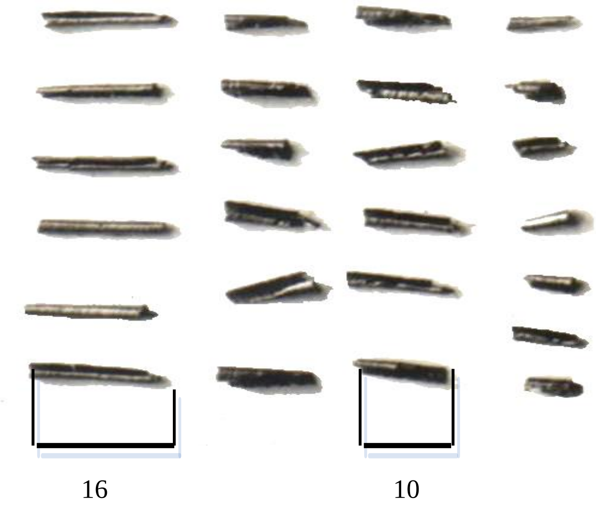


Fig. 11. Chips cut by a hardmetal finishing cutter (т=20 mm)

Fig. 11 shows chips cut by a hardmetal finishing cutter (fig. 8). There are no box chips and the length of the chips does not exceed 10-16 mm while the length of the tooth cutting edge of the milling cutter is 20 mm. The length of the teeth cutting edge of the teeth in the developed designs of milling cutters does not exceed 20 mm and is the same for the modules with m = 12-65 mm. In this case, a number of teeth of the cutter is by1.5-2 times greater than the milling cutters of other designs have.

Chips (fig. 11) are compactly twisted, and their backside is shiny, which indicates a free cutting process, minor efforts and deformations in the SPEED system.

Hardmetal hob cutters with m = 12 - 65 mm (fig. 12) that have disposable rotary tools made of ВК 10-ХОМ alloy were designed to improve the milling cutter.

Fig. 12. The right housing of a special hardmetal milling cutter with m=20 mm that has hardmetal disposal rotary tools made of the ВК 10-ХОМ alloy

Under the factory conditions at the PrAT “NKMZ”, hardmetal hob cutters with disposable rotary tools were designed and calculated by modelling and a solid model was obtained on SOLID WORKS programme. The control programme was further developed for machining grooves for inserts that are tangentially placed using a numerically controlled machine tool manufactured by the firm “Ferrari” (Italy). The machining time for cutting the grooves of a cutter housing isTmach= 16-20 hours.

Finishing the teeth of the worn and conditioned large gear rims can be further intensified by increasing the lobe configuration of hob cutters.

While gear machining, long-pitch multi-thread hob cutters (m> 12) of the standard design were not spread due to manufacturing complexity, a comparatively small number of cutting teeth and so on (fig. 13).

The designs of double-flute hardmetal hob cutters suggested in this work allow them to be used for machining the worn and conditioned large gear rims with the tooth module with m = 12-40 mm.

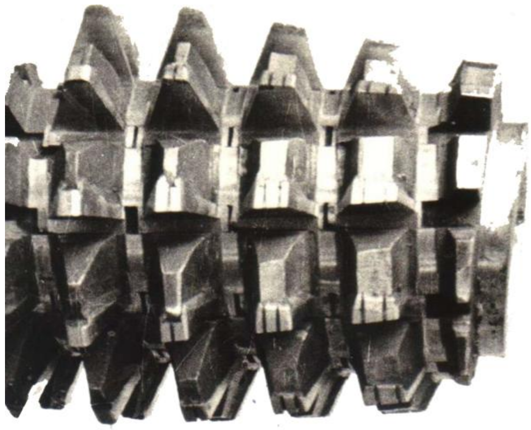
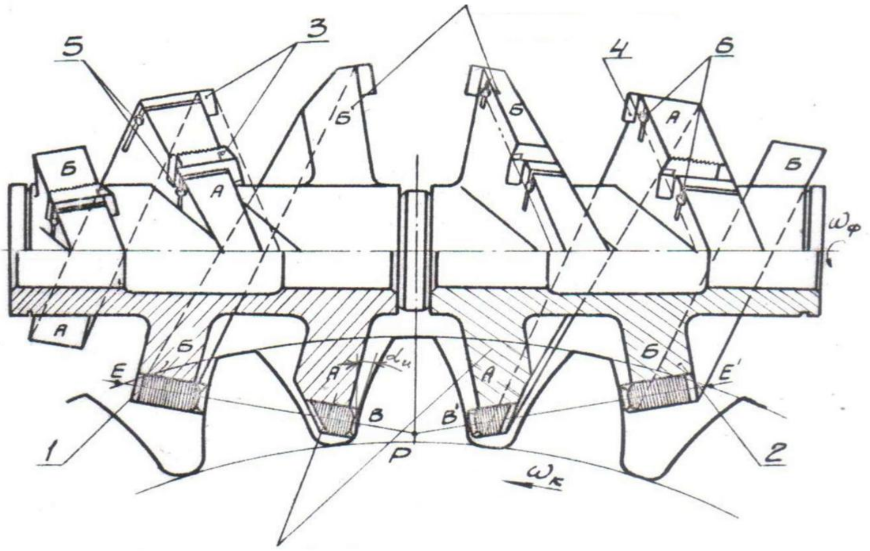


Fig. 13. A rough hob cutter with m=28 mm “Progress” with a prominence and a chip control flute on the teeth of the starting taper

Two milling cutters are designed – special double and universal single ones [7, 11, 12]. A distinctive feature of a special double-cased cutter is the displacement of first A flutes (fig. 14) from the starts of the second B flutes by the angle Q = 180°. The angle of teeth profile of this milling cutter depends on a number of teeth of the machined wheel (α_n=5°19°30') and the ranges of its usability are determined like special single flute cutters [3].



the start of the second flute

the start of the first flute

Fig. 14. The basic design of a double-cased special double-flute cutter (α_u =5° – 19°30')

The first flute of the cutter (1) (fig. 14) machines the right flank of the wheel teeth along the active patch BE of the machine line of engagement BE, while the second flute (2) machines the left flank of the teeth along the patch *B'E'*. The taper angle of the flutes screw thread equals to the machine angle of engagement of the "tool-workpiece" pair, in the instant case – $\alpha_n = 20^\circ$. Fig. 14 shows that the bottom boundary points *B* and *B1* of the teeth involute flanks are machined at the moment when a tooth of a wheel placed on the interaxial perpendicular shift to the right or to the left by β_k angle. Consequently, basing on the kinematics of the coupling of a tool and a workpiece, the start points of cutter flutes (fig. 14) should be shifted by θ_z angle.

Let us determine the angles β_k and θ_z :

$$\beta_k = \sigma_b - (\gamma_2 - \mu_y) = \sigma_b - \left(\frac{360^0}{z_k} - \mu_y \right), \tag{1}$$

where μ_y is the angle that corresponds to the setup distance ly (fig. 14).

$$\mu_y = \arcsin \frac{ly}{r_b}, \tag{2}$$

where r_b is the radius of the basic circumference of the wheel teeth.

Basing on the kinematics of the machine engagement of the double-flute cutter, the angle θ_z is determined according to the dependence:

$$\theta_z = \beta_k z_k = (\sigma_b - \frac{360^0}{z_k} + \mu_k) z_k \,. \tag{3}$$

Like angles σ_b , γ_2 , μ_k , the angle θ_k depends only on a number of teeth z_k of the machined wheel. Angle ranges within a number of teeth z_k = 30–200 are presented in table 1.

Table 1. *Changes of the angle of shift of* θ_z *flutes*

Zk	30	60	100	150	200
Θz	104039'	103039'	103025'	103019'	103014'

Table 1 shows that when a number of the wheel teeth z_k increases, the angle θ_z decreases. The angle θ_z within z_k = 30–200 changes insufficiently and equals to $1^0$25' only. Therefore, it is sufficient to make a cutter with the angle of flutes shift θ_k =104039' and this cutter can machine the wheels of the whole range of teeth.

The cutter provides the most qualitative machining if a number of teeth of the cut wheel is not divisible by a number of the cutter flutes, i.e. by two. Only in this case, each cutter flute cuts all slots of the wheel teeth and both involute flanks of the teeth can be machined completely and identically.

The results of the research

When a wheel is machined by a milling cutter with a number of teeth that is divisible by two, only a half of the wheel teeth can be fully machined in one operation. Therefore, after the first operation of the tool, the wheel should be rotated by one angular pitch of the teeth and one more operation should be performed.

The design parameters of hob cutters, especially multi-flute ones, significantly affect the quality and precision of machining gears. In this regard, such parameters as faceting and waviness of the working involute flanks of the teeth are considered. Both the studied above designs of double-flute cutters and single-flute standard cutters of known designs ensure the same faceting and waviness on the wheel teeth flanks. 0.6–0.8 rotation of each flute is engaged in profiling the involute flank of the wheel teeth by double-flute milling cutters, while in the context of single-flute cutters 1.2 – 1.8 rotation are needed; however, the suggested double-flute cutters have a number of teeth placed along the rotation circuit that is twice as much.

The amount of calculated or geometrical waviness on the processed surface of the wheel teeth is calculated by a set of design parameters of the cutter and a workpiece that is machined, that is by the profile angle of the cutter, its dimensions, the helix angle of the wheel teeth and so on. To determine the magnitude of the geometric waviness, the equation of the path of the tooth cutting edge point of a hob double-flute cutter in relative motion can be used. The waviness parameter h_c on the machined surface of the wheel teeth can be determined by the coordinate of the point of intersection of the two projections of the cutter tooth path that are shifted relative to one another by the amount of the tool feed S. The initial dependence for determining the wave height h_b is:

$$h_b = 2r_k \cos(\beta - \frac{\gamma_b}{2}) \sin\frac{\gamma_b}{z_k} - r_f \sin\gamma_b \sin\beta_y , \qquad (4)$$

where r_k is the radius of the rotation of a wheel tooth point adjacent to the corresponding point of the cutter tooth; r_f is the radius of the rotation of the target point on the cutter tooth; β is the central angle corresponding to the distance from the machine axis to the target points of the pair "tool – workpiece"; γ is the target angle of the wave formation; βy is the angle of bringing a cutter in the machine support into operation position.

The equation (4) is used for calculating the amount of waviness in case of machining the wheel by a single-flute hob cutter under the standard pattern of cutting and by a double-flute sinlge-casing cutter, the basic design parameters are given in Table 2.

Table 2. *Hob cutters specifications*

Parameter name	Parameter meanings	
	Single-flute standard (STP 48-15-70)	Double-flute sinlge-casing
outer diameter *D*, mm	295	295
a number of teeth at the length of one thread turn z_f	10	18
the angle of the teeth profile α_u	200	200
the angle of the turn gradient τ	4046'	9028'40"
the radius of the cutter tooth rotation that produces waviness at the tip of the wheel tooth r_f, mm	104,24	103,19

The calculations were carried out under the same tool feed rate *S* = 4 mm/rev and while machining spur gears with the module *m* = 20 mm and a number of teeth z_k = 40 and z_k = 200. The calculated amounts of waviness are obtained at the tips of the wheel teeth, i.e. in the places where the waviness is of the largest amount. The results of calculations are presented in Table. 3.

Table 3. *Calculating the amounts of waviness height* h_b

Cutter design	H_b, mcm	
	$Z_k = 40$	Z_k =200
Single-flute standard	35	27
Double-flute one-cased	70	58

The data from table 3 show that a double-flute cutter produces waviness on a machined surface that is twice as large as the waviness formed by a standard single-flute cutter. This happens due to the greater curvature of the trajectory of the motion of its teeth while machining. The waviness does not exceed the allowance for the wheel teeth profile within 8-9 degrees of precision according to GOST 1643-81, which is quite acceptable for pre-processing before subsequent gear grinding or other types of finishing.

The waviness in case of finishing milling limits the tool feed rate and, consequently, the performance rate. The suggested designs of double-flute milling cutters should be efficiently used for preliminary edge cutting machining the hardened wheels for subsequent gear grinding. While pre-machining, the tool feed rate is not limited by waviness of the machined surface but by the physical and mechanical properties of the material of the cutting part of the milling cutter and of the material of the wheel being machined which have a decisive impact on the durability of the tool.

The discussion of the results

The previously described universal designs of hardmetal cutters can be profiled according to the considered technique on the basis of the involute hob. The need for such profiling arises both while the final edge cutting machining of hardened wheels in order to reduce noise and increase the smoothness of the transmission operation and with preliminary edge cutting machining of the teeth for subsequent tooth grinding. The abrasive tool coupled with a workpiece in a machine reproduces a theoretically exact involute on the gear grinding machine. The approximation of the profile of the wheel teeth to the theoretical involute already at the stage of preliminary edge cutting machining enables significant reducing the time for low-performance gear grinding of a worn and reconditioned large gear rim.

The universal double-flute cutter (fig. 15) has the standard angle of teeth profile α_n =20°. Its screw addendums of the case are conical and placed opposite to one another and the start points of the addendums have an angular shift within the teeth being machined Z_k =30-300 equal to Zoffset.= 104°0' [7, 9].

Both suggested designs of double-flute milling cutters ensure the most qualitative machining in case if a number of teeth of the cut wheel is not divisible by a number of cutter flutes, i.e. by two. Only in this case, each flute of the milling cutter participates in shaping all the slots of the wheel teeth and complete and identical machining of both lateral involute tooth flanks will be achieved.

While milling a wheel with a number of teeth divisible by two, only a half of the wheel teeth can be completely machined in one operation. Therefore, the wheel should be rotated by one angular teeth pitch after the first operation of the tool and one more operation should be performed.

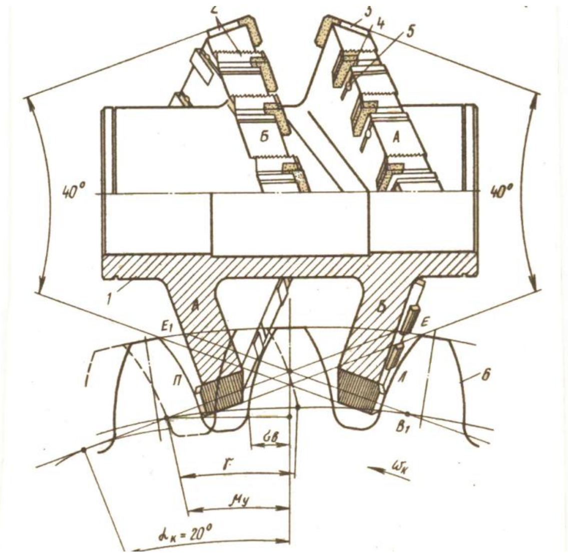


Fig. 15. The basic design of a sinlge-casing double-flute cutter

The design parameters of hob cutters, especially multi-flute ones, significantly affect the quality and precision of machining worn and reconditioned large gear rims. At the same time, such parameters as faceting and waviness of the working involute surface of the teeth are considered [1, 9, 12].

For the efficient use of the technology for reconditioning large high precision gear rims, heavy hobbing machines with a mechatronic control system should be re-engineered to ensure cutting speeds of up to 3-5 m / s.

Conclusions

Industrial confirmation of the possibility and expediency of using hob cutter with a prominence (m = 20–28 mm) while rough cutting of worn and reconditioned large gear rims were proved industrially. To obtain the required durability of roughing milling cutters, it is recommended that the angle of the prominence profile be set at 8 ° – 10 °.

The use of hardmetal hob cutters for finishing enables increasing the performance rate by 2 to 3 times in comparison with high-speed cutters of other designs and makes it possible obtain the required quality and precision of manufacturing worn and reconditioned large gear rims.

The technology of optimization of reconditioning large high-precision gear rims with the use of the design of special and universal hardmetal single- and double-flute cutters with both re-sharpened cutting elements and with disposable rotary tools turn plates was developed and introduced.

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Receive 10.02.2018

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ОПТИМІЗАЦІЯ ТЕХНОЛОГІЇ ВІДНОВЛЕННЯ КРУПНОГАБАРИТНИХ ЗУБЧАТИХ ВЕНЦІВ ПІДВИШЕНОЇ ТОЧНОСТІ

Предметом дослідження є питання, пов'язані з оптимізацією технології відновлення великогабаритних зубчастих вінців підвищеної точності приводів гірничодобувних комплексів, шахтного підйомного обладнання, важких транспортних засобів і є актуальним напрямком по зниженню витрат на відновлення і експлуатацію дорогого унікального обладнання. **Мета** - забезпечити інтенсифікацію виробничих процесів, збільшення робочих навантажень, швидкостей, зниження зношування зубчастих вінців підвищеної точності. **Завдання.** Розробка нової технології оптимізації відновлення великогабаритних зубчастих вінців підвищеної точності, для чого запропоновано метод обробки зубів після наплавки попередніми фрезеруванням спеціальними черв'ячними фрезами з «протуберанцем» і остаточної обробки зубів спеціальними фрезами, оснащеними твердосплавними пластинками, які виробляють обробку зубів по лінії зачеплення, на чого не потрібно виготовляти ріжучі зуби фрез по всій довжині, що значно підвищує якість обробки, підвищення стійкості фрез, оснащених твердим сплавом. Процес відновлення великогабаритних зубчастих вінців підвищеної точності відносяться до ресурсозберігаючих технологій, тому що в порівнянні з виготовленням нових деталей значно скорочуються витрати на матеріали при виготовленні, зменшується кількість технологічних операцій, знижуються витрати на верстатне обладнання, пристосування, ріжучий і вимірювальний інструмент. Плавна робота зубчастої передачі може бути забезпечена тільки при постійному передатному відношенні, але через похибки виготовлення і похибок, пов'язаних з експлуатацією, величина передавального числа в кожен момент часу не є постійною, що призводить до інтенсифікації зносу великогабаритних зубчастих вінців підвищеної точності. **Результати.** Отримано промислове підтвердження можливості і доцільності застосування черв'ячних фрез з «протуберанцем» (m = 20–28 мм) при черновому зубонарізуванні зношених і відновлених великогабаритних зубчастих вінців. Для отримання необхідної стійкості чорнових фрез кут профілю «протуберанця» рекомендується призначити в межах 8–10 °. Застосування при чистовому зубофрезерованню черв'ячними твердосплавними фрезами дозволяє підвищити продуктивність обробки в 2 – 3 рази в порівнянні з швидкорізальними фрезами інших конструкцій і отримати необхідні якість і точність виготовлення зношених і відновлених великогабаритних зубчастих вінців. **Висновки.** Розроблено та впроваджено технологію оптимізації відновлення великогабаритних зубчастих вінців підвищеної точності із застосуванням конструкції спеціальних і універсальних одно - і двухзаходних твердосплавних фрез, як з переточуваними ріжучими елементами, так і з непереточуваними поворотними пластинками.

Ключові слова: нова технологія оптимізації, відновлення великогабаритних зубчастих вінців, підвищена точність, червячні фрези з «протуберанцем», спеціальні фрези, обробка зубів по лінії зачеплення, підвищення якості обробки.

ОПТИМИЗАЦИЯ ТЕХНОЛОГИИ ВОССТАНОВЛЕНИЯ КРУПНОГАБАРИТНЫХ ЗУБЧАТЫХ ВЕНЦОВ ПОВЫШЕННОЙ ТОЧНОСТИ

Предметом исследования являются вопросы, связанные с оптимизацией технологии восстановления крупногабаритных зубчатых венцов повышенной точности приводов горнодобывающих комплексов, шахтного подъемного оборудования, тяжелых транспортных средств и являются актуальным направлением по снижению затрат на восстановление и эксплуатацию дорогостоящего уникального оборудования. **Цель** – обеспечить интенсификацию производственных процессов, увеличение рабочих нагрузок, скоростей, снижение изнашивания зубчатых венцов повышенной точности. **Задание.** Разработка новой технологии оптимизации восстановления крупногабаритных зубчатых венцов повышенной точности, для чего предложен метод обработки зубьев после наплавки предварительным фрезерованием специальными червячными фрезами с «протуберанцем» и окончательной обработки зубьев специальными фрезами, оснащенными твердосплавными пластинками, которые производят обработку зубьев по линии зацепления, для чего не нужно изготавливать режущие зубья фрез по всей длине, что значительно повышает качество обработки, повышение стойкости фрез, оснащенных твердым сплавом. Процесс восстановления крупногабаритных зубчатых венцов повышенной точности относятся к ресурсосберегающим технологиям, так как по сравнению с изготовлением новых деталей значительно сокращаются затраты на материалы при изготовлении, уменьшается число технологических операций, снижаются затраты на станочное оборудование, приспособления, режущий и измерительный инструмент. Плавная работа зубчатой передачи может быть обеспечена только при постоянном передаточном отношении, но из-за погрешностей изготовления и погрешностей, связанных с эксплуатацией, величина передаточного числа в каждый момент времени не является постоянной, что приводит к интенсификации износа крупногабаритных зубчатых венцов повышенной точности. **Результаты.** Получено промышленное подтверждение возможности и целесообразности применения червячных фрез с «протуберанцем» (m=20-28 мм) при черновом зубонарезании изношенных и восстановленных крупногабаритных зубчатых венцов. Для получения необходимой стойкости черновых фрез угол профиля «протуберанца» рекомендуется назначить в пределах 8-10°. Применение при чистовом зубофрезеровании червячных твердосплавных фрез позволяет повысить производительность обработки в 2 - 3 раза по сравнению с быстрорежущими фрезами других конструкций и получить необходимые качество и точность изготовления изношенных и восстановленных крупногабаритных зубчатых венцов. **Выводы.** Разработана и внедрена технология оптимизации восстановления крупногабаритных зубчатых венцов повышенной точности с применением конструкции специальных и универсальных одно - и двухзаходных твердосплавных фрез, как с перетачиваемыми режущими элементами, так и с неперетачиваемыми поворотными пластинками.

Ключевые слова: новая технология оптимизации, восстановление крупногабаритных зубчатых венцов, повышенная точность, червячные фрезы с «протуберанцем», специальные фрезы, обработка зубьев по линии зацепления, повышение качества обработки.