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NOISE RESEARCH OF TOOTH WHEEL OF THE PINION STAND OF THE RADIAL-SHIFTING BEND WITH MODIFIED TEETH (GEARS)

Abstract. A new combined method for manufacturing bars and tubes with a stable sub microcrystalline structure is proposed in the article: intensive plastic deformation by the method of radial-shear rolling with a combination of pressing. The influence of the modified teeth of the gear wheels of the radial-shear stand on the noise and vibration of its drive is investigated. At the same time, a special methodology was developed and appropriate research tools were used. To determine the noise level in tooth gears with modified teeth of the wheels, a special stand was designed and manufactured. As the object of investigation, medium-speed disc type straight-toothed pairs of medium sizes were chosen. The tests carried out on the stands were designed to find out the effect of modified wheel teeth on noise and vibration, the variation of skew, speed and load, and the effectiveness of the effect of the profile modification of the teeth of the wheels on noise and vibration when varying the gap between the teeth, speed and load. The conducted experimental studies to determine the noise levels of tooth gears with modified teeth showed that for transmissions with 7÷9 degree of use of longitudinally modified teeth on one mating wheel, a significant reduction in the load concentration and a reduction in vibration and noise of 3÷5 dB, and the use of a profile modification of the teeth along the entire height of tooth, obtained by hydro abrasive method, allowed to reduce the noise level by 4÷6 dB. If there is no load, the noise level increases with the depth of the profile modification. Under load, as the profile modification increases, the transmission noise level first decreases, then increases.
Keywords: modified teeth, gear train, contact markings (strips), modification depth, gear tooth contact, gear-meshing frequency.

Introduction. Rolling mills belong to the class of heavy energy-intensive aggregates, which are manufactured on individual projects in single copies [1, 2]. Each type of mill is characterized by its design and specific operating conditions, depending on the technology. They are low-speed, powerful crimping mills and relatively lightly loaded high-speed training and wire mills, continuous wide-band hot and cold rolling mills with a wide range of speeds along the stands, rolling mills for bars, pipes and etc.

Intensification of rolling production processes increases the load on heavy-loaded elements of mill stands, gear stands, reducers, combined reducers, etc. [3-5]. The cyclic action of powers leads to the appearance of defects in the mating elements. Gaps in gear train and bearings are one of the main reasons for increasing vibrations and the appearance of dynamic loads, leading to the destruction of parts. The primary task in the operation of mechanisms is the detection of incipient defects at early stage of occurrence using diagnostic tools.

For most mills and their stands, the impact character of the load application is typical, first of all, at the moment when the workpiece is caught by rolls [6]. This circumstance leads to the formation of significant dynamic loads, which are the reason for increasing the noise level in the rolling mill and adversely affect the durability of the equipment. The desire to increase productivity, expand the range of products and improve its quality, and increase the profit of the enterprise is associated with the intensification of the work of rolling mills. This, in turn, led to an increase in static and dynamic loads, increased wear of articulated parts and gaps, reduced longevity, the loss of production due to equipment failures due to fatigue.

The service life of most mills is estimated in tens of years [7, 8]. Maintaining the working capacity of rolling mills equipment is ensured by preventive maintenance, which is a well established, however, outdated maintenance practice. It allows you to continue the operation of rolling mills, while bearing a large cost of repairs.

Modern economic conditions lead to the need to introduce a new maintenance strategy "on the actual state". The last 10-15 years, an exceptionally great attention is paid to the determination of the technical state on the basis of vibration diagnostics of rolling equipment [9-13]. The advantages of using mills with the use of control and diagnostic systems are noted: improving the quality of products, optimizing the technological process and equipment operation, and improving the repair system oriented to the technical condition of the units. In the works [14, 15] examples of the effective and successful application of diagnostic systems are given.

Peculiarities of diagnosing and manifestations of the technical condition of the mechanical equipment of metallurgical enterprises were considered in works [9-15]. The emergence of modern stationary control systems for metallurgical equipment requires the development of new approaches to assessing the technical condition.

In our opinion, it is possible to improve the durability of individual parts of rolling mills by improving their design, for example, gear wheels of pinion stands. It is known [16] that the general indicator of the quality of the gear train is the nature and noise level. Reducing the noise level is one of the most important conditions for increasing the efficiency and reliability of high-speed, heavily loaded gears.

The main task in the production of gears with limited accuracy of their manufacture and installation is to reduce the disturbing forces in the oscillation source, i.e. reduction of its vibroactivity [17]. The use of various modifications of the wheels teeth has made it possible to largely solve the problem of reducing dynamic loads, contact stresses, increasing the smoothness of the gearing and reducing the noise level of the transmission [18]. Despite the fact that these types of modifications in gears have been used for a long time, they have not found wide application in practice in gears with increased hardness of the working surfaces of the teeth.

In the works [19-23], based on theoretical and experimental developments, methods for modifying wheel teeth with increased hardness of working surfaces have been created, and these methods are realized on cylindrical gears with an involute tooth profile. For industrial recommendations of rational parameters of wheel teeth modification, their comprehensive experimental verification on test benches and in gear mechanisms of rolling mills is necessary. In the above studies, statistical and dynamic tests of wheels with modified teeth for identifying the effect on their noise in the transmission were carried out at the stand.

To date, a sufficiently large number of studies have been performed for studying the level and nature of noise in the gear trains [20-23]. The sources of noise excitation are considered and noise transmission criteria and methods for performing air noise and vibration measurements are proposed. Frequency tables of forced oscillations, depending on the geometric parameters of the link, are given. In the study of noise, spectral analysis was used, and the comparison of the components of the noise spectrum with the calculated values of the forced oscillation frequencies made it possible to justify the method for identifying noise sources.

The most dangerous dynamically are the oscillations arising at edge contacts caused by the combined effect of manufacturing errors and the deformation of the linkage [13]. In this case, the amplitude of the oscillations is many times higher than the amplitude of the cyclic error, and the transmission operates with sharply increased noise.

The quantitative parameter of the source noise is its acoustic power [14]. A parameter that can be directly measured with instruments is sound pressure. The total noise level approximately corresponds to the value of the integral of the function of the dependence of the intensity of sound oscillations on the frequency. However, in connection with the logarithmic law of addition of noise levels, the overall noise intensity is mainly determined by the most intensive components.

In the study of the relationships between the errors of gear trains and the parameters of their noise and vibration, the last were the total, octave and one-third octave levels, or the levels obtained as a result of spectral analysis with a constant, relatively wide bandwidth [15]. With the improvement of analog analyzers and the appearance of digital analyzers that make it possible to obtain spectra of signals with a high resolution in frequency, the possibilities of special analysis have expanded substantially.

In work [10] the influence of the profile modification of the wheel teeth on the noise characteristics of the gears was verified experimentally. It is established that the profile modification of the teeth significantly changes the frequency spectrum of the noise of the gear train, reducing the level of the frequency component corresponding to the tooth frequency and its second harmonic by more than 10 dB, in addition, a certain reduction in the subharmonics of the tooth frequency was obtained.

The aim of this work was:

1. Determination of the influence of the modified wheel gears on noise and vibration, variations of a distortion, speed and load.

2. Determination of the efficiency of the influence of profile wheels gear modification on noise and vibration at variation of a gap between gears, speed and load.

Materials and experimental procedure. In this work, we propose a new combined method for the production of bars and pipes with a stable sub microcrystalline structure: intense plastic deformation by radial-displacement rolling with a combination of pressing [24].

The device for continuous pressing of rods comprises a main drive, working and gear stands, rotating in different directions of the rolls and a press-matrix. The rolls have smooth and undulating cone-shaped gripping and crimping portions, respectively, and calibrating cylindrical areas. In this case, the protrusions or valleys of the rolls having the same width and, respectively, height or depth, are made along a helical line with an angle between the tangent to the helical line and a line passing through the point of tangency along the generatrix perpendicular to the base of the roll equal to from 45° to 60°.

The rods are pressed in the following way. The workpiece is fed into the gap between the rolls and deformed with the protrusions and hollows of the corrugated cone-shaped sections of the rolls when the rolls rotate in one direction. Rolls, while rotating, rotate the deformable metal forwardly and squeeze it out through the opening of the press-matrix.

Rolling of the workpiece in the undulating cone-shaped sections of the rolls, with the rotation of the rolls in one direction, provides progressive and rotational motion of the workpiece in the rolling direction, efficient grinding of the structure throughout the section of the workpiece due to the development of shear deformations and reduction in the rolling force. Effective grinding of the structure ensures the production of high-quality products.

In the present work, the influence of the modified teeth gear of wheels of the pinion stand of radial-displacement rolling on the noise and vibration of the drive of this mill is investigated. At the same time, a special methodology was developed and appropriate research tools were used.

Obviously, the most reliable data on the advantages of transmissions with these or those parameters can be identified only in the process of comparative full-scale tests of these transmissions, carried out in a uniform manner on the same test equipment. In this case, the possible incompatibility of experimental results will be completely ruled out, resulting in a number of cases when comparing gears with the same parameters tested in different research organizations with different gear sizes and using different test methods and various testing equipment.

For determination of noise level in gear trains with the modified teeth of wheels the special stand with the loaded close circuit was developed and assembled.

The main design features of the stand are presented on figure 1.

The stand represents design from two parts: drive and assembly for teeth wheels noise testing.

Transmission system consists of sixteen step gearbox units 1, placed on the stand with a curbstone 2 and the 7,5 kW electric motor, located in a curbstone which are connected among themselves by V-belt transmission. The drive torque from the drive through a shaft and V-belt transmission is transferred to a driving shaft of a reducer 3.

The device for tooth wheels noise testing consists of a reducer 3, the mechanism of cogwheel testing and the mechanism of loading 4, which are installed on the stand 5. The mechanism of wheels testing is installed on the carriage and consists of two parts:static and mobile. The static part represents a support

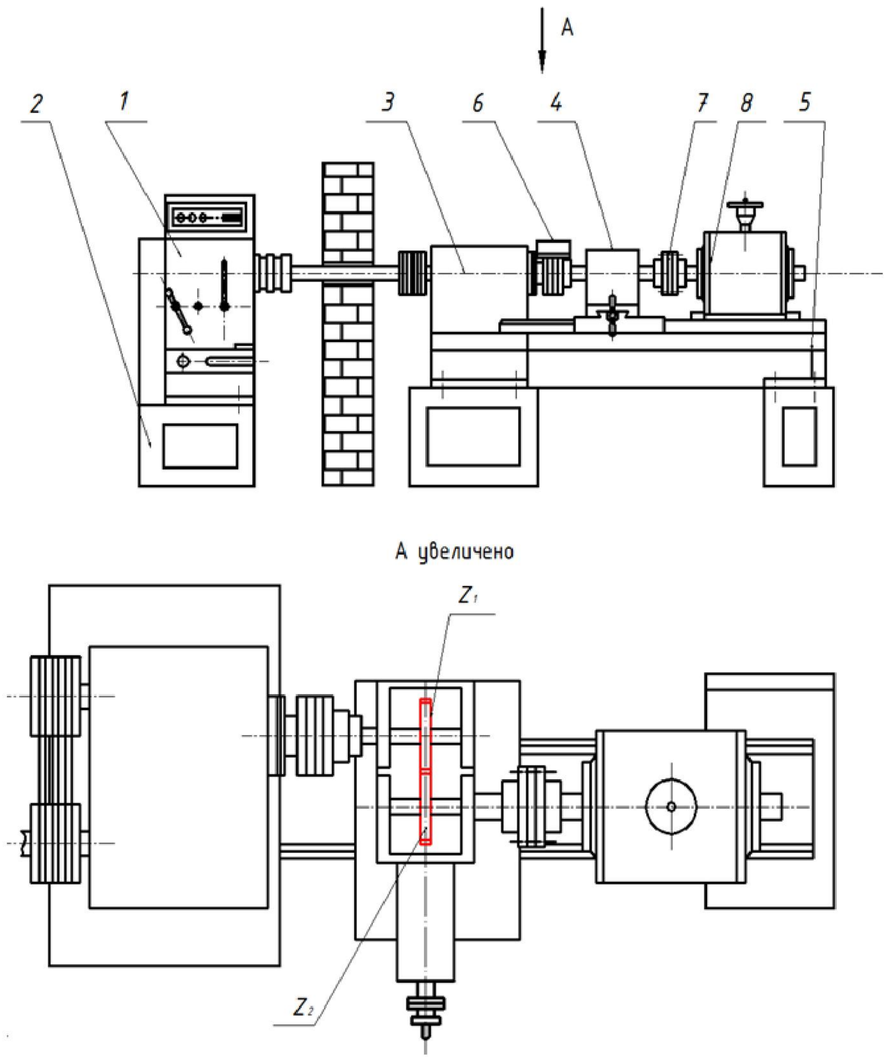


Figure 1 – General view of the stand for cogwheels noise testing

with the shaft and tested wheel, which rigidly fixed on the carriage together with a driven shaft of a reducer 3, connected by the coupling.

The second support with the shaft and the tested wheel rigidly fixed on a table of the carriage, which can move along cross guides by means of a screw pair and the handle. The electromagnetic powder brake 8, connected to a driven shaft with the coupling, creates load. Rotational speed of a driving shaft is controlled by means of the photo sensor; the frequency of reintegration is controlled by means of the electromagnetic sensor (not shown in figure 1). The torque created by a brake is evaluated according to the results of an indicator head (tarred).

At statistical tests loading of a closed boundary was carried out as follows: the driven shaft of a reducer 3 is disconnected with a driving shaft and rigidly fixed with the reducer body by means of the special device (not shown in figure 1). Loading is performed by means of the lever (figure 1b) and the screw mechanism on a dynamometer. Under the influence of the created moment cogwheels z_1, z_2 and shafts 6,7 try to turn, but as the driven shaft of a reducer 3 is connected with the body and the bedplate, this turn can happen only within backlash and elastic deformation of gearing. Teeth of wheels engage to each other and are loaded with relevant efforts. After that, the driving shaft and a driven shaft of a reducer 3 become isolated, fixed and driven shaft is disconnected with the body unloaded the lever and the lever cleans up. The report of cogwheels work cycles is performed on a turn counter.

As the object of investigation, medium-speed disc type straight-toothed pairs of medium sizes were chosen. When choosing the main parameters of gears for research, we proceed from the assumption that approximately 80% of all produced gears fit into the range of modules from 3 mm to 5 mm and diameters not exceeding 200 mm, which corresponds to the projected gears of a radial-shear mill.

Experimental cogwheels made of 40X steel are widely used in gears of mills of various designs. These wheels are manufactured to the 7th grade of accuracy by grinding (roughing and finishing) of all their surfaces after hardening.

The specification of the applied wheels is shown in table 1. The tested wheels are broken up into six groups of pair wheels. In each group, in turn, five couples of wheels with different modification of teeth. These modifications of teeth are characterized as follows:

- tested couple of wheels A. Wheels have a standard profile of tooth;
- tested couple of wheels B. Wheels have profile modification of teeth, received in the hydro abrasive way.

During experiments, tests periods were divided into two periods. An initial stage of break-in at the loadings causing tension no more than 0.6 at loadings and rotating speeds allowed during work. Conditions of break-in were chosen for all samples identical, considering that their hardness was HRC 45-50. Time of break-in for each couple was one hour that represents 46000 cycles of loading at drag torque 300 N·m. and rotating speed 800 rpm.

Table 1 – The sizes of the tested straight-toothed wheels

Characteristics of toothed wheels	1		2		3	
	Traction wheel	Driven wheel	Traction wheel	Driven wheel	Traction wheel	Driven wheel
Module (mm)	3	3	3,5	3,5	4,0	4,0
Number of teeth	59	59	56	56	51	51
Width of toothed ring (mm)	23	23	23	23	23	23
Material	steel 40X	steel 40X	steel 40X	steel 40X	steel 40X	steel 40X
Tooth hardness	45÷50	45÷50	45÷50	45÷50	45÷50	45÷50
Roughness of tooth surface, mkm	1,5÷2,0	1,5÷2,0	1,5÷2,0	1,5÷2,0	1,5÷2,0	1,5÷2,0
Accuracy of tested wheels	7-7-7B	7-7-7B	7-7-7B	7-7-7B	7-7-7B	7-7-7B

The noise measurements of the tooth gears of the transmissions were carried out in the operation modes given in table 2.

Table 2 – Load conditions

Number of rotations of traction wheel *n*, r/min	Load M, N·m
280	0, 200, 400, 600
400	0, 200, 400, 600
560	0, 200, 400, 600
800	0, 200, 400, 600

Removal and analysis of experimental results were conducted on a collected analog complex, shown in figure 2.

For measurement of noise level, the set of the acoustic equipment AK-12 was used, which included: accurate pulse noise- meter 00017 equipped with the one-inch microphone with the measuring microphone amplifier M 102 and a measuring microphone priming cap of MK102 and RG101 of model 00 003.

The microphone is installed in all cases at the same point, in 100 mm from the point corresponding to a gearing pole.

The noise of wheels was analyzed by means of the narrow-band analyzer SK4-26 with bandwidth 1/3 octaves during the gear work. Results of the spectral analysis were registered with the graph plotter N-306. For monitoring of required high-speed mode of gear, the digital frequency meter of 43-33 type was used. When required of repeated noise signals reproduction they were recorded on a DVD disk, and then it was analyzed more precisely.

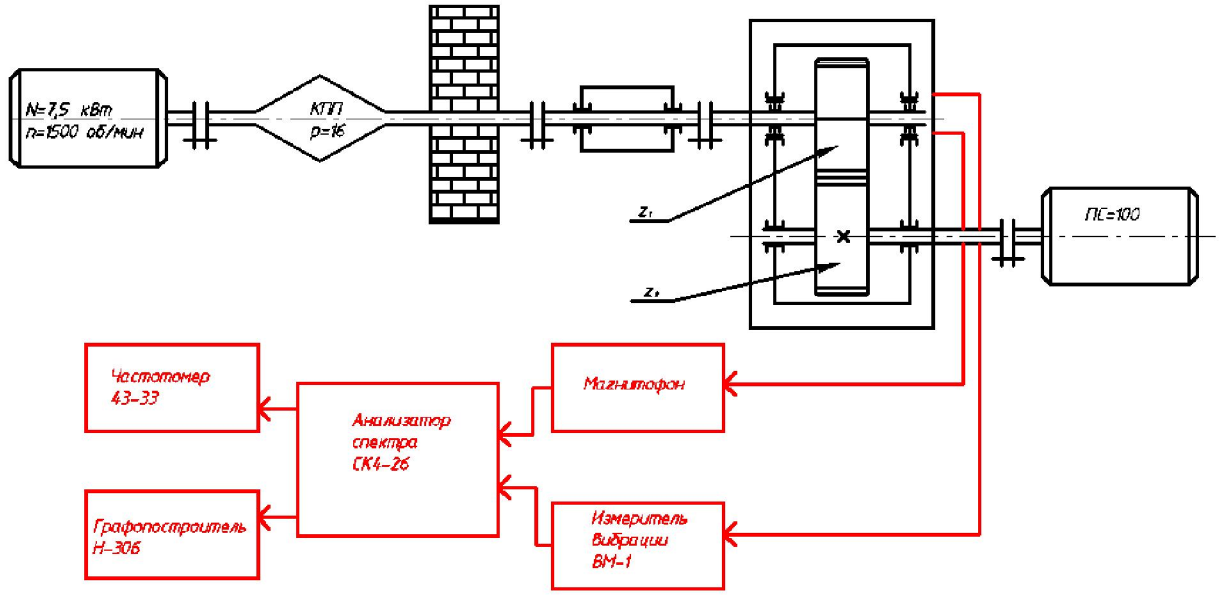


Figure 2 – Scheme of the test stand

Results and discussion

Results of measurement of a noise range for profile-modified and unmodified cogwheels are given in figure 3, the tooth frequency and its main subharmonics and harmonic as of the second order are also given. As it follows from comparison of noise ranges of the unmodified and modified cogwheels, application of profile modification, substantially reduces sound intensity level at a tooth frequency and its harmonica of the second order (to 12 dB), also reduces sound intensity level in subharmonics of tooth frequency (to 5 dB).

The results of the study of the influence of the parameters of the profile modification of the wheels teeth with high hardness of the side surfaces are given below.

A series of experiments was conducted on cogwheels which have profile modification of teeth, received in the hydro abrasive way (Tested couple B). From possible combinations of depth modification on ahead and root for gears $Z_1 = Z_2 = 57$, m = 3,5 mm, was chosen a row, providing continuous increase in depth of profile modification (table 3).

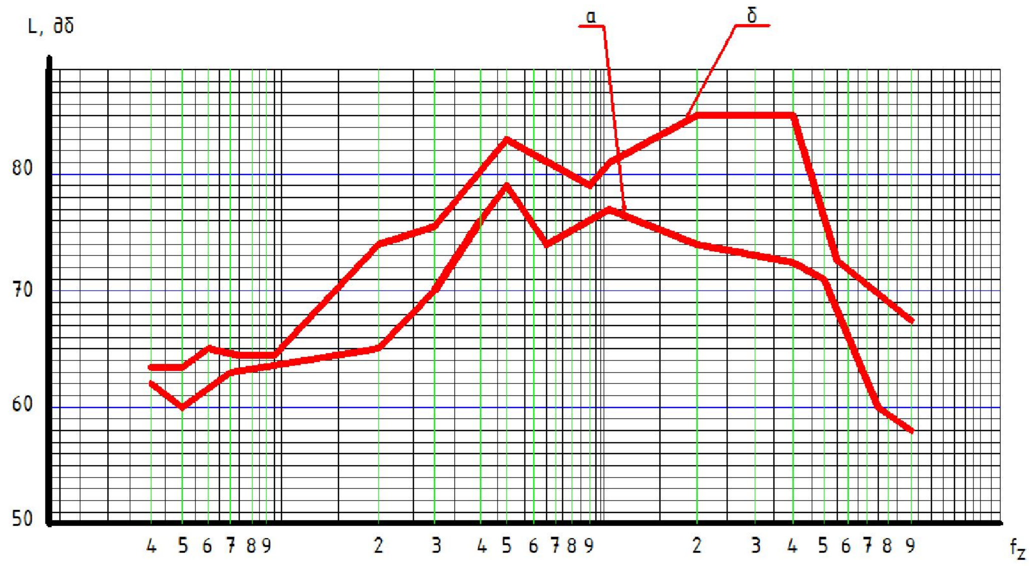


Figure 3 – Gear noise spectrum: a – Profile-modified teeths, b – Unmodified teeths

Table 3 – Depth parameters of profile modification teeth in tested cogwheels at the input and at the output of the gearing

№ of the tested couples of cogwheels	Depth of modification couples of teeth in gearing		
1	0,004	0,012	0,016
2	0,006	0,025	0,031
3	0,008	0,050	0,058
4	0,010	0,075	0,085
5	0,012	0,100	0,112

As a result of the conducted researches, the frequency characteristic of the noise of the gear train with profile-modified teeth is revealed. A characteristic frequency for transmission with a total depth of modification at the input of a pair of teeth in a mesh of 36 microns at n = 560 rpm and M = 200 N·m is shown in figure 4. At this peripheral speed, the transmission frequency was 465 Hz. This value falls into the limiting frequencies of the active band 500 Hz, which are 370 730 Hz. It can be seen from the graph shown that the intensity of sound pressure significantly (by 10 18 dB) increases in the active band corresponding to the frequency of the tooth and multiples of it (1 kHz, 2 kHz), and then decreases significantly. Due to the logarithmic law of addition of the sound pressure intensity, total transmission noise level is determined by the noise level at the mean geometric frequencies of the octave bands corresponding to the tooth frequency and multiples thereof.

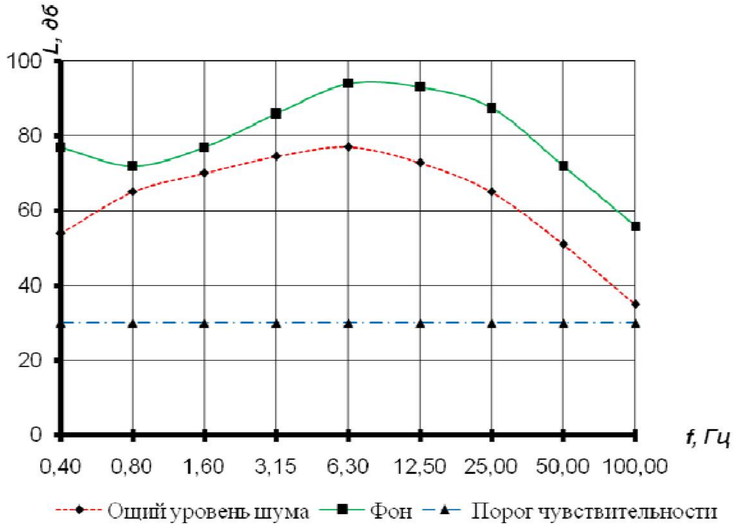
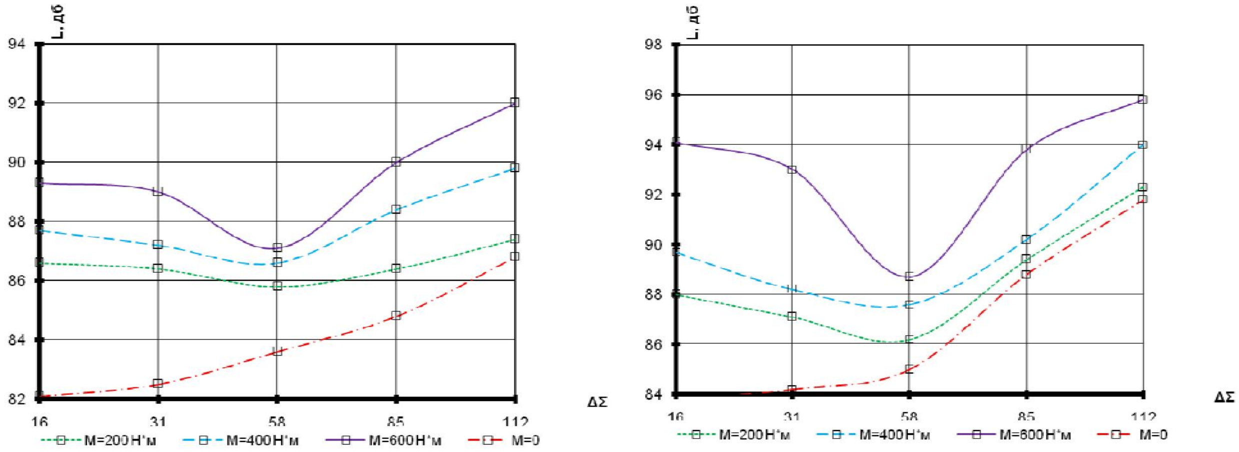


Figure 4 – The frequency characteristic of the noise tooth gear with the profile modified teeth

The characteristic of the background created by the test stand (the drive, an intermediate support, the lubrication system, a brake) in a measurement point is shown by shaped line in figure 4. Checking under the logarithmic law of addition of sound pressure intensiveness showed that additive to the noise level of the tested tooth gear from a background made no more than 0,5 dB, and it corresponds to average dispersion of an experiment by results of three-five measurements in each point

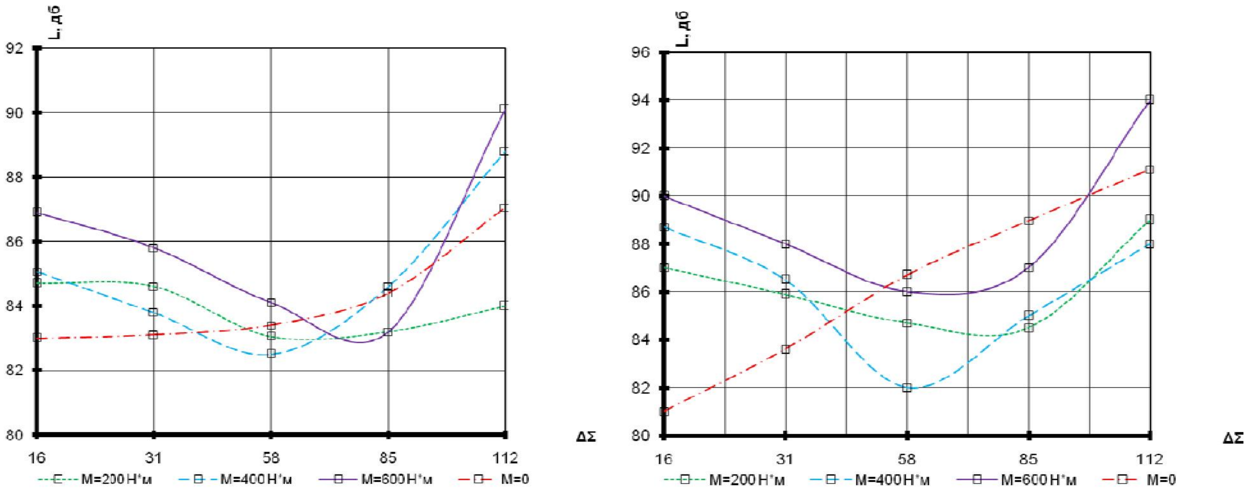
For medium geometrical octave band, center frequencies of 500 Hz, 1 kHz and 2 kHz schedules of dependence of noise level on depth of profile modification at different loadings and rotational speeds were constructed. Curves on the figures 5–7 are made after calculation of statistical characteristics of an experiment and smoothing of the function set in table in not equidistant points by method of the smallest squares.

Without loading at all rotating speeds, with increase in depth of profile modification, the noise level grows in gear. Under the loading, with increase in depth of profile modification noise level at the beginning decreases, and then increases. The general noise decrease in examinees tooth gears at different frequencies of octava strips at different stress and circumferential speeds, is given in table 4.



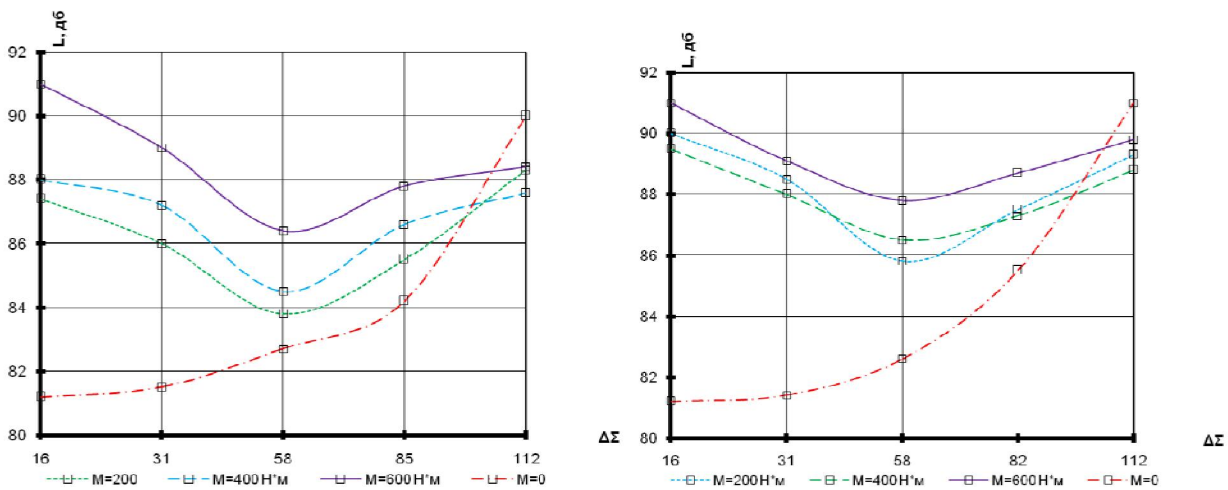
a) *b*)

Figure 5 – Dependence of noise level on depth of the profile modification
at n = 560 r/min, f = 500 Hz, f_{zz} = 532 gts (a) and at n = 800 r/min, f = 500 Hz, f_{zz} = 532 gts (b)



a) *b*)

Figure 6 – Dependence of noise level on depth of profile modification
at n = 560 r/min, f = 1000 Hz, f_{zz} = 532 Hz (*a*) and n = 800 r/min, f = 1000 Hz, f_{zz} = 760 Hz *(b)*



a) *b*)

Figure 7 – Dependence of noise level on depth of profile modification
at n = 560r/min, f = 2000 Hz, f_{zz} = 532 Hz (*a*) n = 800 r/min, f = 2000 Hz, f_{zz} = 760 Hz *b*)

Table 4 – The general noise decrease in tasted tooth gears

Octave band centre frequencies, Hz	Number of rotations, RPM	Stress, N·m	Average noise decrease, dB
500	560	200 400 600	1,9 1,7 3,5
	800	200 400 600	3,0 3,7 3,2
1000	560	200 400 600	3,0 2,7 2,8
	800	200 400 600	3,0 2,7 2,8
2000	560	200 400 600	3,2 2,6 2,4
	800	200 400 600	3,0 5,8 4,7

The average decrease in noise level due to the application of the full profile modification, received in the hydroabrasive way in the considered gears of 7th degrees of accuracy made 3 dB, which corresponds to decrease in intensity of noise approximately by one and a half times because of the logarithmic addition of intensiveness of noise of different sources.

Analysis of the shape and location of the contact spot on the side surface of the wheel tooth showed that with a small (insufficient) depth of the profile modification under the load, edge contact is clearly pronounced on the tooth head. At the optimum depth of the profile modification and close to it, the edge contact under load is absent; the contact patch has the correct shape.

Conclusion. Conducted researches on determination of noise levels of cogwheels with the modified teeth showed that:

1. For gears of 7÷9th extents of use on one of the interfaced wheel longwise modified teeth give a considerable decrease in stress concentration and reduction of vibration and noise of 3÷5 dB;

2. Application of profile modification teeth on all depth of tooth received in the hydroabrasive way, allowed us to reduce noise level by 4÷6 dB.

3. In the case of load absence and increase of the depth of profile modification noise level increases.

4. Under load, with increase in profile modification gear noise level decreases in the beginning, then increases.

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ТҮРЛЕНДІРІЛГЕН ТІСТЕРІ БАР РАДИАЛДЫ ЖЫЛЖЫМАЛЫ ОРНАҚТЫҢ ТІСТЕГЕРІШ ҚАПАСТАРЫНДА ТІСТІ ДОҢҒАЛАҚТАР ШУЫН ЗЕРТТЕУ

Аннотация. Мақалада тұрақты субмикрокристалды құрылымы бар шыбықтар мен құбырларды дайындаудың бірлескен жаңа әдісі ұсынылған: престеу үйлесімі бар радиалды-жылжымалы илемдеу әдісімен қарқынды пластикалық деформация. Радиалды жылжымалы орнақтың тісті дөңгелектерінің шуылға және оның дірілінің өзгеруіне әсері зерттелді. Сонымен қатар, арнайы әдіснама әзірленді және тиісті зерттеу құралдары пайдаланылды. Доңғалақтың түрлендірілген тістері бар тісті берілістердің шу деңгейін анықтау үшін арнайы стенд жобаланып, дайындалды. Зерттеу объектісі ретінде орта жылдамдықтағы дискілердің орташа өлшемді тузу тісті жұптары таңдалды. Стендте жүргізілген сынақтар шу мен дірілге, құбылу ауытқуына, жылдамдық пен жүктемеге және дөңгелектердің тістерінің профильді түрленуінің шу мен дірілге әсер ету тиімділігін анықтауға бағытталған. Түрлендірілген тістері бар тісті доңғалақтардың шуыл деңгейлерін анықтау бойынша өткізілген эксперименталдық зерттеулер көрсеткендей, бір дөңгелектегі доңғалақ бойлық түрлендірілген тістерді пайдалану дәрежесі 7÷9, жүктеме концентрациясының айтарлықтай төмендеуі және діріл мен шуылдың азаюы 3÷5 Дб және тіс биіктігіндегі тістерді профильді түрлендіру, гидроабразивті әдісімен алынған шу деңгейін 4÷6 Дб төмендетуге мүмкіндік берді. Егер жүктеме болмаса, шу деңгейі профильді түрлендіру тереңдігімен бірге артады. Жүктеме кезінде профильді түрлендіру күшейе бастағанда, берілісте шу деңгейі төмендейді, содан кейін артады.

Түйін сөздер: түрлендірілген тістер, тісті берілістер, түйіспе дағы, түрлендіру тереңдігі, тіс байланысы, тіс жиілігі.

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ИССЛЕДОВАНИЕ ШУМА ЗУБЧАТЫХ КОЛЕС ШЕСТЕРЕННОЙ КЛЕТИ РАДИАЛЬНО-СДВИГОВОГО СТАНА С МОДИФИЦИРОВАННЫМИ ЗУБЬЯМИ

Аннотация. В статье предложен новый совмещенный способ изготовления прутков и труб со стабильной субмикрокристаллической структурой: интенсивная пластическая деформация методом радиально-сдвиговой прокатки с сочетанием прессования. Исследовано влияние модифицированных зубьев колес шестереных клетей радиально-сдвигового стана на шум и вибрацию его привода. При этом разработана специальная методика и применены соответствующие средства исследования. Для определения уровня шума в зубчатых передачах с модифицированными зубьями колес был разработан и изготовлен специальный стенд. В качестве объекта исследования были выбраны среднескоростные дискового типа прямозубые пары средних размеров. Испытания, проводившиеся на стендах, имели целью выяснить влияние модифицированных зубьев колес на шум и вибрацию, варьирования перекоса, скорости и нагрузки и эффективность влияния профильной модификации зубьев колес на шум и вибрацию при варьировании зазора между зубьями, скорости и нагрузки. Проведенные экспериментальные исследования по определению уровней шума зубчатых колес с модифицированными зубьями показали, что для передач 7÷9 степени использования на одном сопрягаемом колесе продольно модифицированных зубьев дает значительное снижение концентрации нагрузки и уменьшение вибрации и шума 3÷5 дБ, и применение профильной модификации зубьев по всей высоте зуба, полученной гидроабразивным способом, позволило снизить уровень шума на 4÷6 дБ. При отсутствии нагрузки, с увеличением глубины профильной модификации уровень шума возрастает. Под нагрузкой, с увеличением профильной модификации уровень шума передачи вначале уменьшается, затем увеличивается.

Ключевые слова: модифицированные зубья, зубчатые передачи, пятна контакта, глубина модификации, контакт зубьев, зубцовая частота.

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