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Research on the Manufacturing Precision of Gear Meshing in Group 3 Hydraulic Gear Pumps

The article presents the results of a study of the manufacturing precision parameters of the gear meshing of group 3 hydraulic gear pumps. The relevance of the study is due to the increased operational loads on pumps of this group, which requires ensuring high precision of the geometric parameters of gear wheels in order to achieve optimal tightness, reduce hydraulic losses, and ensure durability of the meshing elements.

The study analyzes main technological errors that arise in the manufacture of gear wheels, namely: profile deviation, pitch deviation, concentricity deviation, and lateral clearance deviation. The influence of these deviations on the main hydro-mechanical characteristics of group 3 gear pumps, including efficiency, vibration and noise levels, as well as the wear resistance of meshing elements under high loads, was assessed. Modern measuring instruments, in particular optical and contact profilometry, were used to control geometric accuracy, which made it possible to quantitatively assess the precision of machining.

Based on the data obtained, recommendations for improving the technology of processing gear wheels of group 3 pumps are substantiated. In particular, the effectiveness of shaving as one of the key stages in achieving the required accuracy is analyzed. It has been proven that the use of this method allows achieving the precision of 7–8 according to DIN 3962, significantly reduces surface roughness parameters, and contributes to improving contact endurance. Particular attention is paid to the influence of heat treatment modes on the stability of the geometric parameters of the meshing, especially under variable load conditions.

During the analysis of shaving gear pumps of group 3, it was found that the maximum deviations are observed in the indicators of accumulated pitch error and radial runout of the gear rim, which have a critical impact on the level of pulsation of volumetric delivery and resistance to fatigue failure. The results obtained allow us to form a substantiated technological strategy for the manufacture of high-precision gear transmissions for pumps operating in severe operating conditions.

Thus, the results of the study are significant for improving the efficiency and reliability of Group 3 hydraulic gear pumps, which are widely used in power engineering, mobile equipment, and industrial hydraulic systems. Improving the precision of meshing elements directly affects the stability of pump output parameters, such as volumetric flow and torque, which is critical in ensuring functional reliability of hydraulic systems.

tooth machining, shaving, gear meshing, gear hydraulic pump, precision

Problem statement. The precision of manufacturing gear meshing of hydraulic gear pumps is a determining factor in ensuring their efficient, uninterrupted, and long-lasting operation. Gear pumps are widely used in hydraulic drive systems in various industries where the reliability and stability of hydraulic equipment are critical. Any deviations from the specified geometric parameters of the meshing elements can lead to additional dynamic loads, increased noise and vibration levels, intensive wear of contact surfaces, and a decrease in the efficiency of hydraulic machines.

The tooth shaving operation, which is a key stage in the finishing of gear wheels, is of particular technological importance in the production process. This process significantly reduces profile shape errors, minimizes surface roughness, and ensures high stability of meshing parameters under loads typical for the operation of group 3 pumps. Due to the ability to influence the microgeometry of the surface and the level of residual stresses, shaving increases contact endurance of the teeth, which is critical for operation under variable pressures and high rotational velocity.

The relevance of conducting an in-depth study of the shearing process is determined by the need to optimize the processing route, aimed at achieving high precision indicators while rationalizing resource and time costs. A comprehensive analysis of precision characteristics, as well as the development of methods for their measurement and control, make it possible to create a scientifically sound basis for improving gear cutting technologies. In particular, establishing dependencies between the parameters of shaving modes and manufacturing precision makes it possible to achieve stable results even when manufacturing large series of wheels.

Improving the processes of tooth surface shaping, taking into account the effect of shaving on the microgeometry, physical and mechanical characteristics of the surface layer, is important for improving the performance of hydraulic gear pumps. The results of such research will contribute not only to improving the quality of the final product, but also to the formation of a competitive scientific and technical base for the development of precision machining technologies in mechanical engineering.

Precision manufacturing of meshing in hydraulic gear pumps plays a key role in ensuring their efficient and long-lasting operation. These pumps are widely used in various industries where stability and reliability of equipment are critical. Deviations in meshing parameters can lead to increased noise levels, vibrations, excessive wear of parts, and reduced efficiency. Of particular importance for ensuring precision is the process of tooth shaving, which is an important stage in the finishing of gear wheels. It minimizes profile errors, improves surface quality, and ensures stable meshing under operating conditions.

The relevance of a detailed study of shaving is determined by the need to optimize technological process aimed at achieving high manufacturing precision at minimum production costs. An in-depth analysis of manufacturing precision parameters and the development of methods for their control will contribute not only to improving the quality of hydraulic pumps, but also to improving existing processing technologies. Improving the processes of machining gear meshes is an important step towards expanding scientific knowledge in this field, which at the same time ensures economic and technological competitiveness of production.

Analysis of recent research and publications. Based on a systematic analysis of scientific publications, it has been established that the gear is the main element that receives and transmits main loads during operation of hydraulic gear pumps. It ensures torque transmission, hydraulic flow formation, and withstands dynamic loads associated with high working environment pressures, which leads to increased requirements for its manufacturing precision, rigidity, and wear resistance [1, 2, 3, 4].

Research of the functional characteristics of hydraulic gear machines is relevant, as confirmed by a significant number of scientific works by both national [5, 6] and foreign researchers [8, 9, 10]. In addition, it is worth noting the active patent activity aimed at improving the design of hydraulic gear machines [11].

At the same time, based on the external appearance of the studied parts, in particular, the nature of the macro-relief of the bottom of the groove and the micro-relief of the tooth profile, it is possible to identify with a sufficient degree of probability technological techniques used in their processing:

- preliminary mechanical processing was carried out using the worm gear cutting method;
- final mechanical processing was performed using shaving method;
- the profile was finished after chemical-thermal treatment using diamond honing method.

Table 1 shows the parameters of the achieved accuracy of gear wheels of imported pumps by gear rim (elements of cyclic surface of the gear rim - ECSGR).

Table 1 – Parameters of modern imported gear pumps.

Parameters name DIN3962	Designation	Moreali m=1,75 z=12	BOSCH m=2,54 z=12	OMFB m=4,5 z=10	Eaton m=2,79 z=12
Profile deviation	$f_{f\alpha}$	7/7	6/7	6/7	6/8
Profile direction deviation	$f_{H\alpha}$	7/7	10/10*	10/10*	-
Deviation of tooth direction	F_{β}	6/5	10/7	9/8	7/7
Accumulated pitch deviation	Fp	5/7	9/8	7/8	8/8
Radial runout of gear rim	F_r	6	9	8	9
Roughness	Ra	-	0,2	0,2	-

Source: developed by the authors

Figure 1 shows the surfaces and imported gear pumps.

However, a number of requirements not taken into account in the design documentation require additional coordination with the technological capabilities of production. This is due to the fact that such requirements can only be met through the implementation of specialized technological techniques that are critical to ensuring functional characteristics of the components.

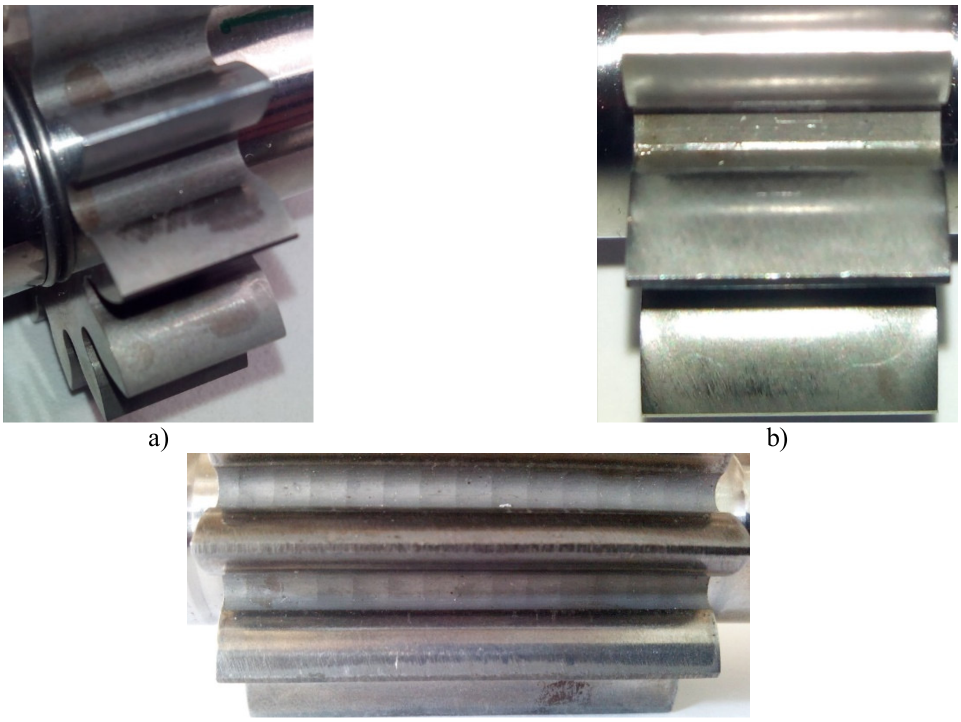


Figure 1 – Tooth profile of imported gear pumps
a) pump «Eaton»; b) pump «Sauer»; c) pump «OMBF».

Source: developed by the authors

The greatest operational loads are borne by involute edges (IE) and cylindrical edges (CE), which is explained by their functional role in separating the pressure and suction zones of the working space of a hydraulic gear pump. In this regard, these elements are subject to increased requirements for shape precision, dynamic strength, and resistance to contact wear.

During operation, IE and CE are subjected to intense contact loads, which, under conditions of uneven loading or residual technological stresses, can lead to local destruction or loss of geometric stability. Therefore, when forming edges, it is necessary to exclude the use of technological methods that contribute to the appearance of stresses in the surface layer, in particular sharp transitions, unacceptable thermal effects, or abrasive micro-wear.

In addition, to ensure reliable sealing and stable contact with adjacent surfaces, the edges must meet high geometric precision requirements, including minimal spatial deviations. Failure to comply with these parameters leads to a violation of contact density, an increase in internal leaks and, as a result, a decrease in the energy efficiency (performance index) of the hydraulic unit.

Objective statement. The objective of this work is to conduct scientific research on the process of finishing machining of gear meshing in hydraulic gear pumps, in particular using the shaving method, taking into account precision parameters regulated by the requirements of DIN 3962. The research is aimed at studying the influence of shaving modes on the formation of precision and quality characteristics of the tooth surface, as well as ensuring stable operational properties of finished parts in the hydraulic unit.

Main material. The research is planned to be carried out on a gear cutting machine model BCH-732NC22-7745 (Fig. 2), which provides high-precision finishing of gear wheels. Geometric parameters of the machined parts will be checked using a Carl Zeiss Contura G2 coordinate measuring machine (Fig. 3), which allows for precise measurement results in accordance with precision standards.

Figure 2 – Gear cutting machine. Model BCH-732NC22-7745

Source: [12]

Figure 3 – Tooth measuring machine Mahr GMX 275

Source: [13]

The shaving of a batch of 100 gears will be performed using processing modes that were determined to be optimal during previous experimental studies. These modes are listed in Table 2 and ensure compliance with the precision parameters in accordance with the requirements of DIN 3962, in particular for the following indicators:

- ffα – tooth profile deviation;
- fHα – tooth profile direction deviation;
- Fp – accumulated tooth pitch error;
- Fr – radial runout of the gear rim.

Table 2 – Modes of shaving of gear meshing

№	Parameter	Value
1	Radial feed Srad, mm/pass	0,02
2	Number of passes	5
3	Longitudinal feed S pass, mm/pass	56
4	Shaver rotation frequency $n_{ш}$, rot./min.	63
5	Allowance, mm	0,04…0,05

Source: developed by the authors

All controlled parameters will be recorded in the report generated by the Mahr GMX275 tooth measuring machine in accordance with DIN 3962 (Fig. 4).

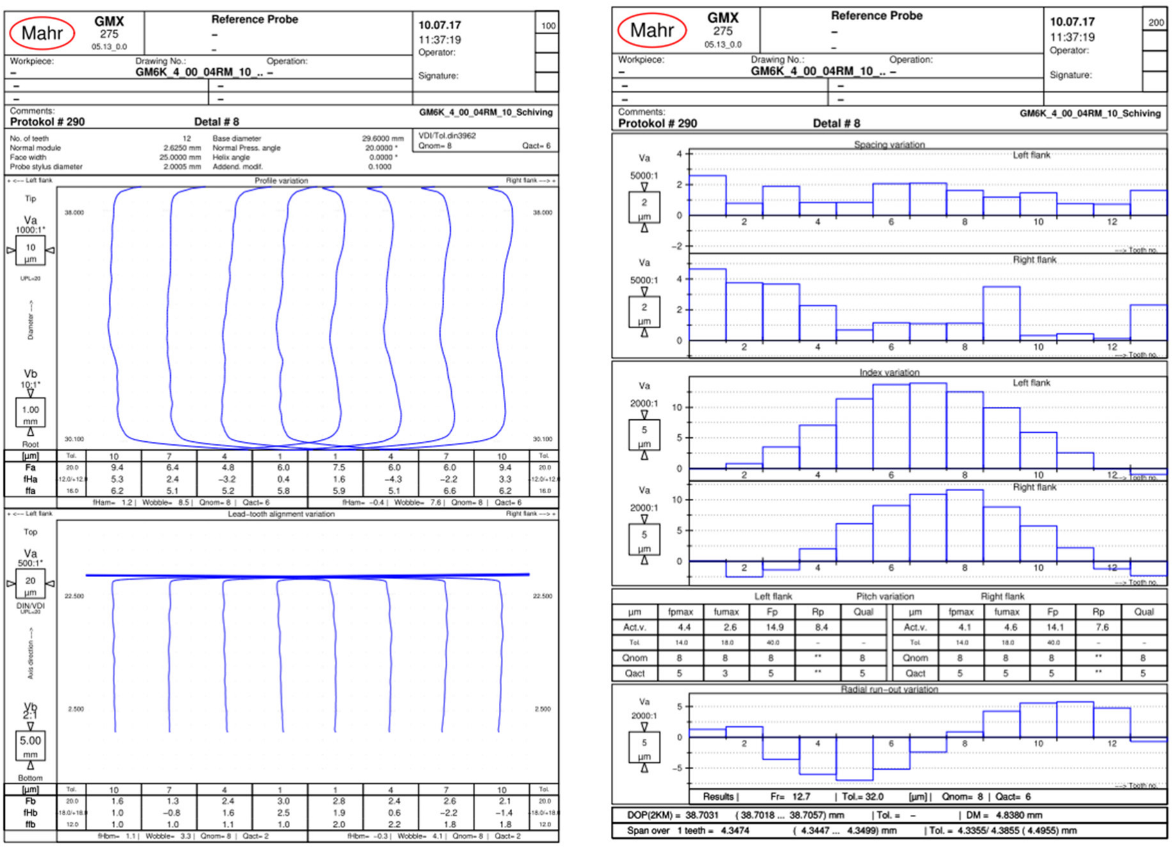
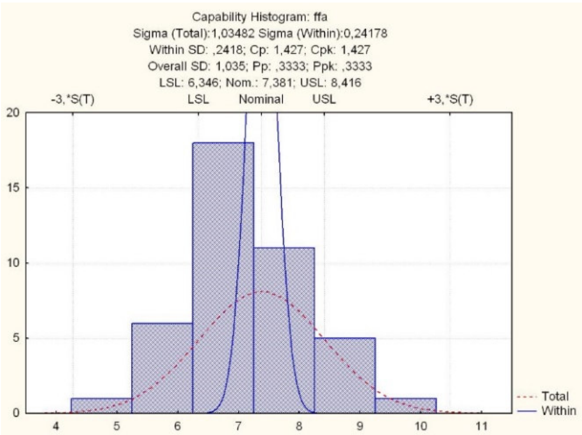


Figure 4 – Report on measuring a part on a coordinate measuring machine Mahr GMX 275

Source: [13]

The results of processing a batch of gears, presented in a histogram in accordance with DIN 3962 requirements, show that the profile parameter ffα has a generally normal distribution with a nominal value of 7.381 and tolerance limits LSL = 6.346 and USL = 8.416, but some values exceed the permissible limits. The Cp and Cpk coefficients (1.427) indicate sufficient short-term accuracy, while the low Pp and Ppk (0.333) indicate significant long-term dispersion due to the influence of external and technological factors. To ensure stability and compliance with the standard requirements, it is necessary to reduce the dispersion, stabilize the processing modes, and adjust distribution center to the nominal value.

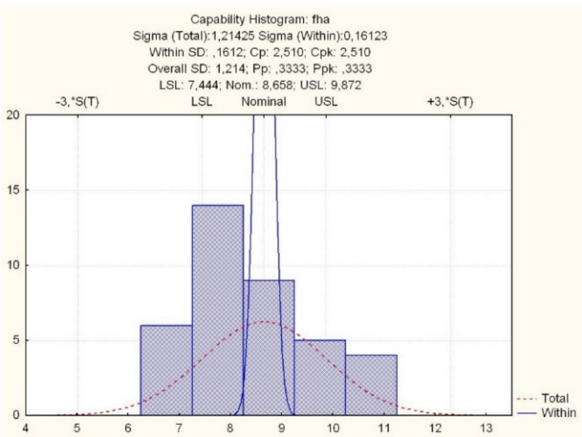
The results of the fhα parameter analysis show that at the nominal value of 8.658 and tolerance limits of LSL = 7.444 and USL = 9.872, the distribution of measured values generally follows a normal distribution, but there is noticeable dispersion, which negatively affects process stability. The process capability coefficients Cp and Cpk (2.510) confirm the high short-term accuracy of processing, but the low values of Pp and Ppk (0.333) indicate problems with long-term repeatability caused by external and technological factors, such as tool wear, equipment rigidity fluctuations, or temperature instability. The majority of measurements are concentrated near the nominal value, but some values exceed the specification tolerances, which can lead to defects. To ensure stability and compliance with DIN 3962 requirements, it is necessary to reduce dispersion, optimize processing modes, increase the rigidity of the “machine-tool-workpiece” system, ensure control and stability of the temperature environment, and improve the technical control system at all stages of production.



total – total distribution of parameter deviation ffα; within – internal variability of the parameter deviation process ffα

Figure 6 – Histogram and normal distribution law of tooth profile parameter deviation ffα

Source: developed by the authors

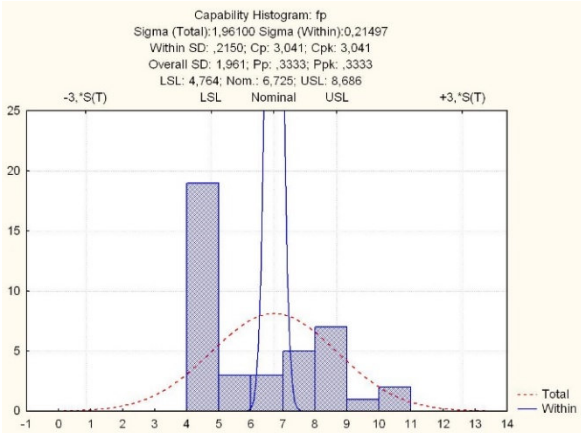


total – total distribution of parameter deviation fHα; within – internal variability of the parameter deviation process fHα

Figure 7 – Histogram of the normal distribution law of deviation in the tooth profile direction parameter fHα

Source: developed by the authors

The results of the fp parameter analysis show that at the nominal value of 6.725 and tolerance limits of LSL = 4.764 and USL = 8.686, the distribution of values is close to normal but has a left skew, indicating asymmetry in the manufacturing process. High short-term coefficients Cp and Cpk (3.041) demonstrate the process's ability to ensure precision within tolerances, but low Pp and Ppk (0.333) and a significant overall standard deviation (1.961) indicate long-term instability and increased dispersion of results. The main concentration of values near the lower tolerance limit, as well as the output of some data beyond it, can cause defects due to violation of the accuracy of the tooth pitch. To improve stability and compliance with DIN 3962, it is necessary to optimize processing modes, increase the rigidity of the technological system, monitor the condition of the tool, and reduce the influence of external factors, which will improve the long-term reproducibility of the fp parameter in serial production.



total – total distribution of parameter deviation Fp; within – internal variability of the parameter deviation process Fp

Figure 8 – Histogram and normal distribution law of the deviation of the accumulated error parameter of the tooth pitches Fp

Source: developed by the authors

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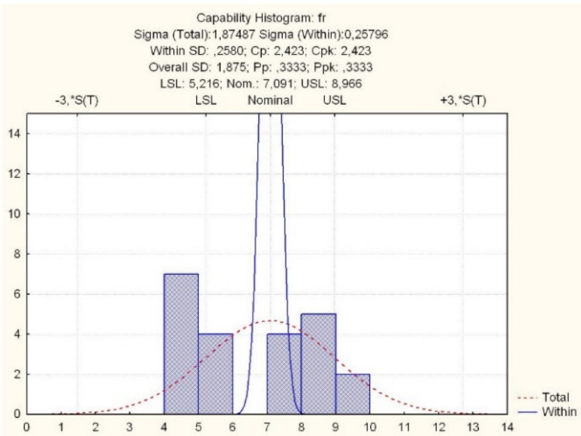

total – total distribution of parameter deviation Fr; within – internal variability of the parameter deviation process Fr

Figure 9 – Histogram and normal distribution law of the radial runout parameter deviation of the gear rim Fr

Source: developed by the authors

The results of the fr parameter analysis show that at the nominal value of 7.091 and tolerance limits of LSL = 5.216 and USL = 8.966, the distribution of values is close to normal but has a left skew, and some of the measurements fall below the lower tolerance limit. High short-term Cp and Cpk coefficients (2.423) indicate the process's ability to ensure accuracy under stable conditions, however, low Pp and Ppk (0.333) and a significant overall standard deviation (1.875) indicate instability in the long term due to external and technological factors. To ensure stability and compliance with DIN 3962 requirements, it is necessary to reduce dispersion, adjust the distribution center, stabilize processing modes, and improve the control of tool condition and temperature conditions, which will increase the long-term reproducibility of the fr parameter.

In general, the histogram in Fig. 7-9 reflects the process that has a normal distribution, but a wide dispersion of values leads to exceeding the acceptable deviation limits. This indicates the need for optimization – either by reducing the spread of values or by adjusting the center of distribution to ensure stability and compliance with the established limits.

Conclusions. Analysis of the shaving process of gear meshing in group 3 gear pumps showed that the use of this method significantly improves the accuracy of the geometric parameters of teeth and the quality of their surfaces. Reducing the roughness of the profile has a positive effect on the contact endurance and performance characteristics of parts, increasing their service life. The results of the study showed that the actual accuracy of the manufactured gears corresponds to grades 7–8 according to DIN 3962. At the same time, the greatest differences in indicators are observed in the parameters of the accumulated tooth pitch error and the radial runout of the gear rim. It has been established that the low quality level according to fHα parameter is due to the need for optimal selection of the allowance shape for shaving and the elimination of measurement errors. Periodically repeated errors in the positioning of parts during gear cutting lead to significant deviations in Fp parameter. The lack of rigid fixation of the gear cutting machine table also significantly affects the stability of this parameter. Thus, to improve accuracy, it is necessary to optimize the allowance shape, improve the positioning methods, and ensure increased rigidity of the machine tool equipment.

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Дослідження точності виготовлення зубчатого зачеплення гідравлічних шестеренних насосів гр.3

У статті представлено результати дослідження параметрів точності виготовлення зубчастого зачеплення гідравлічних шестеренних насосів групи 3. Актуальність дослідження зумовлена підвищеними експлуатаційними навантаженнями на насоси цієї групи, що вимагає забезпечення високої точності геометричних параметрів зубчастих коліс з метою досягнення оптимальних показників герметичності, зниження гідравлічних втрат та забезпечення довговічності елементів зачеплення.

У ході дослідження проаналізовано основні технологічні похибки, що виникають при виготовленні зубчастих коліс, а саме: відхилення профілю, кроку, концентричності та бокового зазору. Оцінено вплив зазначених відхилень на основні гідромеханічні характеристики шестеренних насосів групи 3, включаючи коефіцієнт корисної дії, рівень вібрацій і шуму, а також зносостійкість елементів зачеплення при високих навантаженнях. Для контролю геометричної точності застосовано сучасні засоби вимірювання, зокрема оптичну та контактну профілометрію, що дало змогу здійснити кількісну оцінку точності обробки.

На підставі отриманих даних обґрунтовано рекомендації щодо удосконалення технології обробки зубчастих коліс насосів групи 3. Зокрема, проаналізовано ефективність шевінгування як одного з ключових етапів досягнення необхідної точності. Доведено, що застосування цього методу дозволяє забезпечити досягнення 7–8 ступеня точності за DIN 3962, суттєво знижує параметри шорсткості поверхонь та сприяє покращенню контактної витривалості. Окрему увагу приділено впливу режимів термічної обробки на стабільність геометричних параметрів зачеплення, особливо в умовах роботи при змінних навантаженнях.

Під час аналізу шевінгування зубчастих коліс шестеренних насосів групи 3 встановлено, що найбільші відхилення спостерігаються за показниками накопиченої похибки кроків та радіального биття зубчастого вінця, які мають критичний вплив на рівень пульсацій об’ємної подачі та стійкість до втомного руйнування. Отримані результати дозволяють сформувати обґрунтовану технологічну стратегію виготовлення високоточних зубчастих передач для насосів, що функціонують у важких режимах експлуатації.

Таким чином, результати дослідження є значущими для підвищення ефективності та надійності гідравлічних шестеренних насосів групи 3, які широко застосовуються в енергомашинобудуванні, мобільній техніці та системах промислової гідравліки. Удосконалення точності елементів зачеплення безпосередньо впливає на стабільність вихідних параметрів насосів, таких як об’ємна подача та крутний момент, що є критичним у контексті забезпечення функціональної надійності гідравлічних систем.

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