ABSTRACT
for the degree of Doctor of Philosophy (PhD)
in the field of training 8D071 – "Engineering and Engineering Affairs",
Group of Educational Programs D103 – "Mechanics and Metalworking",
Educational Program 8D07105 – Mechanical Engineering

Tattimbek Gulerke

«Development of a method for thermofrictional treatment of teeth of coarse-modular gears»

Relevance of the Research. The State Program of Industrial and Innovative Development of the Republic of Kazakhstan for 2020-2025 is aimed at diversifying the national economy and increasing the competitiveness of the manufacturing industry, including mechanical engineering, through attracting investments, expanding exports, and introducing advanced technologies. Particular emphasis is placed on the development of knowledge-intensive industries, human capital, and industrial infrastructure.

Kazakhstan is also implementing the Comprehensive Mechanical Engineering Development Plan for 2024-2028, which is focused on increasing production output by 2.17 times and ensuring multiple growth in exports. Priority areas include automotive, railway, agricultural, mining and metallurgical, and electrical engineering industries, as well as localization of component manufacturing and the introduction of modern production technologies.

As a result of studying the state of the problem at domestic machine-building enterprises, it was revealed that there is a problem in the machining of large-module spur gears related to ensuring quality and increasing productivity, as well as to the high consumption of gear-cutting tools due to their premature wear. It was also established that more than 45% of the total volume of gears manufactured at domestic machine-building enterprises are cylindrical gears. Of these, 60% are spur cylindrical gears, the tooth spaces of which are machined by milling using disc-type module cutters employing the form-cutting method. Solving the above-mentioned problem requires the development of a method for machining the tooth spaces of spur cylindrical gears.

In this regard, the research aimed at developing a resource-saving method for machining the tooth spaces of spur cylindrical gears is a **relevant task**.

The objective of the study is to develop a resource-saving method for machining the tooth spaces of spur cylindrical gears.

Object of the study: technological processes for machining the teeth of cylindrical gears.

Subject of the study: the patterns of influence of cutting conditions on the quality indicators of thermofrictional machining of tooth spaces in cylindrical gears.

Research methodology:

The methodology of the scientific and experimental research is based on the principles of manufacturing technology, metal cutting theory, and cutting tool design.

The experimental studies were carried out using a 1K62 engine lathe and a 6M82 horizontal milling machine. The quality indicators of the machined surface, in particular surface roughness and hardness, were measured using electronic instruments, namely a TR100 portable surface roughness tester (profilometer) and a TKM-459 portable ultrasonic hardness tester.

The DEFORM 3D and ANSYS Workbench software packages were used to investigate and simulate the process of thermofrictional milling with pulsed cooling of the tooth spaces of cylindrical gears, as well as to optimize the geometry of the disc-type friction module cutter.

Research Objectives:

1. Study of the state of the problem. Analysis of existing methods and approaches to machining the teeth of large-module spur cylindrical gears. Study of the causes of their premature wear and the wear of gear-cutting tools.
2. Development of the design of a disc-type friction module cutter and manufacture of a prototype.
3. Experimental study of the processes of machining the tooth spaces of large-module spur cylindrical gears by thermofrictional methods.
4. Mathematical modeling of thermal phenomena during thermofrictional machining of the teeth of large-module spur cylindrical gears and optimization of the geometry of the disc-type friction module cutter using the DEFORM 3D and ANSYS Workbench software packages.
5. Calculation of economic efficiency. Development of recommendations for production. Implementation of the results in production.

The scientific novelty of the work is as follows:

1. Development of a method for thermofrictional machining of the tooth spaces of large-module spur cylindrical gears.
2. It was experimentally established that an increase in cutting speed and feed rate has a positive effect on the quality indicators (surface roughness and hardness) of the machined surface. Based on this, the optimal values of cutting conditions were determined:

- during machining by conventional thermofrictional milling (TFM) - n_{sp} = 2 000 rpm; S = 0,52 mm/rev;
- during machining by thermofrictional milling with pulsed cooling - n_{sp} = 1 250 rpm; S_{pr}=100 mm/min; t=22,5 mm.

3. Dependencies for evaluating quality indicators during machining were identified:

- conventional TFM - $Rz=39,31-0,0155 \cdot V+64,1 \cdot S;$
- TFM with pulsed cooling - $Rz=56-0,013 \cdot n+0,194 \cdot S-0,59 \cdot L_1;$

$HB=343,335-0,166$n+0,1·S+6,06t-1,94$\cdot L_1$

4. Using the DEFORM 3D and ANSYS Workbench software packages, a study of thermal phenomena during thermofrictional machining of the tooth spaces of large-module spur gears and optimization of the geometry of the disc-type friction module cutter was carried out, and it was established that:

- with an increase in cutting speed, the temperature value increases, while the distance of its propagation decreases, which contributes to the localization of temperature directly in the “tool-workpiece” contact zone;

- for the best candidate point, the approximate values $a \approx 3$ mm, b ≈ 10 mm and $c \approx 4$ mm were obtained at P4 ≈ 33,306 MPa, P5 ≈ 295,93 °C and P6 ≈ $-5{,}7488 \times 10^{-5}$ m.

Statements Submitted for Defense:

1. A method of thermofrictional machining of the tooth spaces of large-module spur cylindrical gears.
2. Results of an experimental study of the process of thermofrictional milling with pulsed cooling of the tooth spaces of spur cylindrical gears.
3. Dependencies for evaluating quality indicators during machining with a special disc-type friction module cutter.
4. Results of the study of thermal phenomena during thermofrictional machining of the tooth spaces of large-module spur gears and optimization of the geometry of the disc-type friction module cutter using the DEFORM 3D and ANSYS Workbench software packages.

The validity and reliability of the scientific provisions, conclusions and results are confirmed by the correctness of the formulation of the research problem and the adequacy of the theoretical and experimental studies. Patents of the Republic of Kazakhstan were obtained for the design of a disc-type friction module cutter (No. 9408) and for a method of thermofrictional machining of a surface and the design of a friction disc (No. 7579). A certificate of state registration of rights to an intellectual property copyright object of the Republic of Kazakhstan was obtained for the methodology of multi-criteria optimization of the geometry of a disc-type friction module cutter for thermofrictional machining of the tooth spaces of spur cylindrical gears.

The practical significance consists in the development of:

- a method of thermofrictional milling with pulsed cooling of the tooth spaces of spur cylindrical gears;
- a special design and manufacture of prototype disc-type friction module cutters, technological and tooling equipment;
- a methodology for multi-criteria optimization of the geometry of a disc-type friction module cutter for thermofrictional machining of the tooth spaces of spur cylindrical gears;
- recommendations for production.

The personal contribution of the author consists in formulating the objectives and developing the research methodology; developing and manufacturing special designs of disc-type friction module cutters, technological and tooling

equipment; determining optimal machining conditions; organizing and conducting experimental studies of thermofrictional milling with pulsed cooling of the tooth spaces of spur cylindrical gears.

The dissertation research is aimed at fulfilling the main objectives of the State Program of Industrial and Innovative Development of the Republic of Kazakhstan for 2020-2025 and the Comprehensive Plan for the Development of Mechanical Engineering for 2024-2028. The main results of the dissertation have also been implemented in the production activities of "KAZTECHPRO" LLP (Karaganda city, 2024).

Approbation of the research. The main provisions of the doctoral dissertation were presented and discussed at meetings of the Department of Technological Machines and Equipment of S. Seifullin Kazakh Agrotechnical Research University (2022-2026), as well as at international conferences:

- International Scientific and Practical Conference "Youth and Science – A Vision for the Future" (Seifullin Readings – 18) (Astana, 2022);
- International Conference on Integrated Innovative Development of the Zarafshan Region: Achievements, Challenges and Prospects (Navoi, 2022, 2025);
- International Scientific and Practical Conference "Development of the Mechanical Engineering Industry and Training of Highly Qualified Personnel of a New Formation" (Astana, 2025).

Publications

Based on the results of the doctoral dissertation, 15 publications in Russian, Kazakh and English have been published, including 2 articles in international scientific journals indexed in the Clarivate database or included in the Scopus database, 3 articles in journals recommended by the Committee for Quality Assurance in Education and Science of the Republic of Kazakhstan, and 1 article in a national scientific journal. Reports on the presented work were considered at 4 international conferences. 2 utility model patents of the Republic of Kazakhstan and 3 certificates of state registration of copyright were obtained.

Scope and structure of the dissertation. The doctoral dissertation consists of an introduction, five chapters and a conclusion, presented on 121 pages of typed text, including 63 figures, 15 tables, a list of references containing 101 sources, and 5 appendices.

CONCLUSION

During the dissertation work, as a result of studying the state of domestic machine-building enterprises, it was revealed that there is a problem in the machining of large-module spur gears related to ensuring quality and increasing productivity, as well as to the high consumption of gear-cutting tools due to

premature wear. To solve this problem, scientific research work was carried out and the following results were achieved:

1. A method of thermofrictional milling with pulsed cooling of the tooth spaces of spur cylindrical gears was developed.

2. The design of a special disc-type friction module cutter and a methodology for multi-criteria optimization of its parameters using the ANSYS Workbench software package were developed.

3. Dependencies for evaluating quality indicators during machining with a special disc-type friction module cutter were identified:

- conventional TFM - $Rz=39,31-0,0155 \cdot V+64,1 \cdot S;$
- TFM with pulsed cooling

$$- Rz=56-0,013 \cdot n+0,194 \cdot S-0,59 \cdot L_1$$

$$- HB=343,335-0,166\text{n}+0,1 \cdot \text{S}+6,06\text{t}-1,94 \cdot L_1$$

It was established that the most strongly influencing parameters are feed *x2 (S)* and spindle speed *x1* (n_{sp}); when they increase, the roughness value decreases. These results were confirmed during experimental studies.

4. The results of the experimental study of the method of thermofrictional milling with pulsed cooling of the tooth spaces of spur cylindrical gears showed that satisfactory roughness values (Rz = 40-18 μm) and hardness values (HB ≤ 217-248) can be ensured. It was established that an increase in spindle speed and feed rate has a positive effect on the roughness and hardness of the machined surface. The optimal machining modes were determined:

- during machining by conventional thermofrictional milling (TFM) - nsp = 2 000 rpm; S = 0,52 mm/rev;
- during machining by thermofrictional milling with pulsed cooling - nsp = 1 250 rpm; Spr=100 mm/min; t=22,5 mm.

5. The results of the study of temperature distribution using the special DEFORM 3D software package showed that an increase in the rotational speed of the disc-type friction module cutter has a positive effect on increasing the temperature in the “tool-workpiece” contact zone. At the same time, the range of its distribution into the depth of the workpiece body decreases.

6. Recommendations for production were developed. The results of the dissertation were implemented in the production of “KAZTECHPRO” LLP. The economic effect per one tool is 142,000 tenge.