ABSTRACT
dissertation for the degree of Doctor of Philosophy (PhD)
on specialty 6D071200 – «Mechanical Engineering»

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Introduction

DEVELOPMENT OF A COMBINED METHOD OF MULTI-BLADE ROTARY SURFACE TREATMENT OF MATING PARTS

Relevance of the research work

Mechanical engineering is the most important branch of the economy of any industrially developed country. Producing all the devices, machines, machine tools, instruments, as well as goods necessary for the population, the mechanical engineering industry ensures the stability of the agro-complex, energy and metallurgical sectors, transportation and other sectors of the economy. Therefore, the development of the agricultural and production machine building industry is the main goal of the state program of the Republic of Kazakhstan on the development of mechanical engineering.

Mechanical processing of parts accounts for 60% of the total labor intensity of their production. In addition, despite the widespread use of advanced methods of production of machine parts, such as precision stamping and casting, powder metallurgy, etc., for a long time it can be seen that the processing of materials by cutting is the most universal method, and in many cases it is the only possible method that can ensure the production of parts with certain operational properties. Increase of machining productivity is achieved by using new tools for machining and methods of their hardening, optimization of working angles of cutting tools, use of new technological means (fluids) of lubrication and cooling and preparation of methods of their supply to the cutting zone.

The conducted research has shown that in the machining industry the bottleneck is the manufacturing of parts with mating surfaces. In mechanical engineering the quality of mating surfaces of parts is provided mainly at the finishing operations of the technological process - grinding, lapping, polishing, finishing, etc. To the mating surfaces of parts of the body of rotation can be attributed external cylindrical surfaces on which bearings, gears, gears, gears, etc. are installed. Typical technological process of machining of mating surfaces consists of the following operations: turning (rough, finishing), grinding (rough, finishing), polishing.

The application of such different machining operations is also known to have many disadvantages. These include the occurrence of setup deviations when using different machines to perform different operations, adversely affecting surface finish and accuracy, and the need to perform multiple processes to provide the necessary surface requirements. This increases the cost of machining the part. In this regard, to solve the above problems, it is advisable to create an effective combined multi-blade rotary-friction machining method.

In combined multi-blade rotary-friction machining, two different operations are performed: heating of the machined surface layer and cutting. After heating the machined surface, good conditions are created for the cutting process, which has a favorable effect on the roughness and accuracy of the machined surface.

Purpose of the research

The purpose of the work is to develop a combined method of multi-blade rotary-friction machining of mating surfaces of parts, which provide an increase in quality indicators and reduce the mechanical operations of the technological process.

Objectives of the research:

- Analysis of the problem of providing requirements to parts having external mating cylindrical surfaces in conditions of domestic machine engineering productions;
- Analysis of existing methods and techniques of machining of external mating cylindrical surfaces of parts;
- Development of a combined method of multi-blade rotary-friction machining and tool design with the possibility of heating the machined layer for machining external cylindrical surfaces;
- Investigation of stress-strain state of parts of the combined multiblade rotary-friction tool and optimization of their parameters using special computer programs (Apm Winmachine, ANSYS, Solidworks);
- Experimental study of the process of combined multiblade rotary-friction machining with the possibility of heating the machined layer of external mating cylindrical surfaces;
- Improving the wear resistance of rotary cup cutter by researching and applying the lapping method;
- Modeling of temperature formation in contact zones of heating cup cutter and machined surface and cutting cup cutter and cutting layer in the process of combined multiblade rotary-friction machining, as well as the process of cup cutter dressing using ANSYS and LS Pre-Post programs;
- Calculation of economic efficiency of the developed technology and development of recommendations for implementation in production.

Object of research

Technologies of machining of external mating cylindrical surfaces of parts.

Subject of the research

Regularities of cutting process at combined multiblade rotary-friction machining with heating of machined layer.

Research Methodology

- Theoretical research was carried out based on the fundamentals of the science of material cutting theory, mechanical engineering technology, metal technology and basics of materials science.

- Experimental studies were conducted in the conditions of scientific laboratory bases of the departments of «TEMandS» of A. Saginov KarTU and «TME» of S. Seifullin KATRU.
- Qualitative parameters of machined surfaces were measured using electronic devices: portable roughness meter TR 100 and small-size dynamic hardness meter MET U1. During the cutting process and after stopping the machining process, the temperature was measured with a multimeter and a pyrometer.
- Investigation of stress-strain state of special tool parts and optimization of their parameters, temperature formation in contact zones of heating cup cutter and machined surface and cutting cup cutter and cutting layer in the process of combined multi-blade rotary-friction machining, as well as the process of lapping and formation of cup cutter were determined with the help of ANSYS and LS Pre-Post programs.

Scientific novelty:

1. In a comprehensive development of a combined technology for multi-blade rotary-friction machining of external mating cylindrical surfaces of parts, which includes:

- combined method of multi-blade rotary-friction machining allowing to heat the processed layer;
- design of a special combined multi-blade rotary-friction tool (SCMRFT);
- method of increasing the wear resistance of the cutting edge of a cup-cutting cutter of a special combined multi-blade rotary-friction tool.

2. The following has been found

- at combined multi-blade rotary-friction machining the temperature of heating of the processed layer reaches 180ºC, which favorably affects the implementation of the cutting mechanism;
- when using optimum regimes of running-in (n_{sp} = 40 rpm; β = 100; S = 0.81 mm/rev; t = 0.5; τp = 3 min) the period of cup cutter durability is increased by 25-30 min.

3. Dependencies are defined:

– to estimate the roughness of the machined surface $Ra = 18{,}137 + 0{,}0002n^2 - 0{,}18n - 0{,}855\beta + 0{,}014\beta^2 - 16{,}07t + 6{,}12t^2 + 0{,}87t \cdot \beta$.

– to determine the tool life $T=119{,}13+0{,}816\,\tau_n - 3{,}42S+0{,}83\,n_{sp}$.

4. For the first time the method of lapping as a way to improve the wear resistance of cup cutters was proposed and the process modeling and optimization of SCMRFT design were performed using ANSYS and LS Pre-Post PC.

Main points to be defended:

1. Combined method of multi-blade rotary-friction machining of mating surfaces of parts. Design of the combined multi-blade rotary-friction tool.
2. Results of experimental research of the method of combined multi-blade rotary-friction machining of mating surfaces of parts with the possibility of heating the machined layer.
3. Results of experimental studies carried out to improve the wear resistance of the cup cutting cutter of a combined multi-blade rotary-friction tool.
4. Equation of surface roughness dependence on cutting modes after combined multi-blade rotary-friction machining, allowing to heat the machined layer.

5. Equation of dependence of cup cutter endurance period on cutting conditions.

Practical significance consists in designing a special design of combined multiblade rotary-friction tool and preparation of its prototype, determination of optimal values of cutting modes to ensure the required quality of the machined surface of mating parts. Determination of the optimum values of modes of pre-treatment of the cup cutter for increasing the period of durability of the cutter. Development of a methodology for the study of thermal phenomena in the machining process in special computer programs, as well as optimization of tool design.

The validity and reliability of scientific provisions, conclusions and results are confirmed by the correctness of the problem statement, adequacy of theoretical and experimental studies. Patents of the Republic of Kazakhstan (RK) for the method of rotary-friction machining and design of a cup cutter have been obtained. On the method of calculating the design of multi-blade rotary-friction tool in the ANSYS WB environment the certificate of the Republic of Kazakhstan on the state registration of rights to the object of intellectual property copyright has been obtained.

Performance of work

The research work on the thesis was carried out within the framework of the grant theme "Increase of wear resistance of metal-cutting tools by the method of dressing" (registration №AP14972884)". The results of the dissertation work are implemented in the production of "Mechanical Plant RAPID" LLP (Astana, 2023 and in the process of training of bachelors on the program of mechanics and metalworking of the Kazakh agrotechnical research university named after S. Seifullin.

The author's personal contribution consists in setting tasks and developing research methods; development of special designs and preparation of prototypes of combined multiblade rotary-friction tool, determination of optimal processing modes, planning and conducting experimental studies of combined multiblade rotary-friction machining of mating surfaces.

Approbation of the work

The main provisions of the doctoral dissertation were reported and discussed:

- International Scientific and Practical Conference Saginov Readings (Karaganda, 2018-2020);
- At the meeting of the Department of TEMandS NAO "Karaganda Technical University named after Abylkas Saginov" (2023);
- at scientific seminars of the Department of "Machine Building Technology" of Y. A. Gagarin Saratov State Technical University and its branch of the Department of "Technology and Material Processing Technology" of Engels Technological Institute (Engels, Russia, 2018);
- at the technical meeting of INTECHCOM LLP (Saratov, Russia, 2018)..

Publications

According to the results of the doctoral dissertation published 18 works in Russian, Kazakh and English languages, including: 4 articles in the international scientific edition, according to the Clarivate database or included in the Scopus database, 5 articles in the editions recommended by the Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan. Reports of the presented work were considered at 5 international conferences. 2 patents of the Republic of Kazakhstan for utility model, 1 patent of the Republic of Kazakhstan for invention and 1 certificate of state registration of rights to the object of copyright were received.

Scope and structure of the work

The doctoral dissertation consists of an introduction, 5 chapters and a conclusion, set out on 169 pages of typewritten text, which are explained by 102 figures, 18 tables, a reference list of 108 titles, 8 appendices.

CONCLUSION

In the course of the dissertation work, research and analytical work carried out in the conditions of domestic mechanical engineering industries have shown that the processing of mating cylindrical surfaces of parts is an urgent problem. For processing of mating cylindrical surfaces of parts uses such machining operations as rough and finish turning, rough and finish grinding, rough and finish polishing. It is found that the use of more machining operations reduces accuracy, increasing machining errors, increases machining time and increases the cost of manufacturing the part. The following has been achieved by the performed research work to solve the above problems.

1. A method of combined multiblade rotary-friction machining with the possibility of heating the machined surface has been developed and a prototype design of a combined multiblade rotary-friction tool has been developed, which makes it possible to carry it out.

2. A method of increasing the wear resistance of cutting cup cutters of the combined multi-blade rotary-friction tool has been developed.

3. In the design of the combined multi-blade rotary-friction tool, the parameters that ensure the tool strength were determined and optimized.

4. By the method of combined multi-blade rotary-friction machining with the possibility of heating the machined surface, the optimum values of cutting modes for machining parts with mating cylindrical external surfaces have been determined.:

– for machining workpieces made of steel 45 n_{sp} =800 rpm; s =0,12 mm/rev; t = 0,3 mm, β=15º;

– for machining workpieces made of steel 40Ch n_{sp} =850 rpm; s =0,11 mm/rev; t = 0,3 mm, β=15º.

5. By processing the research results, the dependencies were revealed:

– for evaluating the roughness of the machined surface $Ra = 18{,}137 + 0{,}0002n^2 - 0{,}18n - 0{,}855\beta + 0{,}014\beta^2 - 16{,}07t + 6{,}12t^2 + 0{,}87t \cdot \beta$.

– for determining the tool life period $T=119,13+0,816\ \tau_n -3,42S+0,83\ n_{sp}$.

6. According to the results of simulation study performed in the program ANSYS WB, it was found that increasing the spindle speed when heating the machined surface of the workpiece made of steel 45 material directly affects the temperature increase in the heating zone.

7. According to the results of simulation of metal cutting process with the help of ANSYS/LS-Dyna program (LS Pre-Post) it is established that heating of the machined surface of the workpiece, when machining with a cutting cup cutter, favorably affects the temperature increase in the cutting zone and reduction of the value of total forces.

8. The optimum modes of cup cutters dressing have been determined: when machining workpieces from steel 45 and steel 20Ch n_{sp} = 40 rpm, β = 10^0, S=0,81mm/rev, t = 0,5; τ_n = 3 min.

9. According to the results of simulation studies carried out in the program ANSYS WB, it is established that the hardened layer is formed on the cutting edge of the cup cutter and its thickness is 0.7 mm when machining steel 45 and 0.3 mm when machining steel 20X.

10. It was found that the cost of machining by the method of combined multi-blade rotary-friction machining the part decreases by 156.6%, and the labor intensity of machining - by 174.8% in comparison with the traditional method of machining parts with mating surfaces.

11. The results of the dissertation work are implemented in the production of "Mechanical Plant Rapid" LLP. Expected economic efficiency is ~1.37 million tenge per year.