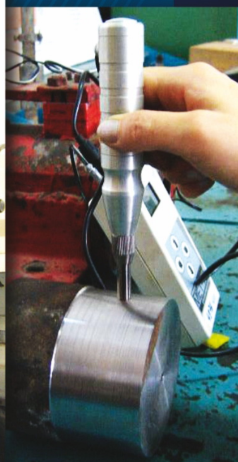
ISBN 978-83-66216-16-7

T.M. Buzauova, K.T. Sherov,
A. Zhauyt, A.S. Turusbekova

STUDY OF WEAR AND RESTORATION OF THE MINING MACHINES PARTS

MONOGRAPH





iScience
Warsaw, Poland - 2019

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN
KARAGANDA STATE TECHNICAL UNIVERSITY

T.M. BUZAUOVA, K.T. SHEROV, A. ZHAUYT,
A.S. TURUSBEKOVA

STUDY OF WEAR AND RESTORATION OF THE MINING MACHINES PARTS

Approved by the Academic Council of the University as a monograph

MONOGRAPH

Warsaw-2019

UDC 621.90 (07)
BBC 34.63-5 Z7
B83

Recommended by the Scientific and Technical Council of the University

Authors: Buzauova T.M., Sherov K.T., A. Zhauyt, Turusbekova A.S.

Reviewers:
K.M. Beisembaev – *Department of Technological Equipment, Mechanical Engineering and Standardization, Karaganda State*
B.T. Mardonov – *Vice-rector for International Relations of Navoi State Mining Institute, Republic of Uzbekistan, Doctor of Technical Sciences, Professor,*
A N. Nurzhanov – *Department of Mechanical Engineering and Standardization, S. Toraighyrov Pavlodar State University, Doctor of Technical Sciences, Professor.*

Buzauova T.M.
Study of wear and restoration of the mining machines parts: Monograph/ T. Buzauova, K. Sherov, Zh. Algazy, A. Turusbekova; Karaganda State Technical University. – Warsaw: iScience Sp. z o. o., 2019. - 126 p.

The monograph is intended for students, master and doctoral students of the specialty "Mechanical engineering" to study the process of wear and restoration of parts of mining machines, and may also be useful to students, undergraduates, engineers and specialists in various fields of activity.

ISBN 978-83-66216-16-7

CONTENTS

INTRODUCTION

Relevance of the topic. Severe operating conditions of mining equipment cause intense wear of the working surfaces of the parts of its main components and mechanisms. The large dimensions of the parts, considerable metal consumption and complexity of the structures of mining machines, their high cost, including through the use of special wear-resistant steels, lead to the need to maximize the service life of each part. In this regard, the issues of organizing high-quality repair of equipment using modern efficient technological methods for restoring the size and geometric shapes of worn-out elements for the mining industry are quite relevant, and the costs of introducing new technologies are justified both from a technical point of view and from an economic one.

A characteristic feature of modern machines is the productivity of the working process, which is associated with an increase in their working parameters (power, speed, pressure, etc.) while reducing the specific weight and dimensions of the machines. This leads to an increase in the intensity of the work units and parts, to increased wear of the mates, to a decrease in their service life. Under these conditions, increasing the reliability and durability of machine parts is the most important task, which is solved mainly by applying progressive methods of restoring and hardening worn parts. At the enterprises of the engineering industry, modern equipment has a fairly high reliability. However, during operation, equipment is exposed to various factors, as a result of which operational reliability is reduced and the occurrence of failures becomes increasingly possible.

CHAPTER 1. ANALYSIS OF THE RESEARCH ON THE RESTORATION OF WORN CONJUGATING MINING MACHINES

The mining industry is characterized by a high level of technical equipment, where more advanced technological schemes are applied, requiring a large number of machines and devices in the processing line. The development of enrichment technology occurs along the path of complicating technological schemes while simultaneously increasing the capacity of the factories and the speed of the processes. In the buildings of the processing plants with developed technological schemes, up to 30-50 units operate in one sequential circuit [1, 2].

Machines for medium and small crushing of ores at the processing plant of the Republic of Kazakhstan are cone-type crushers (CC). The technological scheme of crushing of copper ores in CC-2 is given in Appendix B. Crushers for medium and small crushing are a cone-type gravitational crusher, which is crushed continuously between a fixed outer crushing cone (regulating ring) and a gravitationally moving (swinging relative to a fixed point with a constant amplitude) internal crushing cone [3].

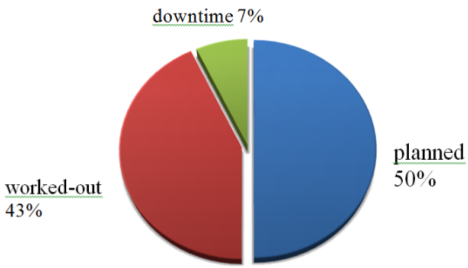
The advantage of these crushers is a relatively high degree of crushing of the material, a uniform composition of the product by size, the possibility of a relatively wide regulation of the discharge gap.

Mining and processing machines designed for grinding ores and materials are most intensively subjected to abrasive wear [4].

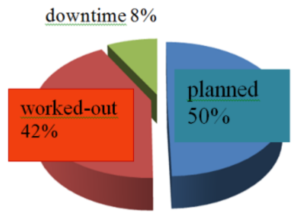
A characteristic feature of the work of mining and processing plants is the threading of a continuous process. All equipment is connected to a single technological chain, thus stopping or refusing to operate any machine making up this chain leads to stopping of the whole chain. In order to prevent such emergency stops, all without exception chain links, both of the machine and of intermediate devices, must comply with the service life, i.e. to withstand operational periods of work. The time spent on the replacement of parts of the processing machines, leads to downtime of the technological chain of equipment, which leads to high economic costs and inefficiency of the processing equipment [5, 6].

Wear deteriorates the interaction of parts and components, can cause significant additional loads, shocks in mates and vibration, and cause sudden damage [7].

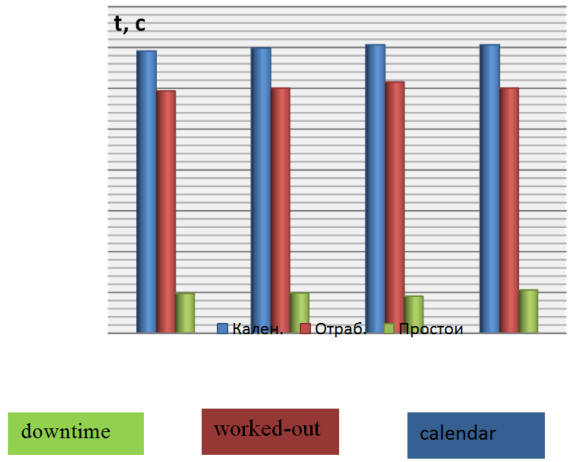
The level of technical use of cone crushers (2016-2018) was studied at the processing plant in Zhezkazgan. Using statistical data on the operation of cone crushers at the enterprises of LLP Kazakhmys Corporation, their downtime was identified (Figure 1.1, a, b, c).



a)



b)



c)

Figure 1.1 - Data work of the cone crushers at the enterprises

LLP Kazakhmys Corporation respectively for 2016, 2017, 2018

The graphs show that downtime of the cone crushers during 2017-2018. is 7-9%, which in general has a significant negative impact on the performance of the technological chain, because equipment downtime in a given circuit disrupts the entire cycle. The analysis of statistical data revealed inconsistencies in the operation of the cone crusher with operational characteristics, as well as the causes of downtime for the relevant periods (Figure 1.2)

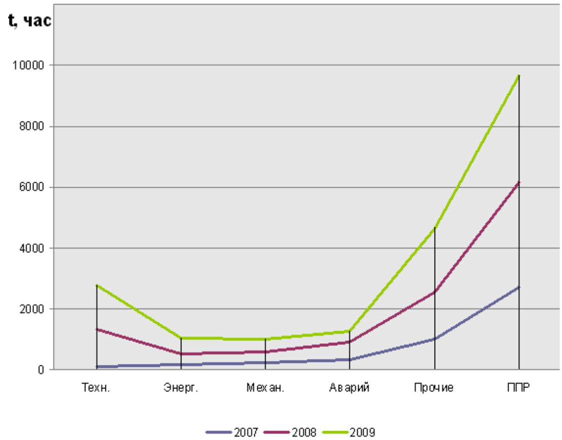


Figure 1.2 - Downtime for reasons during 2016-2018

According to Figure 1.2, it is observed that the largest share of downtime falls on scheduled repairs and routine inspections. Downtime due to faults is 8-12% according to cone crushers (average and small crushing).

The main reasons for the failure of cone crushers are the following: failure of the armor of the cone and the middle part, the protective cap, parts of the upper suspension, rings of dust compaction, thrust rings, eccentric crusher [8].

The study also determined the average service life (years) of some main parts and assemblies of cone crushers for medium and small crushing. Identified data is shown below:

Cone average crusher (CAC)-2200:

Lower and middle rings of the lower part... 5

Washer and sleeve of the fixed crosshead ………..3.5-4

Shaft eccentric …………………………………....1.5-2

Cone small and thin crusher (CMTC) -2200:

Middle bottom ring ……………………................2

Details of the upper suspension (fixed sleeve, washer, sleeve tapered) ……...3.5-4

Shaft eccentric …………………………………....1-1,5

From the above, it is observed that in a CAC and a CMTC the eccentric is the most vulnerable, although the eccentric by its functional purpose performs an important function in the operation of crushers, therefore extending the life of this node is relevant.

The reasons for the failure of the eccentric of cone crushers CAC-

2200 and FCC -2200 are given in table 1.1.

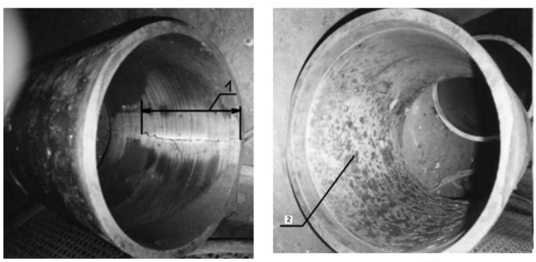
Table 1.1- Causes of failure of the eccentric of cone crushers CAC-2200 and FCC -2200 (in% of the total number of failed)

Place of use	Eccentric					
	Abrasive wear		Casting defects		The others	
	MCC	FCC	MCC	FCC	MCC	FCC
CC №2	75	85	10	5	15	10

As the analysis of the above data shows (Table 1.1), due to abrasive wear, the eccentric assembly of FCC cone crushers used at the beneficiation plants of LLP Kazakhmys Corporation is most often replaced. The most typical type of failure of this cone crusher unit is abrasive wear, cracks, flaking of babbitt pouring of its inner and outer surfaces caused by dynamic loads (Figure -1.3, a, b).

As the eccentric, which has a large mass, is used, only a small metal layer is involved in the work, therefore, theoretically, 5-6 mm is considered the ultimate wear. The wear surfaces of the eccentric casing are the outer diameter from the base Ø637 with a length of 500, and from the side of the collar.

In the factory, the part is restored using the “wrapping” method on worn out surfaces. When using this method as it was used, it turned out that the repaired surface becomes more vulnerable “soft” and, as a result, quickly wears out, therefore, the ore beneficiation process cycle is broken, which leads to an increase in the cost of production.



a) b)

a) 1-cracks on the inner surface with a length L = 350mm;
b) 2-peeling of babbitt coating on internal surfaces by 85%
Figure 1.3 - Cylindrical bushing wear

1.1 Object of study

Crushing is the process of reducing the size of pieces of a mineral as a result of their destruction by the action of external forces that overcome internal forces of adhesion of particles of a solid. Crushing can be a basic process or preparatory. Crushing at the processing plants is a preparatory process, since It aims to prepare the source material for further grinding and enrichment.

The forces required to destroy pieces of material are developed in crushing machines, called crushers. Cone crushers are used as crushing aggregates for crushing factories of high productivity (12-15 million tons per year and more). The process of destruction in such crushers occurs between the inner surface of the fixed and the outer surface of the rolling cone due to periodic convergence and divergence of the cones forming these. When the generators come together, the material is crushed, and when they diverge, the material is discharged down. The crushed product from a coarse crusher can be fed directly by a belt conveyor to a crusher for medium crushing [9].

Crushers FCC of all versions in accordance with State Standard 69.37-69 and State Standard 5.833-71 "Cone Crushers" are designed for crushing ores, non-metallic minerals and similar materials.

The crusher FCC-2200 is designed for small, thin crushing with a cone armor diameter $\varnothing$ 2200 mm (Figure -1.4). The crushing material is subjected to 4-5 fold clamping during the passage of the working space and is ejected from the crusher under the action of gravity and inertia force that occurs when the taper is rocked [10].

The main parameters and characteristics of FCC-2200 are listed in table 1.2.

The eccentric is one of the main details, on the accuracy, the restoration of which largely determines the performance of the cone crusher. An eccentric is a cylindrical thick-walled part with an offset center of the axis - eccentricity: l up. = 41.85 mm, l down. = 94.23 mm and lifting angle $\alpha=2°$, loaded surface length 1 = 1500 mm, the largest Ø700 mm, mass m = 2040 kg. The eccentric unit is subjected to vibrations, shock and variable loads during the operation of the crusher.

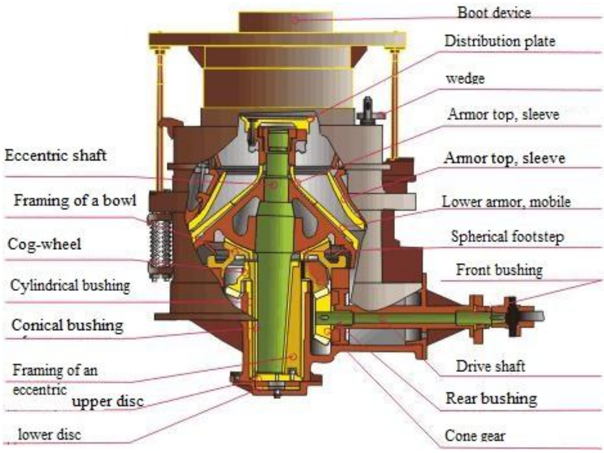


Figure 1.4 - General view of a FCC-2200

Table 1.2 - Technical characteristics of FCC – 2200

Name of parameters	Norm
Productivity (with a bulk density of material, 1,6t / m^3), m^3 / h	75-220
The diameter of the base of the rolling cone, mm	2200
Loading slot width, mm	130
Width of the discharge gap, mm	5-20
The length of the parallel zone of the slit, mm	350
The largest size of the loaded pieces, mm	100
Approximate force T: crushing, kN - at hit of not crushing body, kN	300 400
Speed of rotation of the eccentric, rpm	224
Drive motor, type	AZD-13-52 and AZD-13-5212T
power, kWt	220-250
Voltage, V	3000 or 6000
Net weight, kg	82000

In the course of the analysis, it was established that only a small metal layer is involved in the work, therefore, we determine the wear limit and the expected period of operation of the node in order to choose one or another method of recovery.

CHAPTER 2. DETERMINATION OF THE WEAR OF MACHINE PARTS

2.1 Features of the flow of abrasive wear in the coupling

Wear is a change in size, shape, mass or surface condition of a product or tool due to the destruction (wear) of the surface layer of the product during friction.

Wearing parts, working parts and tools is a natural process that inevitably accompanies the work of machines, mechanisms, industrial equipment and represents one of the forms of their physical aging. Wear leads to changes in the size, shape and condition of the working surfaces of the parts and thus causes a gradual decrease in the functional qualities and performance of the machines, as well as an increase in the probability of their failure. The wear resistance of parts determines the amount of expenditures on maintaining machines in working condition and the overall service life until decommissioning.

Ensuring high wear resistance of parts is one of the prerequisites for reliable operation of machines and obtaining the maximum economic effect from their use, because it is due to wear that most of the moving elements (80–90%) of moving parts and working parts of machines are lost. Opportunities to improve wear resistance are continuously expanding thanks to the improvement of structural and lubricating materials, structures and manufacturing technology of machines. This allows you to successfully solve the problem of ensuring the required service life, despite the rapidly growing tension of the machines work.

Among the various types of wear of machine parts, the most common and fast-flowing is abrasive, in which the destruction of the surface layer of parts is carried out by solid particles that are in different states and affect the material differently. The search for ways to increase the resistance to abrasive wear is connected with ensuring optimal durability of most machines and equipment used in agriculture, construction, mining, etc.

The prevalence of abrasive wear is caused not only by the fact that many machine parts, their working bodies and tools according to the nature of their functions inevitably come into contact with materials that can cause an abrasive wear process (soil, soil, rocks, construction materials, ore, etc.) Abrasive wear suppresses less intensive processes of wear of parts and in those cases when contact with extraneous solid particles is not related to the operation of the machine, but is due to pollution of the environment, since it is almost extremely difficult to completely eliminate contamination by solid particles of ambient air, water, and lubricants, fuel and various technological media in contact with the friction surfaces of machine parts.

2.2 Types of abrasive wear of machine parts

For a long time, researchers attributed abrasive wear exclusively to the cutting effect of abrasive particles, which seemed completely obvious and had not been questioned for several decades. Starting with the work of the French researcher F. Robin (1910), in experimental studies of abrasive wear and wear resistance of materials, tests were carried out by rubbing samples on the surface of an abrasive cloth, grinding stone or file, i.e. is not only possible, but also the most likely result.

Studies of abrasive wear, started by the author in 1952, were conducted in relation to the working conditions of parts of mining machines. Coal particles could not remove the microblog on metallic materials, and meanwhile the details of coal machines weighed very intensively. Studies have shown that abrasive particles, in contact with the surface layer, create in it a wide range of contact stresses, the nature of the distribution of which and the upper limit of numerical values depend on the properties of the wearing material, as well as on the hardness, shape, size of particles and the conditions of their impact on the part surface. Abrasive particles, like the unevenness of rough surfaces, are involved in friction and the transfer of load from one rubbing body to another, creating a non-stationary system of single friction contacts. The mechanism of destruction of the surface layer of the material under the action of abrasive particles can be significantly different, since the levels of contact stresses arising are different.

Abrasive wear is the most common type of wear on machine parts. This is due not only to the fact that many parts of machines and, especially, tools, by the nature of their functions, are in direct contact with materials capable of causing abrasive wear (soil, soil, building materials, coal, ore, etc.), but also and the fact that abrasive wear due to localization and a high degree of concentration of contact stresses and the resulting relatively high intensity of destruction of the surface layer, as a rule, even with a small number of abrasive particles suppresses others Gia types of wear. So, abrasive wear is ahead of the destruction of the material during chipping, cavitation and other types of wear with a lower level of contact stresses.

Under the abrasive wear is commonly understood as the process of direct destruction - microcutting of the surface layer of the part with solid (abrasive) particles. The term “abrasive” itself, derived from the Latin word abrasio - scraping is associated with this representation. But in this paper, the term "abrasive" is applied more generally to determine the types of wear caused by extraneous hard ("abrasive") particles, regardless of whether they cause micro-cutting of the material or some other type of destruction.

The resulting terminological inconsistencies, of course, are known inconveniences, however, it should be taken into account that the presence of abrasive particles and their participation as active agents in wear is always determined unmistakably, while special studies are required to establish their cutting action. Wearing a plow blade, for example, is considered abrasive due to the fact that it is caused by the soil mass, leaving aside considerations about the mechanism of wear.

Wear caused by solids has distinctive features. This is primarily a high degree of concentration of contact stresses caused by abrasive parts in the surface layer; then, strongly pronounced discreteness and mutual independence of frictional contacts. If discreteness is peculiar in general to all types of contact of solids, then independence of contacts is inherent only in the interaction of wearing surfaces with abrasive particles, as well as with flows of liquid or gas. The formation of contact areas in this case occurs differently than for mating rough surfaces, which is one of the features of abrasive wear.

The type of wear is determined by the nature of the interaction of abrasive particles with the surface layer of the material.

2.3 Abrasive wear processes

The process of abrasive wear is unambiguously determined by the type of destruction of the surface layer and softening of the material. The identification of these two components makes it possible to establish the identity of the phenomena causing the abrasive wear of different objects. In the process of wear, it is possible to increase the strength (hardening) of the material, which, however, in most cases does not lead to a qualitative change in the process of wear (does not change the type of fracture), affecting only the intensity of the destruction of the material.

There are four main types of material softening under friction: mechanical, thermal, adsorption, and chemical.

Mechanical softening occurs as a result of the deformation of the surface layer, leading to the occurrence and development of structural defects, embrittlement of the material, an increase in internal stresses, etc.

Thermal softening of the material occurs under the action of heat generated by friction (for example, tempering of steel, softening of polymers, etc.).

Adsorption softening is the result of the physical interaction of the material with surface-active substances, causing a decrease in hardness and dispersion work [36].

Chemical softening is characterized by the formation of products of chemical interaction of the wear material with the external environment or by the flow of internal chemical and mechanochemical processes relaxing materials, in particular, in polymeric materials [36, 40]. In actual conditions of friction, combinations of various types of softening are possible - physicochemical, mechanochemical, etc.

Under the given conditions of abrasive impact, a well-defined wear process takes place in this material, but in different materials the wear processes may be different. A change in working conditions within certain limits is not accompanied by a change in the wear process, but only affects its intensity. Wear is a self-adjusting process, depending on the external conditions and the properties of the wear material.

In a wide range of abrasive wear conditions of various materials, abrasive particles can cause the destruction of the surface layer of the following four types: brittle, viscous, polydeformational and fatigue.

Fragile and ductile damage (micro-cutting) occurs during a single action of abrasive grain and will be referred to as direct destruction in the future, unless an indication of their nature is required.

Polydeformational and fatigue fractures occur during cyclic deformation of the material by abrasive grains, respectively, in the plastic and elastic regions. These types of destruction in the following presentation are called multi-cycle.

The term “polydeformation destruction” was requested instead of inconvenient and verbose expressions of the type — separation of particles due to repeated deformation (re-deformation), destruction due to over-hitting, etc. This type of destruction is also called deformation.

From the standpoint of the dislocation theory, the separation of brittle and viscous damage is conditional, since in both cases dislocation movements occur, which does not allow us to speak of the absence of residual deformations preceding brittle fracture. But practically, when diagnosing the type of surface destruction, relatively rough external signs are used, which allow to unambiguously qualify typical viscous fracture with obvious traces of plastic deformation of the material.

Characteristic features of the fatigue process of material destruction in the volume — the presence of a latent period, the dependence of the number of cycles to failure on the level of acting stresses, sensitivity to the environment, etc. are in some way or other characteristic of the contact cyclic action of abrasive particles, but a complete analogy between volume and contact fatigue is still not available. When the surface layer of material is deformed by abrasive particles, the degree of concentration of contact stresses is relatively high, and they are continuously redistributed due to the multiplicity and independence of contacts. In addition, there are features due to the scale effect and a much stronger effect on the material of the external environment under conditions of contact deformation.

The concepts of wear as a multi-cycle process of plastic deformation developed by a professor P. E. Dyachenko (Institute of Mechanical Engineering), who showed that when a part is rolled around by a roller, the material is superficially destroyed due to “over-hardening”.

Professor I. V. Kragelsky offered a quantitative theory of the wear and tear of solids, taking into account the fatigue nature of surface damage, which, by its basic ideas, turned out to be applicable for abrasive wear [37, 38].

The processes of abrasive wear are divided into simple, mixed and complex.

Simple processes of wear are characterized by the development of the destruction of the material of any one type. No softening of the surface layer during simple wear processes. There are four simple abrasive wear processes for the number of types of destruction. Two of them, during microcutting, are reproduced, in particular, by friction of samples of materials on an abrasive cloth with hard and sharp grains. Mixed wear processes are characterized by the simultaneous action of several (usually two) types of destruction; here, as with simple processes, material softening

2.4 Formation of the processes of materials wear

In each of the materials, under externally identical conditions, a well-defined wear process is formed under the influence of factors depending on the hardness, shape and loading of abrasive particles, and also depending on the intensity of mechanical, thermal, adsorption and chemical strengthening. Wear of materials is a self-adjusting process, since it depends on the reaction of each material on the mechanical action of abrasive particles and on the nature of its interaction with the external environment.

We consider the general scheme of the formation of simple processes of wear materials *A*, *B*, *C*,..., *Q*. In the surface layers of these materials, under the same wear conditions, different contact stress spectra arise; values of indicators of strength properties (сг, $а_т$, o_n) of these materials are also different. The resistance of materials to wear depends on the level of contact stresses and the ratio

In the study of abrasive wear and wear resistance of materials in recent years, significant progress has been achieved. Many researchers have invested in the knowledge of the mechanism and patterns of wear, in creating the foundations of the methodology for studying the durability of materials and machine parts, in solving numerous complex practical tasks.

Wear parts determine the need for maintenance repairs and the release of spare parts for this, the cost of which depends on the wear resistance of the rubbing elements of the machines. The latter is, as a rule, the decisive factor in regulating the overall service life of machines in connection with the exhaustion of economically feasible opportunities to further maintain their performance.

The mutual dependence of the service life of the elements and the system of these elements that make up the machine is quite obvious. For most modern machines, solving the problem of ensuring economically justifiable durability requires the establishment of well-defined relationships between the service life of the elements and the system as a whole, taking into account the technical and economic admissibility of replacing part of these elements with new (restored) machines. The search for optimal ratios is not simple, since in each particular case it is necessary to determine the measure of the permissibility of the inevitable compromises between the requirements of production and operation of machines. The cost of a machine is an integral part of the cost of its products, but the total quantity of these products, all other things being equal, depends on the duration of the machine’s operation. In this regard, it is necessary first of all to establish a rational service life of this machine, and then, in the process of designing and refining, ensure that the service life of parts at which the use of a machine within a specified period of time ensures maximum economic efficiency of the specified technological process.

2.5 Determination of wear in coupling

Depending on external influences on the surface of friction, the properties and structure of the surface layers of the material and the processes occurring in them, the nature and intensity of the surface destruction during friction have a different character.

Parts and friction units of most machines and equipment used in the mining industry, agriculture, crushing and grinding machines and equipment for processing industries, etc. are subject to abrasive wear.

Wear occurs when the friction of two mating surfaces, and both surfaces wear simultaneously. This leads to a change in the relative position of the coupling surfaces [11].

The cause of wear of the eccentric unit is the action of friction forces, in addition, due to the change of forces, the resistance of the crushing cone to movement causes fatigue phenomena, internal stresses and dynamic loads are redistributed, which also causes wear [12, 13, 14].

As a result of wear, the dimensions and geometric shape of parts change. When the tapered bushing is worn out and the outer diameter of the tapered shaft, the eccentric shifts relative to the axis and captures the cone shaft, thus increasing the number of revolutions of the cone, in other words, "rushing" occurs.

The crusher works in a constant mode, and also depending on the load; therefore, during the operation of the machine, the initial fit changes in the pairing of the eccentric knot. Large gaps in the joints of the eccentric 2a and 2c (Fig. 2.1) adversely affect the operation of the cylindrical and conical sleeves, for this reason, the vertical shaft works with blows from which the sleeves are destroyed. The clearances of the eccentric assembly and their inspection should be within the following limits [15]:

- cylindrical, clearance c. $2^{+0,4}_{+0,1}$
- conical, gap a. $1,5^{+0,5}_{+0,1}$
- conical, clearance b $4,2^{+0,5}$

At idle, the cone shaft of the crushing cone should fit snugly to the thin side of the eccentric when it presses with its thick side to the cylindrical bushing pressed into the central glass of the bed [15, p. 23].

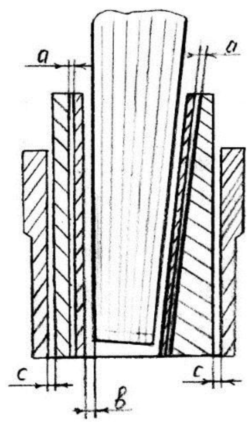


Figure 2.1 - Clearances in the joints of the eccentric

This important condition is necessary to create the minimum pressure on the sleeve from the forces of inertia that have arisen in the crushing cone during normal rotation. When crushing, the tapered shaft fits snugly to the thick part of the eccentric, which is pressed by the thick side to the cylindrical sleeve. Thus, at idle and working stroke, contact between the lower end of the shaft and the moving cone is ensured along the entire height of the eccentric bushings [10, p. 15]. However, in the process of operation, the crushing cone deviates by its large mass to the thick side of the eccentric (upper), and the lower end of the shaft abuts against the lower thin part of the eccentric, thereby the eccentric is under pressure and load in these I-III, IV-VI points. Figure 2.2 shows that in sections I-III, IV-VI there is a gradual wear.

To predict a trouble-free period of work, it is required to make measurements of the wear of the eccentric. Measurements were made on the eccentrics removed (assembled with a gear wheel) in the direction from the base to the top; in sections I-VI, regularities of eccentric wear were revealed before it reached the limiting state (Table 2.1).

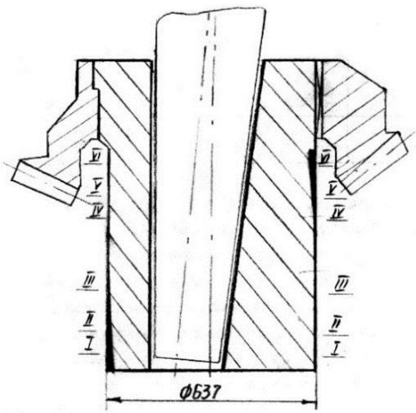


Figure 2.2 - Eccentric node

Table 2.1 - The results of measurements of the wear values of eccentrics

Eccentric cross section, N²	The amount of eccentrics wear, mm.			
	1	2	3	4
1	1,66	2,38	1,6	1,025
2	1,53	2,21	1,3	0,95
3	2,47	2,62	2,85	2,35
4	2,52	2,81	2,93	2,43
5	3,47	3,4	3,7	3,66
6	4,28	4,15	5,17	4,43
Operation time, month.	12	10	8	9

Next, we construct the dependence of the wear value on the cross section of the eccentric (Figure 2.3).

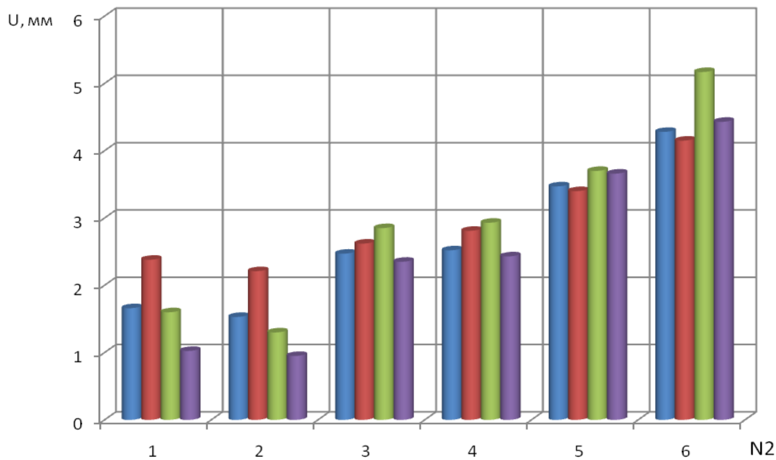
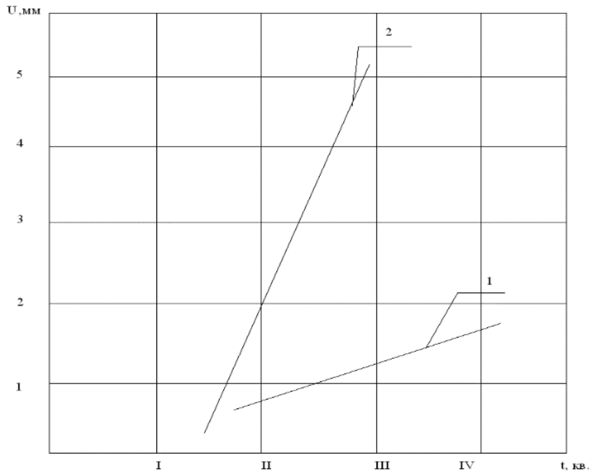


Figure 2.3 - Dependence of wear on the sections of the eccentric

From figure 2.2 it can be seen that the wear rate increases from the base of the eccentric to the top. It is important to notice how wear flows through these sections. It is required to identify, according to these sections, for what period of work the eccentrics reach the limit of wear (Figure 2.4).



1-the planned uptime; 2-the average uptime

Figure 2.4 - Duration of the eccentric work

In the course of the research, it was found that when the eccentric wear reaches 4-5 mm, in fact it will reach maximum wear, as a result, the gaps in the joints increase. Consequently, in 240 days or 8 months the eccentric will reach the limit of wear or fail.

Famous works of researchers [11 p. 45; 12 p. 57; 13 p. 12] to increase the service life of the cast eccentric by restoration to the repair size, which was used at the enterprises of the Republic of Kazakhstan does not provide the necessary increase in the reliability of the restored part.

An effective means of improving the quality of restoration is the hardening processing of the surfaces of parts, which makes it possible to significantly increase the fatigue strength of the metal and other operating characteristics of the machines [16, 17].

The use of hardening processing in the recovery of parts of mining and processing machines increases the service life and provides significant cost savings.

To increase the service life of parts of mining production working in aggressive, hydroabrasive environments, it is necessary to apply restoration methods that increase the service life of the restored part by increasing the wear resistance of the surface layer [18, 19].

Therefore, an increase in wear resistance can be achieved by using new equipment recovery technologies.

CHAPTER 3. ANALYSIS OF EXISTING METHODS FOR THE RECONSTRUCTION OF MINING EQUIPMENT PARTS

3.1 Ways to restore parts

In repair practice, the following basic methods of restoring worn parts are used: mechanical and metalworking, welding, surfacing, metallization, chrome plating, nickel plating, steel plating, gluing, hardening the surface of parts and restoring their shape under pressure. As a rule, after the restoration of the part in one of the ways, it is subjected to mechanical or metalworking, which is necessary to restore the fit of the mating parts, eliminate ovality or taper of their surfaces, ensure the required cleanliness of processing.

Mechanical and metalworking restore parts with flat mating surfaces (guide beds, strips, wedges). When the guides are worn up to 0.2 mm, they are restored by scraping, when worn up to 0.5 mm - by grinding, and when worn more than 0.5 mm - by chipping, followed by grinding or scraping [1].

When repairing shafts, axles, screws, etc., their center holes are first checked and repaired. After this, surfaces with minor wear (scratches, risks, ovality up to 0.02 mm) are polished, and with more significant wear they increase, grind and grind to repair size.

When repairing worn parts, it is often difficult to choose a method for basing the part to be processed due to a change in the main installation base of the worn part. In such cases, they are guided not by the main installation, but by the auxiliary bases, and from them they process working surfaces. Along with the restoration of parts by machining during repair, the unusable part is sometimes replaced with a new one.

3.2 Restoration of machine parts and mechanical and mechanical processing

Mechanical processing is applied both independently and together with other technological processes (plastic deformation, metallization, welding and welding) [2]. The processing of each part is individual and allows you to obtain the necessary surface roughness of planting and other exact dimensions that meet the requirements of interchangeability of parts. This leads to the fact that the production is single or small-scale.

By machining, the following parts are restored: a) for a new (different from nominal) size; b) under the nominal size.

Repair of parts for a new (different from the nominal) size is performed: by the method of obtaining an individual size and by the method of obtaining repair sizes.

The method of obtaining an individual size is that the more valuable and complex part is repaired until the damage is repaired, and the simpler and cheaper part mated to it is either fitted to it or re-made. The dimensions of the parts are arbitrary, only the specified fit is preserved, there is no interchangeability. During the repair of the first (main) part, the minimum metal layer is removed, which increases the service life of the part, but this requires a great deal of time for fitting and high qualification of the worker. This method applies only to single, particularly complex and expensive parts, as well as for some easily fitted parts (when sliding the bearings, when fitting the brake pads) or in the case where the parts of the assembly unit are not interchangeable.

Repair of parts for repair size is that a metal layer is removed from the main part (for example, a cylinder, a piston pin), keeping the original tolerance for size. The mating part (piston or piston pin bushing) is manufactured to the repair size with the original tolerance.

Repair size is a pre-set size, different from the factory, nominal, under which the part is repaired.

At repair of details under the repair size the metal layer is removed; this reduces the mechanical strength and rigidity and increases the specific pressure, and this affects the service life and the nature of the work details. Therefore, set the size limit.

The limiting size is called such a part size, at which its further operation or repair (by further metal removal) is unacceptable and the part is finally rejected or repaired to its nominal size.

Repair by way of additional repair parts (RP) is widely used in the restoration of worn holes due to the placement of sleeves, bushings, rings or screwdrivers in them. In addition, this method involves the replacement of individual parts of the parts - the defective part is removed, and an additional part is put in place of it. This method of repair allows you to repair parts with significant wear. At the same time, the part does not heat up, and therefore its structure is not disturbed and a high quality of repair is obtained.

This way is repaired:

1) holes - setting repair sleeve, sleeve or ring;
2) shafts - by pressing a sleeve, ring or setting half-sleeves;
3) parts of various shapes - a method of removing a defective one and installing a new element of a part: replacing a ring gear, a spline hub, a

spline end, etc;

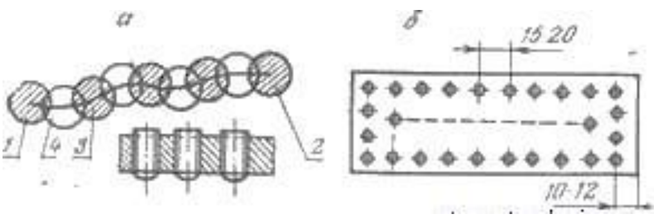
4) flat surfaces - setting slats or linings.

Repair of parts by metalworking and mechanical processing is carried out by grinding, scraping, filing, pinning, patching and gluing [3].

The lapping is effective in cases when it is necessary to obtain a very tight fit of the surfaces. In this case, one detail is ground to the other, or each of the parts - to the third, previously checked (grinding on the plate). In a number of mates, due to wear and tear, the fit density and the tightness of the connection are disturbed. If the surface defects of these parts are small, grinding and grinding in (for example, engine valves) are applied. Solid abrasive powders (GOI pastes, sandpaper, crushed glass, aluminum oxide, chromium or iron) mixed with mineral oil, kerosene or turpentine are used as lapping materials. In a mechanized way, parts are ground on special machines and devices.

Scraping gives an accurate and clean surface after pre-processing it with a file, cutter or other cutting tool. Scraping is used when removing a small layer of metal. This method achieves high accuracy - up to 30 carrier spots per square 25X25 mm, surface roughness no more than Ra = 0.32 microns. The surface treated with the scraper is well lubricated, as the lubricant is kept in the resulting scrubbing risks. Scraping is widely used in fitting the plane of the connector parts, guides, bearing shells, bushings, etc.

The filing is used to remove roughness and burrs from the surfaces in order to fit the mating surfaces. Filing process planes, grooves, holes of any shape, surfaces located at different angles, etc. To give sawdust surfaces of greater purity of finish, they are cleaned with files with chalk, sandpaper and grinding wheels of various grades. Filing and cleaning of parts is mechanized using filing and filing-stripping machines, as well as manual filing, filing-grinding and cleaning machines [5].



a - pinning; b - with patch application

Figure 3.1 - Scheme for repairing cracks:

By pinning, they restore tightness and operability of parts with small cracks. When pinning surface around the cracks cleaned and at the ends of the cracks drilled holes (Fig. 3.1, a) for threads with a diameter of 4... 6 mm so that the crack could not spread further. After that, they mark and center the hole in such a way that hole 4 overlaps the diameter of the hole by 7 times. The holes in the holes cut the threads and screw the pins into them. The protruding ends of the pins are cut off at a distance of 1.5... 2 mm from the surface of the repaired part. Then pin and drill the hole, cut into it the thread and screw the pin. In such a sequence, the pinning is continued until the entire crack is filled with the pins. After that, the protruding parts of the pins are punched, washed down and soldered with soft solder.

The item repaired in this way is tested for tightness; in the event of a leak, it is eliminated by underpinning the pins. This method repairs the water jacket of the internal combustion engine and other parts.

Cracks and holes that have a significant length or area are usually sealed with patches.

The patches on the screws are set as follows (Fig. 3.1, b). The surface of the part around the cracks or holes are cleaned. The ends of the crack are drilled with a drill diameter 3... 5 mm. Then cut a patch of this size so that it covers a crack or a hole by 25... 35 mm. Patches are made of copper, brass, aluminum or steel. The thickness of the patch depends on the size and purpose of the repaired part. The patch is customized in place by light blows of a hammer [6]. Further, along its perimeter, at a distance of 10... 12 mm from the edge, mark the centers of the screw holes, which are located one from another at a distance 15... 20 mm, and twist them. Holes are drilled with a drill diameter 4... 8 mm. Then they use the patch as a conductor and drill holes in the wall of the part with the same drill, cut the threads in them with a tap and, brushing the patch on the inner side with small red lead, screw it with screws. After 15... 20 hours, when the paint dries, it is necessary to tighten the screws and test the part for tightness. To ensure greater tightness under the patch put the cloth pads, painted on both sides with red lead or white.

Bonding parts. New types of universal synthetic adhesives developed by Soviet scientists make it possible to firmly connect metals, wood, glass, plastics, friction linings, etc., both among themselves and in any combination with each other.

Gluing close up the cracks in the blocks and cylinder heads of engines in crankcases; glue the friction linings of brake pads, clutches, replace the press fit in bushings, ball bearings, etc.

ED5 and ED6 epoxy resins and BC-UT glue are used to repair parts. To seal cracks in the cast-iron parts make up a special paste (weight h.):

To prepare the paste, it is recommended to first prepare a four-component paste. For this, the resin is preheated 60... 90 ° C, after which dibutyl phthalate is introduced, mixing it with resin, graphite and mica dust, stirring the mixture all the time (at least 5 minutes). The mixture is cooled to room temperature and stored in a sealed container.

The technological process of sealing cracks in the unloaded areas of cast iron parts is carried out in the following order:

1. The part where there is a crack is cleaned and treated with abrasive cloth to shine.
2. At the ends of the crack, drill holes with a diameter 4... 5 mm, cut them and screw in brass pins.
3. With an abrasive wheel from a handheld electric drill, cut (pack) a groove of a triangular cross section with a depth 0.75... 0.80 mm from the wall thickness.
4. Finally prepare the necessary portion of pasta. To this end, polyethylene-polyamine is added to the prepared four-component mixture in an amount 10 wt. h. The paste is thoroughly mixed for 5... 6 minutes and at the same time the prepared area is degreased with acetone or other solvents of fats.
5. Paste is applied with a spatula into the packaged groove and in this form is left to dry for 24 hours. The process can be accelerated by heating the part.
6. After the paste hardens, the part is subjected to a hydraulic test with water under a pressure 0.3... 0.4 MPa.
7. If the parts withstand this pressure, then the place to seal the cracks is puttied and painted.

3.3 Restoration of parts by welding and overlay welding

When repairing equipment, welding is used: to obtain permanent connections when restoring damaged parts, to restore the size of worn parts and to increase their wear resistance by welding more resistant metals.

Automated processes of welding and surfacing are more advanced and cost-effective compared to manual methods. Automatic and semiautomatic arc welding and surfacing under a flux layer are most common in repair practice. Manual methods of welding and surfacing are less perfect, but are indispensable for the repair of machine parts in non-specialized repair shops due to their maneuverability, versatility and simplicity of the process.

Gas welding is used to restore parts from gray cast iron. Parts of small size and weight are welded without preheating, and large parts are preheated.

Electric arc welding is more economical and creates a more reliable welded joint compared to gas welding.

Proper preparation of parts for welding ensures high quality of the deposited layer and its strong adhesion with the base metal. Before welding, parts clean and cut their edges [7]. The surface of the parts is cleaned with a steel brush, file, emery cloth, abrasive wheel, sand blasting apparatus, then washed with gasoline or kerosene, and also subjected to alkaline etching. The edges of the sheets butt-welded are cut (mowed) at an angle (60–70 °), and the edges of kinks and holes are leveled.

Surfacing is one of the main methods of repairing parts. It is widely used in cases where the friction surfaces need to give greater durability. Fused two, three or more layers, often with hard alloys, which allow to increase the service life of parts several times. The quality of the surfacing largely depends on the condition of the surface being repaired. Cast iron and steel parts from mild steel before surfacing degrease to remove oil from pores and cracks. To do this, the surface of the part is fired with a gas torch, blowtorch or in heating furnaces. The soot deposits of oxides after firing are removed from the surface of the part with an emery cloth or cloth moistened with kerosene or gasoline. The area of the part for surfacing is treated with steel brushes or abrasive wheels.

3.4 Restoration of parts by metallization

Metallization is the application of molten metal to the surface of a part. Molten metal in a special device, the metallizer is sprayed with a stream of air or gas into the smallest particles and transferred to a previously prepared surface of the part. The applied layer is not monolithic, but is a porous mass consisting of the smallest oxidized particles.

The method of metallization restores the dimensions of the seats for rolling bearings, gears, couplings, crankshaft journals, etc. In order for the metallization layer to be firmly connected to the surface of the part, the surface is cleaned of dirt and oil and sandblasted. The hardness of the metallization coating is determined by the quality of the applied material. To increase the surface hardness of parts and increase their resistance to mechanical wear, as well as to restore the size of parts, they are covered with a chromium layer (chrome) with a thickness 0.25 and 0.3 mm.

The high velocity of the particles (120..300 m/s) and the insignificant flight time, calculated in thousandths of a second, determine at the moment of impact their plastic deformation, filling of irregularities and pores of the part surface, adhesion with it and between themselves, formation of a continuous coating (Fig.3.2). After the formation of the first coating layer, the molten metal is layered again, as a result of which it is possible to obtain coatings with a layer thickness 0.02.10 mm and even more.

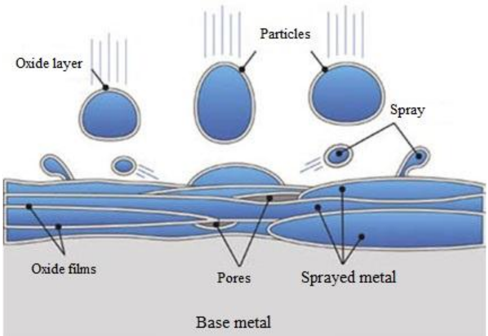


Figure 3.2- The formation process of the metallization coating

The principle of operation of metallization apparatus is based on the fact that the metal is continuously delivered into the apparatus, where it is melted by a gas flame or an electric arc, and then sprayed with compressed air into the smallest particles that are applied to the surface. A schematic diagram of the operation of the metallizer is shown in Figure 3.3.

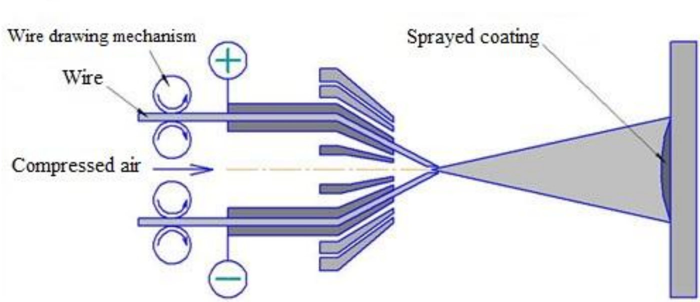


Figure 3.3- Scheme of operation of the metallizer

As a starting metal for coating, any metal that can be melted with a gas flame or electric arc can be used. The sprayed coating usually has the color of an oxidized metal, and only after processing with metal brushes or some other processing does the surface take on the usual metallic luster.

The sprayed coating is characterized by two basic properties, different from the properties of the metal, from which the coating is formed. These properties are hardness and porosity, and each of them makes the coating wear-resistant. Porosity provides a margin on the surface of the oil, necessary to maintain a standing oil film.

The next property of the sprayed coating is the adhesion strength with the base and the adhesion strength of the particles constituting the coating. This property determines the suitability of the sprayed coating for this purpose.

The sprayed coating is kept on the details the stronger, the better prepared the surface to be metallized. In no case should this surface be smooth, and therefore it is always subjected to either sand blasting or steel shot processing. If it is necessary to apply thicker coatings, surface preparation is carried out on the machine or produced by electric-spark processing.

According to the method of melting metal distinguish arc, gas and plasma metallization.

Arc metallization consists in melting the source material with an electric arc and spraying it with a jet of compressed air on the surface of the part. An electric arc burns between two wires pulled by the rollers. A jet of compressed air pulls the arc. With the help of electric arc metallization, you can restore to nominal dimensions of parts with wear reaching 20 microns... 10 mm. In addition, the metal layer, built up with the help of arc metallization, has a high hardness and high metal consumption, which increases its wear resistance. The size of the sprayed particles ranges from 10-50 microns. Spraying speed from a distance of 30 mm from the nozzle 250 m/s. Used devices EM-17, EM-14, EM-9, EM-10.

Flame metallization is carried out using apparatus in which metal wire or powder materials are sprayed with an acetylene-oxygen flame. The advantages of this method increase the adhesion strength, reduce the size of the sprayed metal particles, and reduces its oxidation.

Plasma metallization is carried out using plasmatrons, in which the plasma-forming gas (argon) flows through an electric discharge column, is partially or completely ionized and turns into a plasma. The plasmatron consists of a cathode and an anode cooled by water. From a constant current source between the cathode and the anode of an electric arc is excited. The plasma-forming gas introduced into the combustion zone is ionized and exits the plasmatron anode in the form of a jet of small cross section. The high electrical conductivity of the plasma jet significantly increases the current density, the temperature of the gas and the rate of its expiration. The working temperature of the jet reaches 7000-15000 °C at an outflow rate of up to 1500 m / s. Use the installation UPM-3M, UMP-4-64, UMP-5-68. With this method, the mechanical properties of the coating and its more durable connection with the surface of the part are higher than with other methods of metallization.

When restoring the eccentric by metallization of worn surfaces, the following conditions should be observed:

- restored surfaces should have the strength properties not lower than the initial ones. This requirement is satisfied by the surface deposited by electric arc metallization, which ensures the equal strength of the sprayed layer with the base metal;
- the process of metallization should completely exclude distortion of the eccentric, which is achieved by choosing a specific sequence and direction of metallization.
- should be strictly maintained metallization mode.
- the technological sequence of machining of the eccentric must be strictly observed.

From the conducted analyzes of restoration methods, it can be noted that when the wear limit varies between 5-6 mm, electric arc metallization gives a high reliability of restoration, the layer applied by metallization not only gives an increase in strength, but also a cleaner surface, which is very important for sliding bearings.

Because only a small metal layer is involved in the work, then it is required to theoretically investigate the technological and physical features, to determine the wear limit and the expected period of the node.

3.4.1 Technological and physical characteristics of metallization

The coatings obtained by sputtering by metallization are so different in their properties from the metals from which they are formed that they are in most cases completely new materials. The difference between coatings and raw materials also lies in the fact that almost all properties of coatings are highly variable and depend on the metallization technology and on the quality of surface preparation. Studying the properties of coatings, the properties of individual metal particles, their bases, as well as the properties of the coating as a whole, are usually considered. The properties of the metallization coatings can be positive and negative. They can be close to the properties of the metals from which they are formed, or are identical with them and can partially or completely lose the properties of the original metal. Knowledge of the differences between the properties of the source metal and the metal coating are the key to the success of the metallization.

The structure of the metallization coating. The structure of the deposited metal layer is shown in Fig. 3.4. At the bottom of the figure, the structure of the metal base (steel) is visible. The white stripe passing in the center is a layer obtained as a result of the surface electric preparation. In the upper part of the image there is a coating sprayed from steel (increased a hundred times). As is clearly seen, the coating is applied from a number of thin layers separated by oxides and pores.

Oxides and pores are very characteristic of the structure of the metallized coating. They are formed as a result of the metal particles sprayed by the metallization apparatus being oxidized during their flight to the surface being metallized. The particle size of the metal is from 0.001 to 0.2 mm. Despite the fact that the speed of flight of particles is high and ranges from 140 to 180 m / s, and the molten particles undergo oxidation for only one thousandth of a second, this time is sufficient for the metal particles to be coated with an oxide shell. Getting on the surface being metallized, the particles flatten out, and the brittle oxide shell breaks, with most of it being sprayed. Part of the oxide, however, remains in the sprayed coating. The coating formed in this way is only a large number of particles bonded to each other without any kind of fusion, both with the base metal and with each other [11].

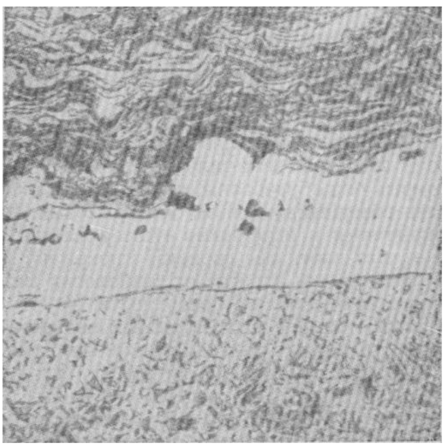


Figure 3.4 - Spray Coating Structure

The chemical composition of the source material during the formation of the coating changes in the direction of reducing the percentage composition of the components (Table 3.1):

Table 3.1

	C	Mn	Si	S
Source metal (wire), %	0,47	0,65	0,33	0,033
Electrometallizer sprayed coating %	0,31	0,25	0,16	0,02

The strength of adhesion of the coating to the base. The strength of adhesion of the coating to the base largely depends on the degree of roughness of the prepared surface.

The bonding strength of the cover with the base during metallization is sufficient, as evidenced by the work [12] devoted to the reconditioned parts of tractors and other machines, often experiencing significant loads in operation.

The dependence of the adhesion strength on the quality of surface preparation and the type of the base metal is clearly illustrated by the table on page 102. [13].

To make the surface metallized, the desired roughness most widely used the following types of preparation: mechanical, chemical, electrical or diffusion way [14, 15, 16]. Analyzing the data, we conclude in which cases this or that method of preparing surfaces for metallization is used.

Sandblasting preparation is used when spraying coatings with a thickness 0.02 to 3.0 mm when restoring the size of worn-out machine parts, repairing cracks in castings, metallizing with stainless steel and applying decorative coatings on products of complex shape.

The application of notches followed by sandblasting is used for coatings with a thickness of 0.15 to 4 mm for the repair of machine parts having the form of rotation bodies with a diameter of up to 50 mm. Widely used in restoring the size of the necks of crankshafts.

Preparation by cutting a torn thread is used for coating with a thickness 0.5 to 20 mm. Widely used in the repair of worn shafts and bushings of steel.

Preparation by cutting a torn or round thread by rolling the tops is used when applying coatings with a thickness of 0.5 to 30 mm when restoring the size of worn shafts and holders of non-hardened and non-cemented steels.

Preparation by winding wire and sandblasting is used when applying coatings with a thickness 0.7 to 35 mm when restoring shafts from hardened or cemented steel.

Electrical preparation is used when applying coatings with a thickness 0.7 to 10 mm. It is used in the recovery of inner hardened and cemented surfaces.

As a result of undesirable stresses arising in coatings during metallization of internal cylindrical surfaces, preparation by the methods described above cannot be done.

When spraying coatings with a thickness of up to 0.5 mm, surface preparation can be carried out with a sandblaster. If the part has a small diameter, then during preparation it is necessary to use the instructions to the sandblaster, since in the absence of the pretender it is impossible to thoroughly clean the surface. When spraying coatings with a thickness of more than 0.5 mm, past sandblasting preparation is already insufficient, since it does not provide the required adhesion strength of the coating to the substrate. In these cases, it is necessary to cut torn threads on the surface to a depth of about 0.4 mm with a very fine pitch (0.5 mm). Even better results can be achieved by cutting a round of thread with subsequent rolling. To secure the ends of the coating on the main surface are grooves.

Efficient results in metallization of the inner cylindrical surfaces are achieved by heating. As a result of heating, the internal diameter of the parts increases, and after the part cools, the adhesion strength of the base with the coating increases significantly.

If the metallized part is exposed to heat, then during the preparation of the surface, it can be limited only by sandblasting, even in those cases when the thickness of the coating exceeds 0.5 mm and is 2.5 or even 3.0 mm.

Mechanical properties of metallization coating. The tensile strength of the metallization coating depends on the interconnectedness of the particles and in no case on the strength of the particles themselves.

In the western literature, many values are given that characterize the strength of coatings to rupture. The disadvantage of these data is that the tests are not normalized and as a result of using various methods, the data obtained are contradictory and sometimes erroneous. The test results also largely depend on the metallization technology.

The tensile strength and relative elongation of coatings sprayed with an arc-type apparatus for metallization, according to the literature [17], are characterized by the following values for various metals.

Table 3.3

Sprayed material	Tensile strength kg / mm ^{2}	Relative extension, %
Aluminum	13,6	0,23
Aluminum alloy -94% AL, 6% Si	26,2	0,54
Aluminum bronze	21,7	0,62
Phosphor bronze	12,6	0,35
Copper	9,1	0,45
Steel - 0.1% C	21,0	0,30
Steel - 0.25% C	24,3	0,46
Steel 0.80% C	19,2	0,42
Stainless steel -14% Cr, 0.4% C	28,1	0,50
Stainless steel -18% Cr, 8% Ni	21,7	0,27

As can be seen from the table, the tensile strength of the sprayed coatings is less than that of cast metals. However, the coating sprayed from an alloy of aluminum and silicon (94% A1, 6% Si), the tensile strength is higher than that of cast metal. In conventional casting, such an alloy is characterized by a tensile strength of 14 kg / mm ^{2}, and in chill casting - 21 kg / mm ^{2}.

The magnitude of the relative elongation of the deposited metals is much smaller, but the curve characterizing the test for relative elongation is similar to the curve obtained in tests of cast metals [18].

Despite the fact that the metallized coatings have a tensile strength lower than that of cast metals, it nevertheless is sufficient for practical needs, the Saratov Institute of Agricultural Mechanization named after M. I. Kalinina also carried out tests of the steel coating containing, 2% of carbon deposited using an electrometallization apparatus. The test results showed that the tensile strength of such a coating is characterized by values from 19.5 to 20 kg / mm ^{2}.

The values of strength and relative elongation of the coating sprayed from non-ferrous metals given here are higher than those reported in the western literature [19].

Analyzing the results of mechanical tests of sprayed coatings, it was revealed that they largely depend on the metallization technology and, in particular, on the following factors:

1. Pressure and flow of compressed air. As the pressure of compressed air increases, the energy of the sprayed particles increases and,

as a result, their cohesion with each other increases.

2. Distances from the nozzle of the apparatus to the metallized surface. With increasing distance from the nozzle of the apparatus to the surface, decreases the speed of flight of particles and when falling on the surface, and hence the force. The strength of the mutual adhesion of particles will be less. In addition, particles, flying a greater distance, will be more oxidized, due to which the adhesion strength will decrease even more.

The strength of the mutual adhesion of particles is also influenced by the performance of the apparatus, the voltage on the electric arc, oxygen pressure and other factors that either reduce the speed of flight of the particles or increase the degree of their oxidation.

Compression strength. Coatings sprayed from steel are characterized by compressive strength ranging from 80 to 120 kg / mm ^{2} (sprayed zinc has a compressive strength of about 13 kg / mm ^{2}, and aluminum 20 kg / mm ^{2}).

The strength of the sprayed metal in compression also depends on the metallization technology. With a decrease in the distance between the nozzle and the surface, as well as with increasing air pressure, the compressive strength increases.

The effect of metallization on the fatigue limit. Metallization details a little effect on the limit of its fatigue. The decisive factor in this case is the preparation of the surface, that is, an increase in the degree of roughness. Below are the values characterizing the influence of the method of preparation on the fatigue limit of the *Cfatigue* ($2x10^7$ variable load), and the coefficient of change of the fatigue limit *ac*. Base metal: steel with a content 13% Cg and 3.5 Ni [20].

Table 3.4

	Cfatigue, kg/mm^2	ac
Steel chipping preparation	37,9	0,76
Thread cutting preparation	21,0	1,37
Preparation by cutting thread followed by rolling	18,9	1,52
Preparation by spark detection	24,6	1,17

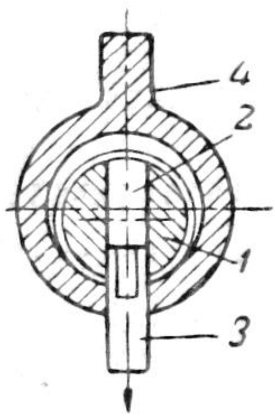
These data indicate that the surface fatigue increases when sandblasted surface preparation, despite the fact that surface roughness is given. It is precisely as a result of sandblasting that the greater compressive stress arises on the surface, the greater the air pressure and the coarser and heavier the grain of sand (steel crumb). But thin-walled parts, however, can be deformed.

All other methods of preparation reduce the fatigue limit, either as a result of the appearance of concentrated stresses (mechanical preparation), or as a result of the appearance of tension on the surface (electrical spark preparation). Spraying the intermediate layer at the limit of fatigue does not affect.

Testing of metallization coatings. Test methods are not established and have a number of drawbacks, therefore, the test results are often contradictory.

According to the literature, the adhesive strength of the coating with the base, as well as the tensile and shear strengths are tested according to the scheme (Fig. 3.5) [21].

A roller 1 with a diameter 47.6 mm is sprayed with metal: (Fig. 3.5, a). The finger 2 is inserted into the roller with a diameter 12.7 mm. finger thread when metallizing the roller is protected from sticking metal nut. After metallization, the bar 3 is screwed onto the threaded part of the finger, which is necessary for fixing the tensile machine in the clamps. The roller is inserted into the yoke 4, which has a tide, which is also not necessary for fixing in the clamps of a bursting machine. Thus, the adhesion strength of the sprayed coating with the finger 2 is tested. The test results are determined by the strength of the pressing of the finger in the roller 1.



a

Figure 3.5 - Testing the strength of adhesion of the coating to the base

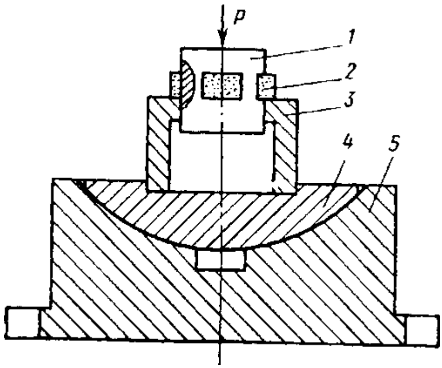


Figure 3.6 - Testing the adhesion strength of the coating with the base
(V.S. Harchenkov's sample)

For testing the sprayed samples, V. S. Kharchenkov designed and manufactured a special device (Fig. 3.6). sample 1 with coating 2 is inserted into the matrix 3, which through the spherical support 4 rests on the body of the device 5 mounted on the table of the testing machine mod.P-0.5. When the sample is loaded with an axial force, a shear (cut) of the coating layer from the base metal occurs. The magnitude of the axial loading force falling on the surface of the coating gives the desired value of the adhesion force:

$$\tau = \frac{P}{F},$$

where P is the magnitude of the axial force, kgf;
F - coverage area, mm^2.

When testing the properties of the coating itself (tensile strength and relative elongation), it is based on the well-known method of tensile testing of a metallized rod. The test results were often highly controversial and it was dangerous to rely on them. Recently, such tests have been carried out on tubes made of sprayed metal. In this case, a finger is coated with a coating of the required thickness, after which the finger is squeezed out of the coating. The tube thus obtained is processed for a tensile test [17].

The ductility of the coating is established during bending tests. Figure-3.7 shows the bending test for an aluminum coating sprayed onto 1.5 mm thick sheet steel.

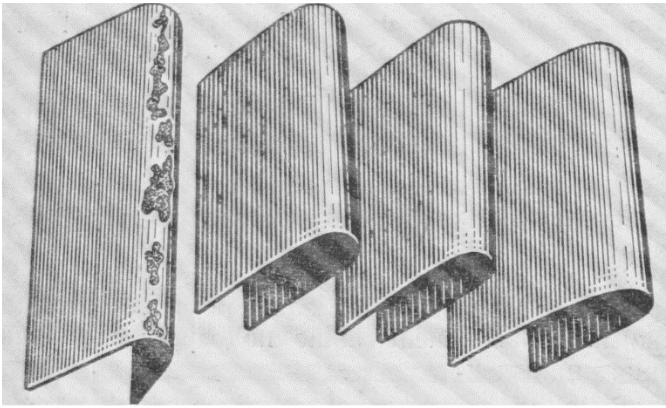


Figure 3.7 - Bending coating test

CHAPTER 4. ANALYSIS OF STATISTICAL DATA OF FREQUENTLY WEARING PARTS AND SELECTION OF THE OBJECT OF STUDY

4.1 Overview of statistical data analysis methods

The object of research in applied statistics is the statistical data obtained as a result of observations or experiments. Statistical data is a collection of objects (observations, cases) and signs (variables) characterizing them.

Variables are values that can take on different values as a result of measurement.

Independent variables are variables whose values can be changed during the experiment, and dependent variables are variables whose values can only be measured.

Variables can be measured at different scales. The difference in scales is determined by their information content. Consider the following types of scales, presented in order of increasing their informativeness: nominal, ordinal, interval, scale of relations, absolute. These scales also differ from each other in the number of admissible mathematical operations. The “poor” scale is nominal, since not a single arithmetic operation is defined, the “rich” is absolute.

Measurement in the nominal (classification) scale means the determination of the belonging of an object (observation) to a particular class. Measurement in the ordinal (rank) scale, in addition to determining the class of membership, allows you to streamline the observations by comparing them with each other in some respect. However, this scale does not determine the distance between the classes, but only which of the two observations is preferable. Therefore, ordinal experimental data, even if they are depicted in figures, cannot be regarded as numbers and perform arithmetic operations on them 5. In this scale, in addition to calculating the frequency of the object, you can calculate the rank of the object. Examples of variables measured in the ordinal scale: student marks, prizes in competitions, military ranks, a country’s place in the list of quality of life, etc. Sometimes nominal and ordinal variables are called categorical, or grouping, as they allow the study objects to be divided into subgroups.

When measured on an interval scale, the ordering of observations can be performed so precisely that the distances between any two of them are known. The scale of intervals is unique up to linear transformations ($y = ax + b$). This means that the scale has an arbitrary point of reference -

conditional zero. Examples of variables measured in the interval scale: temperature, time, altitude of the terrain above sea level. Above the variables in this scale, you can perform the operation of determining the distance between observations. Distances are full numbers and you can perform any arithmetic operations on them.

The scale of relations is similar to the interval scale, but it is unique up to a transformation of the form y = ax. This means that the scale has a fixed point of reference - an absolute zero, but an arbitrary scale of measurement. Examples of variables measured in the relationship scale: length, weight, current strength, amount of money, society’s expenses for health care, education, army, life expectancy, etc. The measurements in this scale are full-fledged numbers and any arithmetic can be performed on them.

The absolute scale has both absolute zero and an absolute unit of measure (scale). An example of an absolute scale is a numerical line. This scale is dimensionless, so measurements in it can be used as an indicator of the degree or base of the logarithm. Examples of measurements in absolute scale: the proportion of unemployment; illiteracy rate, quality of life index, etc.

Most statistical methods relate to methods of parametric statistics, which are based on the assumption that a random vector of variables forms a multidimensional distribution, usually normal or converted to a normal distribution. If this assumption is not confirmed, you should use non-parametric methods of mathematical statistics.

Correlation analysis. Between variables (random variables) there may be a functional relationship, manifested in the fact that one of them is defined as a function of the other. But there can be another connection between variables, manifested in the fact that one of them reacts to a change in the other by changing its law of distribution. Such a connection is called stochastic. It appears when there are common random factors affecting both variables. As a measure of the dependence between variables, the correlation coefficient (r) is used, which varies from –1 to +1. If the correlation coefficient is negative, this means that as the values of one variable increase, the values of the other decrease. If the variables are independent, then the correlation coefficient is 0 (the opposite is true only for variables with a normal distribution). But if the correlation coefficient is not equal to 0 (the variables are called uncorrelated), then this means that there is a relationship between the variables. The closer the value of r to 1, the stronger the dependence. The correlation coefficient reaches its limiting values +1 or -1, if and only if the relationship between the variables is linear. Correlation analysis allows to establish the strength and direction of the stochastic relationship between variables (random variables). If the variables are measured at least on an interval scale and have a normal distribution, then the correlation analysis is performed by calculating the Pearson correlation coefficient, otherwise Spearman, tau Kendal, or Gamma correlations are used.

Regression analysis. In regression analysis, the relationship of one random variable from one or several other random variables is modeled. In this case, the first variable is called dependent, and the rest - independent. The choice or assignment of dependent and independent variables is arbitrary (conditional) and is made by the researcher depending on the task he is solving. Independent variables are called factors, regressors, or predictors, and the dependent variable is called the performance indicator, or response.

If the number of predictors is 1, the regression is called simple, or one-factor, if the number of predictors is greater than 1 - multiple or multifactorial. In the general case, the regression model can be written as follows:

$$y = f(x1, x2, \dots, xn) \qquad (4.1)$$

where,
y is the dependent variable (response),
xi (i = 1,..., n) are predictors (factors),
n is the number of predictors.

Through regression analysis, we can solve a number of important problems for the problem under study:

1. Reducing the dimension of the space of the analyzed variables (factor space), due to the replacement of some factors of one variable - response. More fully, this problem is solved by factor analysis.
2. Quantitative measurement of the effect of each factor, i.e. Multiple regression allows the researcher to ask a question (and probably get an answer) about "what is the best predictor for...". At the same time, the impact of individual factors on the response becomes clearer, and the researcher better understands the nature of the phenomenon being studied.
3. Calculation of the predicted response values for certain values of factors, i.e. regression analysis creates the basis for a computational experiment in order to get answers to questions like “What will happen if...”.
4. In the regression analysis, a causal mechanism appears more

explicitly. The forecast is more amenable to meaningful interpretation.

Canonical analysis. Canonical analysis is intended to analyze the dependencies between two lists of features (independent variables) characterizing objects. For example, one can study the relationship between various adverse factors and the appearance of a certain group of symptoms of the disease, or the relationship between two groups of clinical and laboratory indicators (syndromes) of a patient. Canonical analysis is a generalization of multiple correlation as a measure of the relationship between one variable and many other variables. As you know, multiple correlation is the maximum correlation between one variable and a linear function of other variables. This concept was generalized to the case of a relationship between sets of variables - signs characterizing objects. It is enough to confine ourselves to considering a small number of the most correlated linear combinations from each set. Suppose, for example, the first set of variables consists of signs y1,..., yr, the second set consists of - x1,..., xq, then the relationship between these sets can be estimated as a correlation between linear combinations a1y1 + a2y2 +... + apyp, b1x1 + b2x2 +... + bqxq, which is called the canonical correlation. The task of canonical analysis is to find the weights in such a way that the canonical correlation is maximum.

Methods for comparing averages. In applied research, there are often cases when the average result of a certain sign of one series of experiments differs from the average result of another series. Since the averages are the results of measurements, then, as a rule, they always differ, the question is whether the detected discrepancy of the averages can be explained by inevitable random experimental errors or it is caused by certain reasons. If we are talking about comparing two means, then Student's criterion (t-criterion) can be applied. This is a parametric criterion, since it is assumed that the trait has a normal distribution in each series of experiments. At present, the use of non-parametric criteria for comparing averages has become fashionable.

Comparison of average results is one of the ways to identify the dependencies between the variable signs characterizing the studied set of objects (observations). If, when dividing research objects into subgroups using a categorical independent variable (predictor), the hypothesis about the mean inequality of a certain dependent variable in subgroups is true, then this means that there is a stochastic relationship between this dependent variable and the categorical predictor. For example, if it is established that the hypothesis about the equality of the average physical and intellectual development of children in the groups of mothers who smoked and did not smoke during pregnancy is incorrect, then this means that there is a relationship between smoking a mother of a child during pregnancy and his intellectual and physical development.

The most common method of comparing average variance analysis. In the terminology of analysis of variance, the categorical predictor is called a factor.

Analysis of variance can be defined as a parametric, statistical method designed to assess the influence of various factors on the result of an experiment, as well as for the subsequent planning of experiments. Therefore, in the analysis of variance, it is possible to investigate the dependence of a quantitative trait on one or several qualitative signs of factors. If one factor is considered, then one-factor analysis of variance is used, otherwise multi-factor analysis of variance is used.

Frequency analysis. Frequency tables, or as they are also called single-entry tables, are the simplest method for analyzing categorical variables. Frequency tables can also be successfully used to study quantitative variables, although it may be difficult to interpret the results. This type of statistical study is often used as one of the procedures for exploratory analysis to see how the various groups of observations are distributed in the sample, or how the value of the characteristic is distributed in the interval from the minimum to the maximum value. As a rule, frequency tables are graphically illustrated using histograms.

Crosstabulation (conjugation) is the process of combining two (or several) frequency tables so that each cell in the constructed table is represented by a single combination of values or levels of tabulated variables. Crosstab allows you to combine the frequency of occurrence of observations at different levels of the factors under consideration. By exploring these frequencies, it is possible to identify the relationships between tabulated variables and examine the structure of this relationship. Usually tabulated categorical or quantitative variables with a relatively small number of values. If it is necessary to tabulate a continuous variable (suppose blood sugar levels), then it should first be recoded, dividing the range of change into a small number of intervals (for example, level: low, medium, high).

Matching analysis. Compliance analysis compared to frequency analysis contains more powerful descriptive and exploratory methods for analyzing two-input and multi-input tables. The method, as well as contingency tables, allows us to investigate the structure and relationship of the grouping variables included in the table. In the classical correspondence analysis, the frequencies in the contingency table are standardized (normalized) so that the sum of the elements in all cells is 1.

One of the goals of correspondence analysis is to represent the contents of the table of relative frequencies in the form of distances between individual rows and / or columns of the table in a space of lower dimension.

Cluster analysis. Cluster analysis is a method of classification analysis; its main purpose is to divide the set of objects and signs into homogeneous in some sense groups, or clusters. This is a multidimensional statistical method, so it is assumed that the source data may be of a significant amount, i.e. Both the number of objects of study (observations) and signs characterizing these objects can be significantly large. The big advantage of cluster analysis is that it enables the splitting of objects not by one feature, but by a number of features. In addition, cluster analysis, in contrast to most mathematical-statistical methods, does not impose any restrictions on the type of objects under consideration and allows us to investigate a lot of initial data of almost arbitrary nature. Since clusters are groups of homogeneity, the task of cluster analysis is to divide their set into m (m - integer) clusters based on the characteristics of objects, so that each object belongs to only one splitting group. In this case, the objects belonging to the same cluster must be homogeneous (similar), and the objects belonging to different clusters must be heterogeneous. If clustering objects are represented as points in an n-dimensional feature space (n is the number of features characterizing objects), then the similarity between objects is defined through the concept of the distance between points, since it is intuitively clear that the smaller the distance between objects, the more similar they are.

Discriminant analysis. Discriminant analysis includes statistical methods for classifying multidimensional observations in situations where the researcher has so-called training samples. This type of analysis is multidimensional, since it uses several features of the object, the number of which can be arbitrarily large. The purpose of discriminant analysis is to classify it on the basis of measuring various characteristics (features) of an object, that is, to refer to one of several specified groups (classes) in some optimal way. In this case, it is assumed that the source data, along with the features of the objects, contain a categorical (grouping) variable, which determines the belonging of the object to one or another group. Therefore, the discriminant analysis provides for checking the consistency of the classification carried out by the method with the initial empirical classification. The optimal method is understood as either a minimum of the expectation of losses, or a minimum of the probability of a false classification. In the general case, the problem of discrimination

(discrimination) is formulated as follows. Let the result of observation over an object is the construction of a k-dimensional random vector X = (X1, X2,..., XK), where X1, X2,..., XK are signs of the object. It is required to establish a rule according to which, according to the values of the coordinates of the vector X, an object is assigned to one of the possible sets of i, i = 1, 2,..., n. Methods of discrimination can be divided into parametric and non-parametric. In parametric it is known that the distribution of the vectors of signs in each set is normal, but there is no information about the parameters of these distributions. Non-parametric methods of discrimination do not require knowledge of the exact functional form of distributions and make it possible to solve problems of discrimination on the basis of insignificant a priori information about aggregates, which is especially valuable for practical applications. If the conditions of applicability of discriminant analysis are met - independent variables – signs (they are also called predictors) should be measured at least on an interval scale, their distribution should be in accordance with the normal law, it is necessary to use the classical discriminant analysis, otherwise - using the general discriminant analysis model.

Factor analysis. Factor analysis is one of the most popular multidimensional statistical methods. If the cluster and discriminant methods classify observations by dividing them into homogeneity groups, then factor analysis classifies the signs (variables) describing the observations. Therefore, the main purpose of factor analysis is to reduce the number of variables based on the classification of variables and the definition of the structure of the relationships between them. The reduction is achieved by identifying hidden (latent) common factors explaining the connections between the observed signs of the object, i.e. instead of the initial set of variables, it will be possible to analyze data on selected factors, the number of which is significantly less than the initial number of interrelated variables.

Classification trees. Classification trees are a method of classification analysis that allows predicting the belonging of objects to one or another class depending on the corresponding values of attributes characterizing the objects. Attributes are called independent variables, and a variable indicating that objects belong to classes is called dependent. Unlike classical discriminant analysis, classification trees are able to perform one-dimensional branching on variables of various types, categorical, ordinal, interval. There are no restrictions on the distribution of quantitative variables. By analogy with discriminant analysis, the method makes it possible to analyze the contributions of individual variables to the classification procedure. Classification trees can be, and sometimes are, very complex. However, the use of special graphic procedures allows us to simplify the interpretation of the results even for very complex trees. The possibility of graphical presentation of results and ease of interpretation largely explain the great popularity of classification trees in applied areas, however, the most important distinguishing features of classification trees are their hierarchy and wide applicability. The structure of the method is such that the user has the ability to build trees of arbitrary complexity by controlled parameters, achieving minimal classification errors. But according to a complex tree, due to the large aggregate of decision rules, it is difficult to classify a new object. Therefore, when building a classification tree, the user must find a reasonable compromise between the complexity of the tree and the complexity of the classification procedure. The wide scope of applicability of classification trees makes them a very attractive data analysis tool, but one should not assume that it is recommended to use it instead of traditional methods of classification analysis. On the contrary, if the more rigorous theoretical assumptions imposed by traditional methods are fulfilled, and the selective distribution has some special properties (for example, the correspondence of the distribution of variables to a normal law), then it will be more efficient to use traditional methods. However, as a method of exploratory analysis or as a last resort, when all traditional methods fail, the classification trees, according to many researchers, have no equal. In this method, it is possible to analyze the classification of types of wear, models most often coming to repair.

In practice, there is often a problem of analyzing data of a large dimension. The method of analysis of the main components and classification allows to solve this problem and serves to achieve two goals:

- reduction of the total number of variables (data reduction) in order to obtain "main" and "non-correlating" variables;

- classification of variables and observations, using the factor space under construction.

The method has similarities with the factor analysis in the production part of the tasks to be solved, but it has several significant differences:

- when analyzing the main components, iterative methods are not used to extract factors;

- along with active variables and observations used to extract the principal components, you can set auxiliary variables and / or observations; then auxiliary variables and observations are projected onto the factor space calculated on the basis of active variables and observations;

- the listed possibilities allow using the method as a powerful tool for classifying both variables and observations simultaneously.

The solution of the main problem of the method is achieved by creating a vector space of latent (hidden) variables (factors) with a dimension less than the original one. The initial dimension is determined by the number of variables for analysis in the source data.

Multidimensional scaling. The method can be considered as an alternative to factor analysis, in which a reduction in the number of variables is achieved, by identifying latent (not directly observable) factors explaining the relationships between the observed variables. The goal of multidimensional scaling is the search and interpretation of latent variables that enable the user to explain the similarities between objects defined by points in the original feature space. Indicators of the similarity of objects in practice can be the distance or degree of communication between them. In factor analysis, similarities between variables are expressed using a matrix of correlation coefficients. In multidimensional scaling, an arbitrary type of object similarity matrix can be used as input data: distances, correlations, etc. Despite the fact that there are many similarities in the nature of the issues studied, the methods of multidimensional scaling and factor analysis have a number of significant differences. Thus, factor analysis requires that the data under investigation obey a multidimensional normal distribution, and the dependencies are linear. Multidimensional scaling does not impose such restrictions; it can be applicable if a matrix of pairwise similarities of objects is specified. In terms of the differences in the results obtained, factor analysis tends to extract more factors — latent variables as compared to multidimensional scaling. Therefore, multidimensional scaling often leads to easier interpretable solutions. However, it is more significant that the multidimensional scaling method can be applied to any type of distance or similarity, while factor analysis requires that a correlation matrix of variables be used as input data or a correlation matrix is first calculated from the input data file.

The main assumption of multidimensional scaling is that there is a certain metric space of essential basic characteristics, which implicitly served as the basis for the obtained empirical data on the proximity between pairs of objects. Therefore, objects can be represented as points in this space. It is also assumed that closer objects (in the original matrix) correspond to smaller distances in the space of basic characteristics. Therefore, multidimensional scaling is a set of methods for analyzing empirical data on the proximity of objects, by means of which the dimension of the space of the characteristics of the measured objects essential for a given substantive task is determined and the configuration of points (objects) in this space is constructed. This space ("multidimensional scale") is similar to commonly used scales in the sense that certain positions on the axes of space correspond to the values of the essential characteristics of the measured objects. The logic of multidimensional scaling can be illustrated in the following simple example. Suppose that there is a matrix of pairwise distances (i.e., similarity of some features) between some cities. Analyzing the matrix, it is necessary to arrange the points with the coordinates of cities in a two-dimensional space (on the plane), keeping the real distances between them to the maximum. The resulting placement of points on the plane can later be used as an approximate geographical map. In the general case, multidimensional scaling allows you to position objects (cities in our example) in a space of some small dimension (in this case it is equal to two) in order to adequately reproduce the observed distances between them. As a result, these distances can be measured in terms of the latent variables found. So, in our example, distances can be explained in terms of a pair of geographical coordinates North / South and East / West.

Structural equation modeling (causal modeling). The recent progress in the field of multidimensional statistical analysis and analysis of correlation structures, combined with the latest computational algorithms, served as the starting point for creating a new, but already recognized, structural equation modeling technique (SEPATH). This extraordinarily powerful technique of multidimensional analysis includes methods from various fields of statistics, multiple regression and factor analysis obtained here a natural development and association.

The object of modeling structural equations are complex systems, the internal structure of which is not known ("black box"). Observing the parameters of the system with the help of SEPATH, it is possible to investigate its structure, to establish cause-effect relationships between the elements of the system.

The formulation of the structural modeling problem is as follows. Suppose there are variables for which statistical moments are known, for example, a matrix of sample correlation coefficients or covariances. Such variables are called explicit. They can be characteristics of a complex system. The real relationships between the observed explicit variables can be quite complex, but we assume that there are a number of hidden variables that explain the structure of these relationships with a certain degree of accuracy. Thus, using latent variables, a model of relationships between explicit and implicit variables is built. In some problems, latent variables can be considered as causes, and explicit ones as consequences, therefore, such models are called causal. It is assumed that hidden variables, in turn, may be related to each other. The structure of relations is allowed rather complicated, but its type is postulated - these are relations described by linear equations. Some parameters of linear models are known, some are not, and are free parameters.

The basic idea of structural equation modeling is that you can check whether the variables Y and X are related by the linear dependence Y = aX, analyzing their variances and covariances. This idea is based on a simple property of the mean and variance: if you multiply each number by some constant k, the average value also multiplies by k, and the standard deviation is multiplied by the modulus k. For example, consider a set of three numbers 1, 2, 3. These numbers have an average 2 and a standard deviation is 1. If you multiply all three numbers by 4, then it is easy to calculate that the average value will be 8, the standard deviation is 4, and the variance is 16. Thus, if there are sets of numbers X and Y connected by the dependence Y = 4X, then the variance Y must be 16 times greater than the variance X. Therefore, you can test the hypothesis that Y and X are related by the equation Y = 4X, comparing the variances of the variables Y and X. This idea can be generalized into several ways AC line associated system of linear equations. In this case, the transformation rules become more cumbersome, the calculations are more complicated, but the main meaning remains. At the same time, the transformation rules become more cumbersome, the calculations are more complex, but the basic meaning remains the same - you can check whether the variables are related by a linear relationship by studying their variances and covariances.

General models of discriminant analysis. If the conditions of applicability of discriminant analysis (DA) are not satisfied, so independent variables (predictors) should be measured at least on an interval scale, their distribution should be in accordance with the normal law, it is necessary to use the method of general discriminant analysis (GDA). The method has this name because it uses the general linear model (GLM) to analyze discriminant functions. In this module, analysis of discriminant functions is considered as a general multidimensional linear model, in which the categorical dependent variable (response) is represented by vectors with codes denoting different groups for each observation. The GDA method has a number of significant advantages over classical discriminant analysis. For example, there are no restrictions on the type of predictor used (categorical or continuous) or on the type of model being defined; step-by-step selection of predictors and selection of the best subset of predictors is possible; if there is a cross-test sample in the data file, the best subset of predictors can be selected on the basis of shares misclassification for cross-validation sampling, etc.

Time series. Time series is the most intensively developing, promising direction of mathematical statistics. By a temporary (dynamic) series, we mean the sequence of observations of a certain sign X (a random variable) at successive equally spaced moments t. Separate observations are called row levels and are denoted xt, t = 1,..., n. In the study of the time series there are several components:

$$xt=ut+yt+ct+et,\ t = 1, \ldots, n \tag{4.2}$$

where ut is a trend, a smoothly changing component, describing the net effect of long-term factors (geometric parameters, types of defect, etc.); - seasonal component, reflecting the repeatability of processes over a not very long period (day, week, month, etc.); ct is a cyclic component, reflecting the repeatability of processes over long periods of time exceeding one year; t is a random component, reflecting the influence of incalculable and random factors. The first three components are deterministic components.

CHAPTER 5. STUDIES OF THE METHODS OF THERMAL FRICTION PROCESSING OF PARTS OF MINING MACHINES

5.1 Indicators of surface quality in the processing of thermofriction methods (PFM) and methods for their determination

The high-quality work of the nodes of moving mechanisms operating at high speeds or under heavy loads depends on the change in the gaps in the mating surfaces. Their value is related to the regularities of the intensity of wear of the mating surfaces of friction pairs and indicators characterizing the current state of the microgeometry of these surfaces.

Machining significantly changes the performance properties of parts, primarily due to the formation of a surface of a certain quality: surface roughness and physicomechanical properties of the surface layer [56].

In [57, 58], a technological classification of methods TFP is proposed, which are built on the basis of TFP methods already tested in practice and shows potentially wide possibilities for their application.

The results of the studies showed that the technological capabilities of TFP can be further expanded [59, 60, 61, 62, 63] and led to the creation of a new technology of thermofriction processing [64, 65], allowing to regulate the quality indicators of the treated surface in wide ranges.

The quality of the surface treated by mechanical methods is determined by many parameters. Based on the goal of the work, we investigate the main parameters of the quality of the treated surface at TFP, which is the surface hardness and its change over the depth of plastic deformation distribution, as well as the surface roughness [66]. Consider these options in detail.

5.1.1 Depth of distribution of plastic deformation

During processing, the surface layer of the workpiece is subjected to plastic deformation. The degree of this deformation determines the intensity of hardening, which can be expressed through hardness. The depth of the hardening intensity can be determined from the depth of the deformed layer.

The main factors affecting the depth of distribution of plastic deformation are the magnitude of the applied load, the loading scheme [67], and the occurrence of thermoplastic deformations [68]. The size, which characterizes the depth of distribution of the deformation, is denoted by hh, where the index h means hardening [67, p. 36]. This size is very important because depend on its value: the energy required to implement the cutting process according to [69] 70 ÷ 85% of the total work; depth of the layer with a modified structure, the degree of deformation ε and the speed of deformation έ. From the latter it follows that hh affects the hardness of the material being processed directly during the cutting process (dynamic hardness) and measured after stopping the process [70].

5.1.2 Surface Roughness

The parameters and working conditions characteristic of modern mining machines place high demands on the quality of the surfaces of the mating parts. Surface quality has a significant impact on the performance properties of parts. Thus, the wear resistance of the part depends on the quality of the surface layers. Improving the quality of rubbing surfaces increases the service life of the machine, extends their durability.

The quality of the treated surface is characterized by two main features:

a) the physicomechanical properties of the surface layer of the metal;

b) the degree of surface roughness.

Roughness is a set of irregularities with relatively small steps that form the topography of the surface and are considered within the area, the length of which is selected depending on the nature of the irregularity and is equal to the base length.

The issue of ensuring the quality of cutting by reducing the roughness of the cutting surface during thermofriction processing was investigated in [71, 72, 73, 74, 75, 76, 77, 78]. The analysis of these works shows that some of them believe that in order to reduce the roughness of the treated surface, it is necessary to increase the diameter of the cutting disk [71, p. 41; 72, p. 50; 75, p. 11]. In [76, p. 25] this is tied to the feed and cutting speed, in [73, p. 85] with the ratio of the width and diameter of the disc, and in [74, p. 71], the decisive influence of the “rounding radius on forming disk.

Due to the fact that there are different conclusions in the above-mentioned works, this question requires clarification when processing the eccentric of a cone crusher. Of particular note is the fact that in these works a smooth disk was used, and the use of a disk with a design having its own characteristics, the influence of all parameters can be assumed otherwise.

On the basis of the given state of the question and the results of the preliminary experiments, the task was formulated - the intensification of the TFO process of cylindrical surfaces, in particular, an eccentric of a cone crusher based on the study of roughness and hardness of the material being processed.

5.2 Methods of conducting research Thermofriction processing (TFP) details of a cone crusher

To achieve the accepted goal of the work, it is necessary to develop a set of methodologies for determining parameters that characterize quality or provide relevant information to study the phenomena occurring in the process of the thermofriction processing. The following methods were used in the work:

a) measurement of hardness; b) measurement of roughness.

Metallographic and physical studies:

a) microhardness; b) temperature in the cutting zone.

Experimental studies were carried out on a JPI vertical milling machine and a 3B151 circular grinding machine.

Figure 5.1 shows sketches of friction discs used in a thermofriction processing of a cylindrical surface.

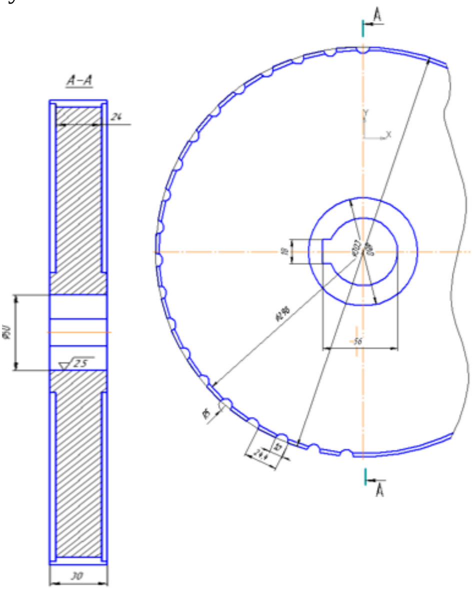


Figure 5.1 - Sketch of the friction disc design for thermofriction processing of cylindrical surfaces

Figure 5.2 shows photographs of friction discs used in the thermofriction processing of the plane and cylindrical surfaces.

Figure 5.2 - Friction Discs

5.2.1 Hardness Measurement

The magnitude of the plastic deformation distribution is experimentally determined by several methods: the method of measuring microhardness, the method of “grids” [79, 80], the method of determining stresses by N.N. Davidenkov [79], by changing the macro- or microstructure by means of metallography [81].

In our case, this parameter was determined using the MET-U1 device shown in Figure 5.3.

Figure 5.3 - MET-U1 device for measuring hardness by the Vickers’s method

Figure 5.4 shows samples processed by thermofriction processing methods for measuring hardness.

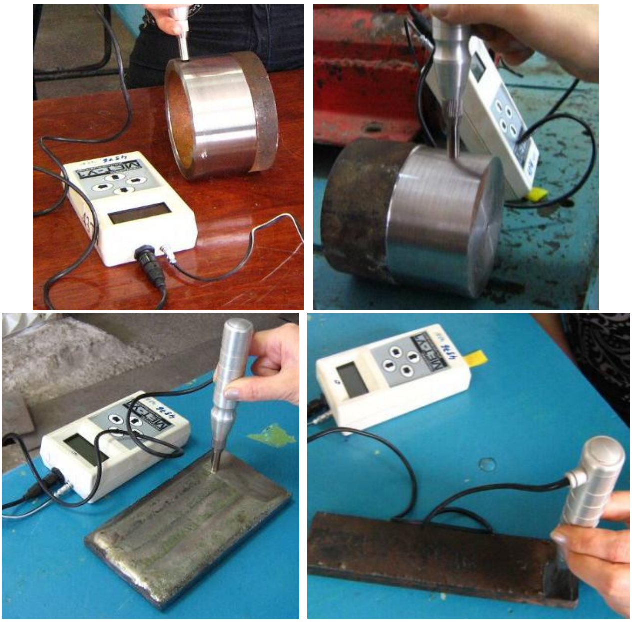


Figure 5.4 - Hardness Measurements of Processed Samples

The hardness of the treated surface was determined using the MET-U1 device using the Vickers's method. The device is automatic, it determines the hardness of the surface layer. With the help of a sensor installed inside the device, the relationship between the impact velocity and kickback rebounds is determined, and the hardness value of the surface layer appears on the device screen. At the moment of impact, the carbide ball mounted on the end of the striker contacts with the measured surface. Inside the striker there is a permanent magnet. The principle of the striker operation is as follows: after the button (trigger) button has been tensioned, the hammer is ejected onto the measured surface using a pre-cocked spring. Then, moving inside the inductance coil and its magnetic field, induces electromotive force in it. The signal from the output of the inductor is fed to the input of the electronic unit, where it is converted into the hardness value of the selected scale and displayed on the display. The tests were carried out at room temperature, in the laboratory conditions of "Technological equipment, engineering and standardization" department at KSTU. The duration of the launch of the indicator was 15-20 seconds.

5.2.2 Roughness measurement

The roughness (roughness class) of a surface is estimated by measuring asperities with various instruments, including the following main ones: profilographs, profilometers, optical instruments.

The principle of operation of profilometers is based on measuring the asperities of the surface by feeling it with a diamond needle. When moving along the surface of the machined part, the needle, due to surface irregularities, oscillates along its axis, and the frequency and amplitude of its oscillations correspond to the pitch and height of the irregularities.

Profilographs are also based on the principle of feeling the surface with a diamond needle. Using a recording device, the surface profile is recorded on a special tape in an enlarged form (given scale). Modern German, Japanese, or "Calibr" profilometers (Russia) have [82] a portable measuring head, which is mounted directly on the measured surface. After graduation of the horizontal position of the probe, the base length is selected, according to the standard, the probe, with the passage of this length, repeats the geometry of the irregularities. The electronic integrating unit in the device determines Ra root-mean-square value.

Under production conditions, the surface roughness of parts is often evaluated by comparing them with standards of purity, which are flat or cylindrical samples made of various materials (steel, brass, etc.).

The surface roughness of the processed samples was measured with TR100 Surface Roughness Tester electronic device, the general view of which is shown in Figure 5.5.

Figure 5.5 - Electronic TR100 Surface Roughness Tester
for Roughness Measurement

The device has an electrical device with special sensors, with the help of which the value of the standard deviation from the centerline of the profile of the machined surface of the part is automatically determined (Figure 5.6).

Figure 5.6 - Measurement of roughness of the processed samples

5.2.3 Temperature measurement

Experimental determination of the temperature during the cutting process is most often performed by various types of thermocouples. In this work, the average temperature in contact was determined using the “artificial thermocouple” method [83].

The essence of this method is that if at points 1 and 2 (figure 5.7) connect two metal conductors A and B of different chemical composition, then provided that the temperature at point 2 (θ_1 and θ_2), in a closed circuit appears electromotive force $E_{АБ} = k(\theta_1\text{-}\theta_2)$, proportional to the temperature difference. If the temperature of point 2 (the so-called free point) of the thermocouple is constant, then the electromotive force generated by the thermocouple will depend only on the temperature θ_1 of working point 1. To measure the values of the electromotive force $E_{АБ}$ between points 3 and 4, they connect a galvanometer or potentiometer. In our case (coordinate self-recording device) CSRD - 4.

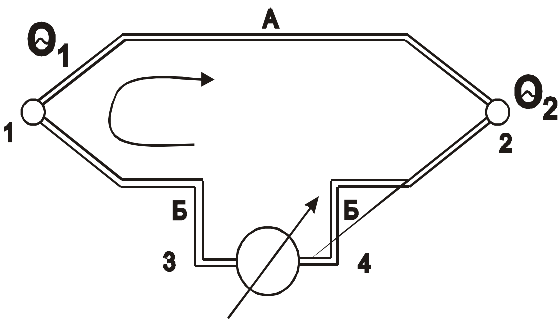


Figure 5.7 - Thermocouple temperature measurement

In this case, the condition of equality of temperatures at the input and output terminals (3 and 4) should be observed.

Materials suitable for the formation of thermocouples, can be almost all metals and alloys. The following values of thermoelectromotive force (TEMF) in millivolts, developed at the temperature of the working end θ_1=100ºC and the free end θ_2=0ºC some metals and alloys paired with platinum:

Chromel (90% Ni + 10% Cr) ……………………………… + 2.40
Iron …………………………………………..………… + 1.80
Molybdenum ………………………………………….. + 1.20
Tungsten ……………………………………………….. + 0.80

Manganin (84% Cu + 13% Mn + 3% Ni) ………..………+ 0.76
Copper …………………………………………………+ 0.76
Tin ……………………………………………………...- 0.42
Aluminum …………………………………………….....- 0.40
Nickel …………………………………………………..- 1,50
Aluminum ……………………………………………...- 1,70
Constantan ……………………………………………..- 3,40
Kopel …………………………………………………..- 3,60

In order to obtain a more sensitive thermocouple, that is, developing a greater thermal energy level, it is desirable to select such a combination of materials as conductors A and B, which form a thermocouple, one of which has the potential of greater positive and another of the largest possible negative temperature potential in contact with platinum.

In the process of TFP, the temperature values at the contact along the periphery and in the layers adjacent to this contact were investigated. Due to the instantaneous change in temperature in areas L_1 and L_2 (see figure 5.7) due to the very high linear velocity and frequency of the pulses, the heating-cooling is accurate, even in the first approximation, the measurement of the difference in these areas is difficult. Although this moment is undoubtedly interesting.

To process the results of the most important dependencies, the method of mathematical statistics was used, it was regression analysis. After performing the analyzes, the Fisher's criterion, F was used to verify the accuracy of the mathematical model of the research object. All measuring tools and devices used in the work were tested for accuracy of readings. In addition, the reliability of the data obtained was determined by comparison with the results of other researchers.

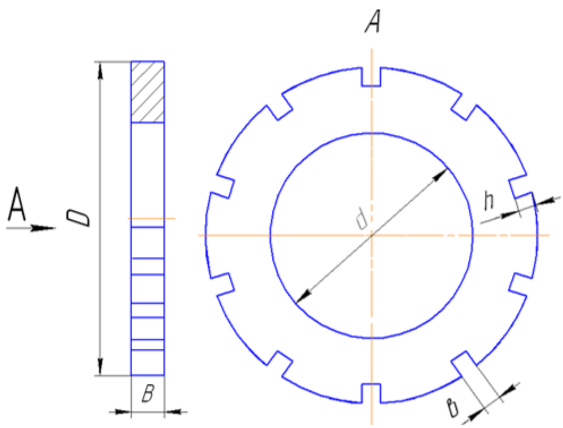
5.3 Methods of thermal friction processing of cone crusher parts

The process of traditional thermofriction processing (TFP) of metals by cutting disks is a combined method using the thermal and mechanical effect of the tool on the cutting layer of the workpiece material. It is carried out by direct contact of the workpiece and rotating with a large peripheral speed (till 80 m / s) a smooth or rolled on the periphery disk made of steel (HB till 150) with a diameter 500-600 mm and a height 40-60 mm. In the zone of contact of the tool with the workpiece, the work of friction forces turns into heat, softening the shear layer. The removal of metal occurs as a result of melting and partial evaporation of the metal particles of the workpiece with the subsequent ejection of their air flow created by the rotating disk. In addition, the movement of the tool provides mechanical removal and extrusion of metal particles from the processing area. Despite the well-known advantages of the TFP method, its widespread use in industry is hampered by a number of drawbacks, namely: a large peripheral speed of the tool - cutting disc (40-80 m / s), considerable cutting forces and intense wear of the bearings of the spindle unit of the machine.

We have developed a method and tool for the thermofriction processing of the plane [61, p. 33] and a thermofriction cutting-strengthening method of cylindrical surfaces [65, p. 33] and the design of the tool that eliminate the aforementioned disadvantages.

Let us consider in detail the essence of the method of thermofriction cutting-strengthening processing of cylindrical surfaces [65, p. 33] and the design of the tool.

Figure 5.8 shows a sketch of a friction disc design for machining cylindrical surfaces

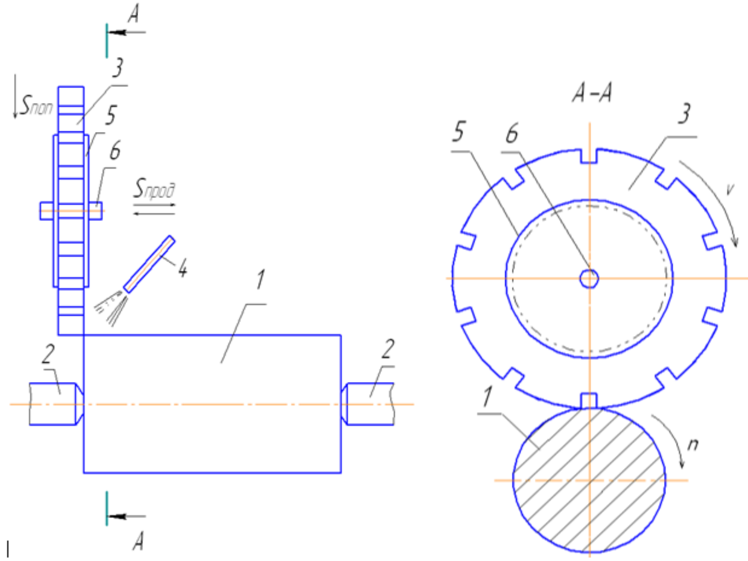


D is the outer diameter; d is the inner diameter; B is the width of the disk; в is the width of the groove; h is the depth of the groove

Figure 5.8 - Sketch of the friction disk design for TFP of the cylindrical surfaces

Figure 5.9 shows a diagram of the thermofriction cutting and hardening processing of a cylindrical surface.

Processing by the proposed method is carried out in the following sequence. The friction disk 3 is fixed with the help of o-rings 5 on the spindle 6 of a circular grinding machine model 3B151 by the type of emery wheels. The workpiece 1 is fixed in the centers 2. The workpiece fixed in the centers is reported by the rotational motion *n*, and the friction disk is rotated at a speed *v* and the feed movement *S* along the workpiece surface. On the surface of the friction disk, provided on the periphery with special grooves, a coolant is continuously supplied with the help of a tube 4 directly to the cutting zone.



1-workpiece; 2 - centers; 3- friction disc; 4- tube for supplying coolant; 5-o-rings; 6- machine spindle

Figure 5.9 - Diagram of the thermofriction cutting and hardening processing of a cylindrical sur face

In this case, the cutting fluid, falling on the surface of the friction disk, spreads over it, cooling the friction disk and taking its speed, gets through special grooves directly on the contact area where the cutting process takes place.

Continuous supply of coolant to the surface of the friction disk provides continuous cooling of the friction disk, and supply of coolant through special grooves made on the periphery of the friction disk, directly into the cutting zone localizes the thermal field, thereby increasing the temperature gradient. Heat in the deformation zone is released directly in the contact, as well as in the layers under it. In this case, a thin surface layer of metal lying in front of the disk will be subjected to thermal cycling with a given frequency, which will cause the formation of microcracks in this layer and facilitate the work of destruction. Increasing the temperature in the layers below the cutting surface will lead to a decrease in hardness.

The latter reduces the energy costs of processing ($N_э$≈5... 7 kW).

5.4 Experimental study of the quality of the surface layer using TFP

The implementation of thermofriction processing (TFP) according to the traditional method is associated with the need to achieve a linear velocity at the periphery of the friction disk 100 m / s or more. In this case, the magnitude of the sliding speed at the periphery contact, the disk is the material being processed, must ensure that the latter is completely softened. At the same time, the cutting tool must meet the requirements of the corresponding dimensional and stiffness.

Therefore, the higher the melting point of the material being processed, the greater should be the slip speed in the contact. Practical implementation of the processing of such materials requires large capital expenditures on equipment. Since the machine spindle must have a rotational speed of more than 10,000 rpm, which accordingly increases the requirements for vibration resistance. The high temperature at the contact required to soften the material being processed leads to a softening of the cutting disc. This can be prevented by increasing the diameter of the cutting tool. This size should be chosen in such a way that the residence time of the cutting edge of the tool in the cutting zone would be the required number of times less than in the free path zone, in which the strength properties are restored due to cooling by blowing air.

The methods of TFP developed by us allow you to control the properties of deformable metal layers due to high-frequency cooling and are resource-saving. Their applications allow to reduce costs: per tool (friction discs are made from simple steel), electricity (no more than 5-7 kW), nsh = 2000-3000 rpm, while you can assign feed values within Sm = 250-1000 mm / min, improving processing performance in comparison with traditional milling with an end mill 6-7 times. Tool life increases by 4-5 times. Making tools from simple structural steels reduces costs by 10 times or more compared to hard alloy.

During the thermal friction processing of the plane by the friction disk, the physicomechanical properties of the material being processed in the contact zone with the tool and the adjacent layers depend on the value of the peripheral speed on the generatrix of the friction disk. Also, the processes occurring in the contact disk-blank largely depend on the value of the peripheral speed.

The work expended on overcoming the deformations of microprotrusions is converted into heat primarily on contact pads. Thermal fluctuations can be observed at these sites, which instantly increase the temperature at the contact where the maximum temperature isoline is located. In this case, the higher the speed, the more heat is generated in this zone. It leads to the softening of the material being processed and facilitates the work of deforming the microprotrusions. Thus, the deformation is a function of temperature and heat generation, while at the same time it is itself a factor determining the intensity of heat generation. The existence of a direct heat-temperature-strain relationship leads to a feedback, strain-heat-temperature. Consequently, the process cycle is closed, tending to the steady-state value due to self-regulation. This circumstance indicates that the intensification of the TFP process can be accomplished by several methods [84].

A more rational of them is the management of the thermal field due to a change in the temperature gradient in the process of the TFP. From [78, p. 34] it is known that heat in the deformation zone is released directly in the contact zone and in the layers lying under it. And also, cooling the surface directly during cutting leads to an increase in the temperature gradient due to the localization of the thermal field. To localize the thermal field in the area subjected to deformation, it is necessary to supply coolant directly to the cutting zone.

In addition to the specified indicators of the quality of the cutting surface in a number of technological processes, there may be requirements for structural changes in the inner layers. This may cause a change in the distribution of hardness in the deformed surface layer. In this case, we should expect a change in the dependence of the intensity of wear on time during friction during operation.

A change in the hardness of the cutting surface and the layers adjacent to it can occur for two reasons. Or, as a result of strain hardening - work hardening, or as a result of heat processing. This may occur due to the heating of the material to a very high temperature and rapid cooling directly in the process. Strain hardening, in principle, will compete with temperature softening [85].

The conditions of a particular process, that is, the level of strain rate and temperature, taking into account the degree of strain [86], will determine the stress at a given point of the material. It is a defining parameter indicating the prevalence of one of the indicated factors.

In the process of the TFP, in the range of specified modes, all these phenomena may occur. Both tool geometry and cutting conditions can affect this.

For experimental studies of the Zhezkazgantsvetmet foundry-mechanical plant, special samples were made, made from the material of an eccentric part of a cone crusher (figures 5.10 - 5.12).

a) b)

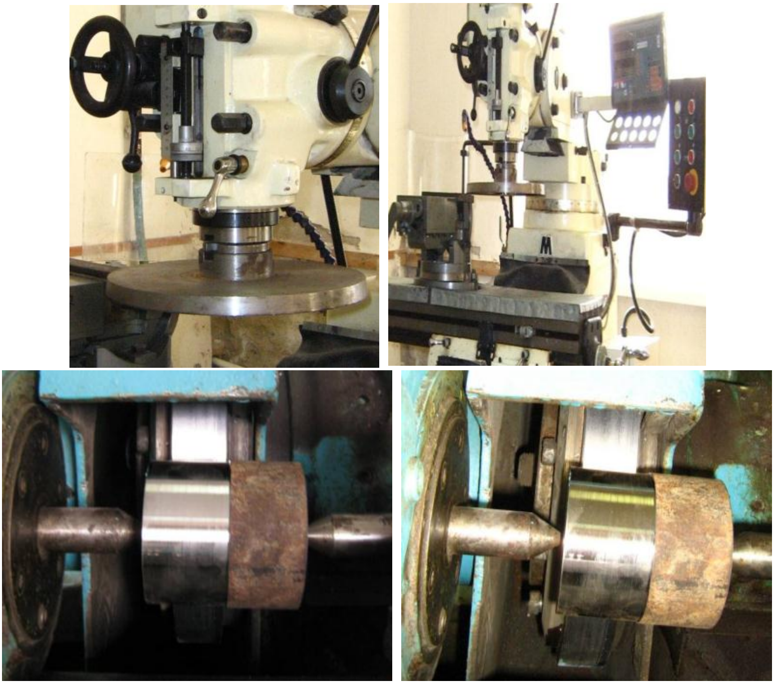
a) samples with welding; b) sample without surfacing

Figure 5.10 - Samples of plates made of 35L steel

Figure 5.11 - Cylindrical sample of 35L steel for research

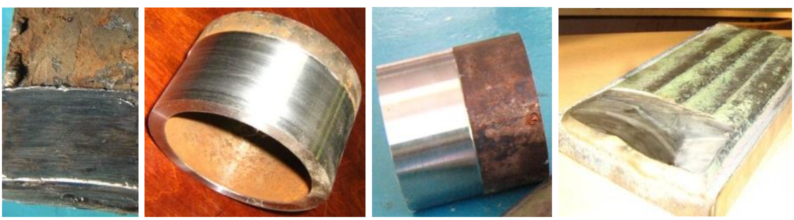
The obtained samples were processed on a JPI vertically milling machine and on a 3B151circular grinding machine.

Figure 5.12 shows the processes of TFP samples.



a) vertical milling machine; b) circular grinding machine
Figure 5.12 - TFP

Figure 5.13 shows photographs of some processed samples.



a) *b)*
a) processed sample without surfacing; b) processed sample with hard facing
Figure 5.13 - Processed Samples

Processing of blanks (samples) was performed under the following modes: spindle rotation speed n = 2000-2700 rpm; friction disk speed *v* = 30-40 m / s; workpiece feed S = 250–280 mm / min; removable stock t = 1-3 mm. The following results were obtained: the roughness parameter of the treated surfaces Ra = 3.2... 1.25 μm; the depth of the hardened layer is 1.2... 2 mm.

The influence of the tool geometry on the roughness and hardness of the surface when changing the diameter of the friction disk was investigated.

Figure 4.14 shows the experimentally obtained dependence of the change in hardness upon changing the diameter of the disk from 300 mm to 550 mm.

From which it follows that an increase in the diameter Di> 500 mm, practically does not lead to the hardening of the cutting surface.

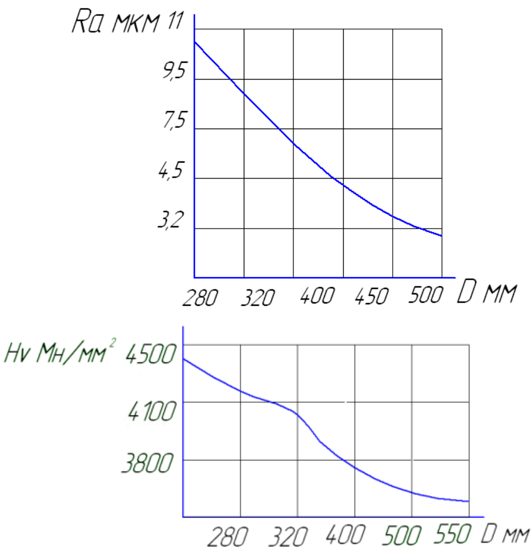


Figure 5.14 - Effect of cutting disc diameter on roughness (a) and hardness (b), with S = 0.3 mm / min; n = 2500 rpm

The processed material - Steel 35L, the cutting disk - Steel 60G.

The results show the ambiguous influence of the size of the friction disk on the processes of hardening the cutting surface. Refine the question allow the results obtained when changing the deformation zone and the sliding speed due to cutting conditions.

Figure 5.15 shows the results obtained when changing the rotational speed of the friction disk.

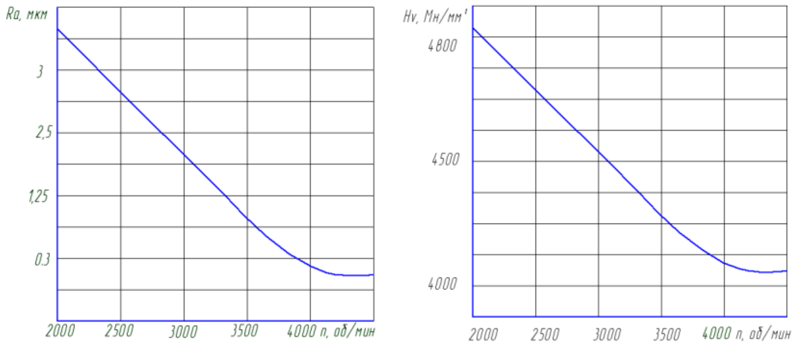
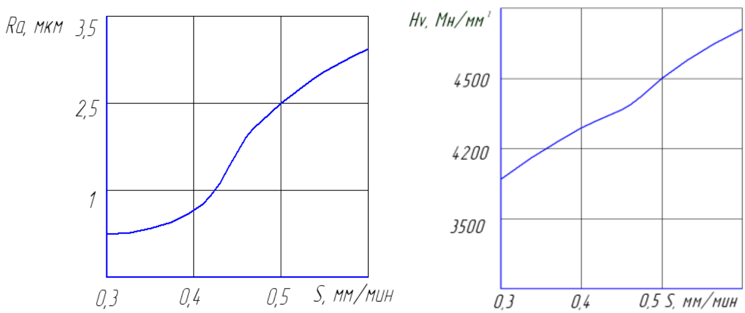


Figure 5.15 - Effect of speed on
roughness (a) and hardness (b), with S = 0.2 mm / min; Du = 380mm



a) b)

Figure 5.16 – Delivering Effect on roughness (a) and hardness (b) of the cutting surface, Du = 380mm; n = 3500 rpm

Cutting conditions and tool geometry using TFP have a very noticeable effect on the strength properties of the deformed layer and the machined surface of the part. These properties, along with the geometry of the machined surface, determine, ultimately, the functional properties of the part when it contacts this surface with other details of a specific mechanism assembly. Therefore, the management of these properties will improve the quality indicators of the machine as a whole.

Increasing “n” from 2000 to 3000 rpm leads to a softening by 500-

600 Mn / mm ^{2}. In this case, more appreciably weakening is observed after n = 3500 rpm. Consequently, an increase in the sliding speed in the friction contact favorably affects the hardness factor. Indeed, regardless of the way in which the increase in the linear velocity V is obtained by an increase in the rotational speed or the diameter of the friction disk, softening will occur. The choice of the parameter for V regulation should be made taking into account their influence on the quality indicators.

According to the results of the experiments, it can be stated that during TFP it is possible to get rid of the appearance of a re-glued or oxidized layer adjacent to the treated surface. Besides, it is important that the hardness gradient can be adjusted by changing the modes.

The increase in feed should lead to an increase in heat generation and an increase in the deformation zone hh. Analysis of the results obtained with a change in delivering (Figure 5.16) shows an increase in hardness of 300 MN / mm^2 when changing “S” from 0.3 to 0.4 mm / min.

To determine the effect of the thermal state on the quality of cutting, it is necessary to determine the modes and geometry of the cutting part of the tool, which T_{cp} <700°C when machining 35L steel. Using the proposed method of calculation [78, p. 34; 87, 88], this problem can be solved.

When processing, the thermal state of the workpiece in the cutting zone largely determines the cutting conditions, and significantly affects the quality. When using TFP in the traditional way [65, p. 33; 76, p. 34; 77, p. 34]: the cutting tool is a smooth friction disk, the values of the speed of the friction disk and feed should provide a temperature close to the melting point of the metal being processed. Otherwise, the implementation of cutting is difficult.

TFP with a high-frequency contact break, when a pulsed heating cycle occurs, cooling is significantly different from traditional technology and in terms of heat distribution. The issue of cutting quality assurance comes down to controlling the average temperature in contact. At the same time, this temperature can be controlled by the following parameters: cutting speed V; feed rate S; disc diameter Du; and tool geometry. By tool geometry is meant the ratio of the lengths of sections L_1 and L2, as well as the pitch of their location.

Selecting these parameters according to conclusions [78, p. 38], further adjustment can be made by changing L1, L2 and their number.

But, if you specify the diameter of the tool Du and assign, the values of L_1 and L_2, their number is obtained from the relationship:

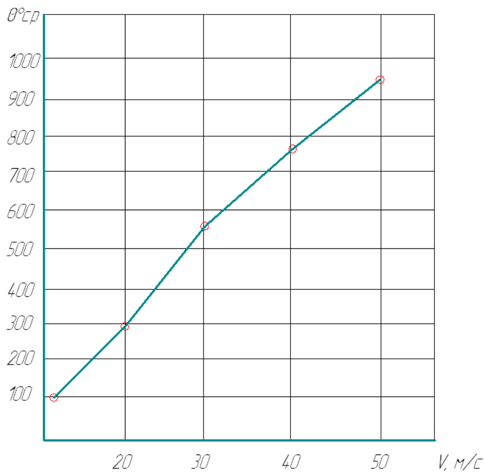
$$z = \frac{\pi \cdot D_t}{L_h + L_{cool}}$$

here D_t - is the diameter of the tool, mm;
Lh - Lheating - length of heating, mm;
Lcool - Lcooling - length of cooling, mm.

An analysis of the results listed above indicates that with increasing speed, the overall temperature level rises. This is due to the large heat release.

According to experimental data, it is desirable to maintain the level of average temperatures between (for 35L steel) values of 500 ÷ 700°C. Since the increase in T_{aver} >700°C leads to hardening of the surface, and a decrease in Taver <500 ° C leads to a significant increase in cutting forces.

Figure 5.17 shows the experimentally obtained dependence of the average temperature change at different cutting speeds



Steel 35L; S = 50 mm / min; ln = 12mm; lo = 17mm

Figure 5.17- Effect of cutting speed on the average temperature in pulsed cooling TFP

Knowing the recrystallization temperature of the material being processed, it is possible to experimentally determine the required average temperature in the contact θ_{cp} from the condition:

$$\theta_{cp} > \theta_{pek}, \tag{5.2}$$

where θ_{cp} - the average temperature in contact, ° C;
θ_{pek} - recrystallization temperature, ° C.

By changing the speed at the periphery of the disk, it is easy to establish the necessary Vu by means of an artificial thermocouple to ensure conditions (5.2).

5.5 Calculation of heat distribution in the eccentric using TFP

As can be seen from the principle of conducting TFP, the main factor of influence, which is heat, on which the quality of the surface layer depends. Then consider the thermal conductivity, or the pressure of the heat fluxes occurring in the eccentric [89].

Consider a uniform cylindrical wall, which is what the eccentric will be when considering it as a heat-conducting area of length l, with an inner radius r and outer r2. The coefficient of thermal conductivity of the material λ is constant. The inner and outer surfaces are maintained at constant temperatures t1 and t2, with t1> t2 and the temperature changing, only in the radial direction r. Consequently, the temperature field here will be one-dimensional, and the isothermal surfaces will be cylindrical, having a common axis with the pipe. Let us select inside the wall an annular layer of radius r and thickness dr limited by isothermal surfaces. According to Fourier's law, the amount of heat passing per unit of time through this layer is equal to:

$$Q = -\lambda F \frac{dt}{dr} = -2\lambda\pi r l \frac{dt}{dr}, \tag{5.3}$$

where λ is the coefficient of thermal conductivity of the material;
r is the inner radius, mm;
l is the length, mm.

Dividing the variables, we have:

$$dt = -\frac{Q}{2\pi\lambda l} \cdot \frac{dr}{r}. \tag{5.4}$$

After integrating equation (5.3) we find:

$$t = -\frac{Q}{2\pi\lambda l}\ln r + C. \tag{5.5}$$

Substituting the values of variables at the wall boundaries (at *r = r1 t = 1* and at *r = r2 t = t2*) and excluding the constant C, we get the following calculation formula:

$$Q = \frac{2\pi\lambda}{\ln\frac{r_2}{r_1}}(t_1 - t_2) = \frac{2\pi\lambda l}{\ln\frac{d_2}{d_1}}(t_1 - t_2) = \frac{\pi l(t_1 - t_2)}{\frac{1}{2\lambda}\ln\frac{d_2}{d_1}}. \tag{5.6}$$

Consequently, the amount of heat transmitted per unit time through the eccentric wall is directly proportional to the thermal conductivity λ, length l and temperature head Δt = t1 - t2 and inversely proportional to the natural logarithm of the ratio of the external diameter of the pipe d2 to internal d1. Formula (5.5) is also valid for the case when t1 <t2, i.e. when the heat flux is directed from the outer surface to the inner [89, p. 50].

The amount of heat passing through the eccentric wall can be attributed either to a unit of length l, or to a unit of internal F1 or external F2 of the surface of the eccentric. In this case, the calculation formulas respectively take the following form:

$$q_l = \frac{Q}{l} = \frac{\pi\Delta t}{\frac{1}{2\lambda}\ln\frac{d_2}{d_1}}. \tag{5.7}$$

$$q_1 = \frac{Q}{F_1} = \frac{Q}{\pi d_1 l} = \frac{\Delta t}{\frac{1}{2\lambda}d_1 l\ln\frac{d_2}{d_1}}. \tag{5.8}$$

$$q_2 = \frac{Q}{F_2} = \frac{Q}{\pi d_2 l} = \frac{\Delta t}{\frac{1}{2\lambda}d_2 l\ln\frac{d_2}{d_1}}. \tag{5.9}$$

Since the areas of the internal and external surfaces of the eccentric are different, the values of the densities of heat fluxes q1 and q2 are also different. The mutual relationship between them is determined by the ratio:

$$q_l = \pi d_1 q_1 = \pi d_2 q_2. \tag{5.10}$$

The equation for the temperature curve inside a uniform cylindrical wall is derived from equation (5.5). Substituting here the values of Q and C, we have:

$$t_r = t_1 - \frac{Q}{2\pi\lambda l}\ln\frac{d_x}{d_1} = t_1 - \frac{t_1 - t_2}{\ln\frac{d_2}{d_1}}\ln\frac{d_x}{d_1}. \tag{5.11}$$

Therefore, in this case, at a constant value of thermal conductivity λ, the temperature varies along a logarithmic curve (Figure 5.18). Taking into account the dependence of the thermal conductivity on temperature λ = λ0 (1 + bt), the equation of the temperature curve takes the following form:

$$t_r = -\frac{1}{b} + \sqrt{\left(\frac{1}{b} + t_1\right)^2 - \frac{Q}{b\pi\lambda_0 l}\ln\frac{d_x}{d_1}}. \tag{5.12}$$

Consequently, in our case, the following dependences were obtained during thermofriction processing (Figures 5.18–5.23).

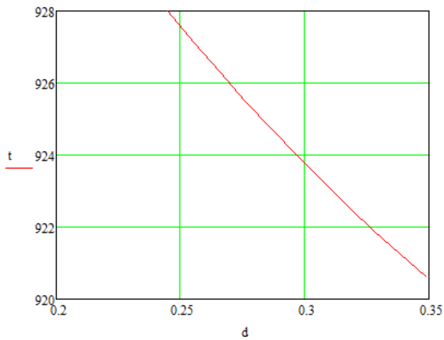


Figure 5.18 - The temperature drop in the eccentric over the maximum section at 928°C

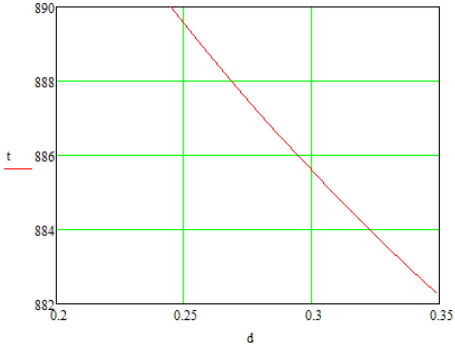


Figure 5.19 - The temperature drop in the eccentric over
the maximum cross section at 890°C

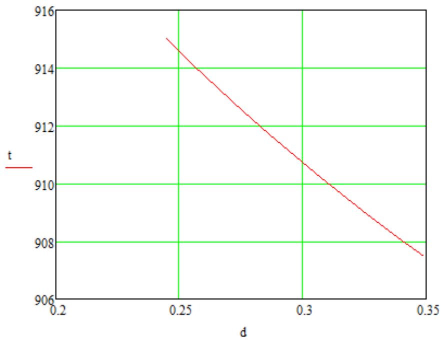


Figure 5.20 - Temperature drop in
the eccentric over the maximum section at 915°C

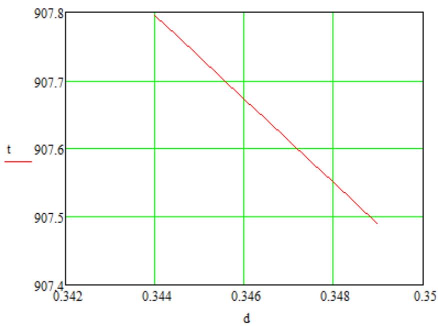


Figure 5.21 - The temperature drop in the eccentric over
the minimum cross section at 915°C

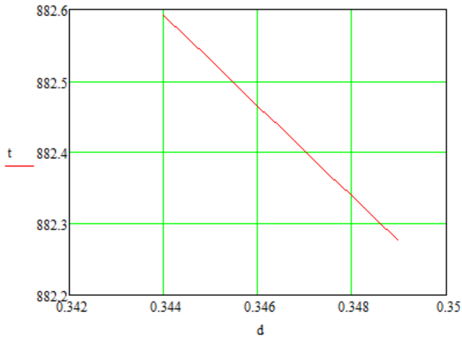


Figure 5.22 - The temperature drop in the eccentric over the minimum cross section at 890°C

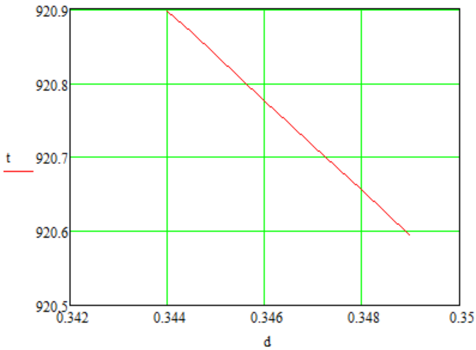


Figure 5.23 – Temperature drop in an eccentric over the minimum cross section at 928°C

The dependences obtained in Figures 5.17-5.23 show that the temperature drop in the body of the workpiece is primarily due to the coefficient of thermal conductivity of the material and has a clear linear function. At the same time, it should be noted that the dynamics of the temperature drop is higher than that of materials during normal heating. A sharp drop in temperature is determined by the time of exposure to heat, which is approximately equal to the length of the friction disk tooth during thermofriction processing, that is, the time of frictional friction of each individual tooth segment.

CHAPTER 6. EXPERIMENTAL STUDIES OF THE ECCENTRIC WEAR

6.1 Study of the dependence of wear on the operating modes of equipment and manufacturing technology

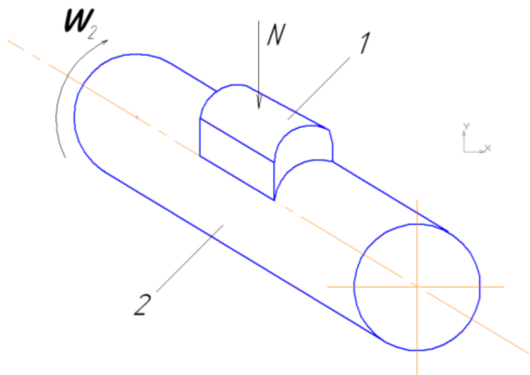
Improving the quality and reliability of machines is a necessary condition for the development of engineering. Reliability of machines is ensured primarily when high quality materials with the required level of mechanical properties are achieved. Most often, the main reason for the failure of machines is the wear of moving couplings [90].

In our case, the eccentric assembly CMTC-2200, made of 35L steel, is a subject to wear. As can be seen from the above, the physical and mechanical properties of the material and the mechanical qualities of the surface layer primarily affect the wear of the part, and only then the working conditions of the product.

The factors affecting the external friction of the part, which leads to wear include: the nature of the rubbing bodies, lubricant, load speed, temperature.

Wear sufficient to break the eccentric reaches only 5-6 mm. The period of wear of a new product and of a restored one differs twice, respectively, 8 and 16 months.

According to the kinematic feature, we establish the direction and mutual arrangement of the rubbing parts. According to the established scheme (figure 6.1) and table 6.1, we determine that the movement will be unidirectional along a generator, that is, the scheme will be 1.1C.



1- eccentric; 2-sleeve

Figure 6.1 - Scheme of friction in a coupling pair of the eccentric-sleeve

Table 6.1 - The main kinematic types of couplings

The shape and mutual position of the coupling	The nature of the relative movement and coupling		
	Across generatrix		Along the generatrix
	one-directional	alternative	alternative
Internal touch of non-planar surfaces with close values of the radii of curvature	1.1 Radial bearing, brake-block	1.2 Radial hinge, spherical hinge, screw-nut	1.3 Ring sleeve, cylinder, guide bush-pusher
«flatness-flatness»	2.1 Axial plain bearing (thrust bearing), mechanical seal	2.2 Axial hinge, mechanical seal hinge	2.3 Ring-groove of the piston, guides like "dovetail"
External tangency of non-planar surfaces with different radii of curvature	3.1 Gearing, cam-pusher, rolling body-clip	3.2 Reversing gearing, guide-rolling body	3.3 Rolling guide body

The main criteria for evaluating tribotechnical characteristics are wear rate and friction coefficients. According to State standard 27674-88, wear rate is the ratio of the thickness of the worn layer to the path on which the wear occurred. That is the wear rate:

$$l = h / L, \tag{6.1}$$

where h is the value of the worn layer, mm;

L is the friction path under specific test conditions (oil, abrasive, sample temperature, load, etc.), mm.

For friction pairs of rotational motion according to the “block-roller” scheme, when determining the mass loss of each of the tested samples, the wear rate is determined by the following formulas.

For pads for the test period with the number of revolutions n:

$$l_1 = \frac{h_1}{L_1} = \frac{\Delta q_1}{2\pi R n F \gamma_1}, \tag{6.2}$$

where $h1$ is the worn layer of the sample-block for n turns (we assume to be uniform over the friction surface of the sample of the block), mm;

Δq_1 is a weight loss of the sample at n turns, microns;

R is the radius of the sample roller, mm;

$F = lb$ is a nominal contact area of the pair (area of the sample-block), mm^2;

l is a sample size-pads and in the direction of relative movement, mm;

b is a sample size-pads in the direction perpendicular to the relative displacement, mm;

γ_1 is a specific density of the sample material-pads, g /cm^3.

For the sample roller for the test period with the number of revolutions n wear rate:

$$l_2 = \frac{h_2}{L_2} = \frac{\Delta q_2}{2\pi RnF\gamma_2}, \tag{6.3}$$

where *h2* is the average thickness of the worn layer of the sample roller for n turns, mm;

$L_2 = l$ is the greatest way of friction points of the surface of the sample-roller for one revolution, mm;

Δq_2 is a weight loss of the sample roller for n turns, microns;

γ_2 is a specific density of the sample-roller material, g / cm^3.

With face friction:

$$l = \frac{\Delta h}{2\pi r_{cp} n}, \tag{6.4}$$

where Δh is the average linear wear for *n* test cycles;

r_{cp} is the average radius of the contact area, mm;

n is the total number of revolutions of the movable sample.

6.2 Doing the experiment and description of the laboratory setup

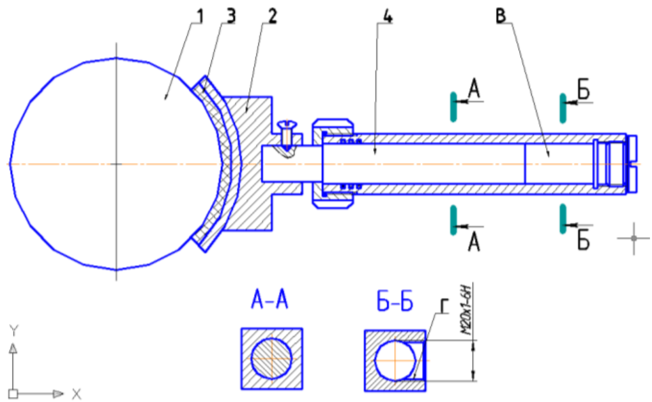
According to the proposed scheme, we find the input parameters for the experiment. To determine the wear rate of the eccentric, during the experiment we will create samples that are listed in table 6.2.

Table 6.2 - Parameters of samples for the experiment

Sample number	Diameter of the samples, mm	Sample material
1-12	105	35Л
13-24	95	Alloy ПЛ-АН 111
25-36	105	Alloy ПЛ-АН 111
37-48	95	35Л

According to State standard 23.224-86, it is recommended to use standard friction machines SMT-1 and UMT-1. Due to the absence of this equipment, it makes sense for a given kinematic pair to use equipment with one rotational and one transverse movement. Such equipment can be any universal lathe. Since the pairing of two parts must lie along the generatrix of them, respectively, along the outer and inner circumference, according to Figure 5.2. This is not possible to achieve due to the inability to control the parameters of the generator from the outside, that is, the part located outside. Therefore, we will make the outer part flat, and all measurements will be carried out for the inner part, which will correspond to the eccentric. We choose a turning and cutting machine 16K20, which can provide us with such a scheme of interaction between two mating parts.

To ensure such a scheme on the machine, that is, to control the value of the clamping force, we construct a special tooling to control the clamping force for wear, shown in Figure 6.2.



1- test sample; 2- holder; 3-babbit layer; 4-pin; C-liquid; D-hole gauge.

Figure 6.2 - Tooling to control the clamping force on wear

6.3 Statistical planning of experiments. Planning an experiment to describe the dependence of wear rate on the pressing force of the coupling parts

Laboratory active experiment provides for the forced change of the studied factors in the required limits. At the same time, a traditional one-factor experiment implies alternating changes of factors one by one with fixing other factors at certain levels.

Under the planning of an experiment, we mean the formulation of experiments according to a predetermined scheme with some optimal properties. At the same time, all investigated factors vary simultaneously, and the influence of unknown factors or factors not included in the study is randomized using special statistical techniques. At the same time, mathematical methods are used not only at the last stage of the study, when processing the results of observations, but at all stages when formalizing a priori information, before setting up experiments, when planning an experiment and processing its results, analyzing the dependencies, and also when making decisions. Thus, experiment planning is a new approach to research, in which mathematical methods play an active role. This methodology allows you to successfully solve the most important question for the researcher: how much and what experiments should be carried out, how to process their results to solve the task with a predetermined accuracy with the minimum possible number of experiments [90, p. 57].

Planning an experiment places increased demands on the thoroughness of the experiment. Statistical evaluations of the results of the implementation of the experiment plan (which will be discussed below) will inevitably reflect the shortcomings in experimentation. Traditional research methods used in the field of machining (one-factor experiment) do not provide for finding the experimental error, as well as verification of the reliability (adequacy) of the dependencies obtained. The relatively high values of variation in the persistence index, which usually take place in the cutting tool testing, create additional difficulties in planning the experiment and increase the amount of tests required. Therefore, reducing the variation of the optimization parameter, which usually is the indicator of persistence, as well as the variation of measurement factors should be the focus of attention of the experimenter.

We note some specific aspects of experiment planning. If it is not possible to provide a uniform processed material for the entire test volume, then the number of different batches of material should be determined in advance and the planning matrix should be divided into orthogonal blocks accordingly. In order to exclude the influence of the variability of the experimental conditions that may occur with the passage of time, it is recommended that a random sequence be used in the formulation of experiments within each block, that is, the experiments must be randomized in time. Randomization is performed using a table of random numbers.

6.4 Planning an experiment

We set the task of describing the dependence of the wear rate on the load *x1*, time *x2*, sample diameter *x3*. We take an incomplete cubic function as a mathematical model.

$$M\{y\} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{123} x_1 x_2 x_3 \quad (6.5)$$

To obtain estimates of the coefficients of this equation, you can use a full-factor experiment of type 2^3. We choose the main levels of factors close to practical application, and the intervals of variation are based on the actual limits of fluctuations of the factors (table 6.3).

Table 6.3 - Levels of factors and intervals of variation

Factor levels	specification	P, H	t, min	*D*, mm
		$\tilde{x}_1$	$\tilde{x}_2$	$\tilde{x}_3$
Main	0	1900	480	100
Variation interval	$\Delta\tilde{x}_i$	100	60	5
Upper	+ 1	2000	540	105
Lower	- 1	1800	420	95

Experiments are performed in accordance with the planning matrix (table 6.4).

Table 6.4 - Planning Matrix 23 and Experimental Results

№ plan point *V*	x_0	x_1	x_2	x_3	x_1, x_2	x_1, x_3	x_2, x_3	x_1, x_2, x_3	Code name of the lines	Optimization parameter
1	+	-	-	-	+	+	+	-	(1)	y_1
2	+	+	-	-	-	-	+	+	*a*	y_2
3	+	-	+	-	-	+	-	+	*b*	Y_3
4	+	+	+	-	+	-	-	-	*ab*	Y_4
5	+	-	-	+	+	-	-	+	*c*	Y_5
6	+	+	-	+	-	+	-	-	*ac*	Y_6
7	+	-	+	+	-	-	+	-	*bc*	Y_7
8	+	+	+	+	+	+	+	+	*abc*	Y_8

Test conditions Tested samples made according to table 6.2. Samples were made so as to obtain combinations of the parameter values indicated in the rows of the matrix of the experiment plan. At each point of the factor space, the experiment was repeated 3 times, therefore, 3 samples were made for each line of the plan. The order of trials of eccentrics is randomized using a random number table. The test results (wear value) are given in table 6.5, columns 2-4.

Table 6.5 - Sample Test Results

Plan point *v*	Y_1	y_3	y_3	$\bar{y}_\vartheta$	s_ϑ^2	$\hat{y}_v$	$(\bar{y}_\vartheta - \hat{y}_\vartheta)^2$
1	$1,6\cdot10^{-4}$	$1,7\cdot10^{-4}$	$1,5\cdot10^{-4}$	$1,6\cdot10^{-4}$	0,01	1,89	2,53
2	$1,8\cdot10^{-4}$	$1,8\cdot10^{-4}$	$1,6\cdot10^{-4}$	$1,73\cdot10^{-4}$	0,013	1,76	2,96
3	$1,9\cdot10^{-4}$	$1,9\cdot10^{-4}$	$2,0\cdot10^{-4}$	$1,93\cdot10^{-4}$	0,003	2,02	3,72
4	$1,8\cdot10^{-4}$	$1,9\cdot10^{-4}$	$1,7\cdot10^{-4}$	$1,8\cdot10^{-4}$	0,01	1,98	3,2
5	$2,1\cdot10^{-4}$	$2,2\cdot10^{-4}$	$2,1\cdot10^{-4}$	$2,13\cdot10^{-4}$	0,003	1,81	4,54
6	$1,1\cdot10^{-4}$	$2,0\cdot10^{-4}$	$2,0\cdot10^{-4}$	$1,7\cdot10^{-4}$	0,27	1,70	2,04
7	$2,0\cdot10^{-4}$	$2,4\cdot10^{-4}$	$2,3\cdot10^{-4}$	$2,23\cdot10^{-4}$	0,043	1,86	4,8
8	$1,0\cdot10^{-4}$	$2,1\cdot10^{-4}$	$2,0\cdot10^{-4}$	$1,7\cdot10^{-4}$	0,37	1,80	1,77
	$\bar{y} = 1.85\cdot10^{-4} \sum s_\vartheta^2 = 0.723$					$\sum = 25.6$	

Table 6.6 - Experiment Parameters

Experiment	Experiment parameter		
	P, H	t, min	*D*, mm
1	1800	420	105
2	1800	420	95
3	1800	540	105
4	1800	540	95
5	2000	420	105
6	2000	420	95
7	2000	540	105
8	2000	540	95

Table 6.7 - The value of the intensity of wear for steel 35L

Experiment	Sample 1	Sample 2	Sample 3
1	$4.809*10^{-13}$	$5.109*10^{-12}$	$4.508*10^{-12}$
2	$5.300*10^{-13}$	$5.300*10^{-12}$	$4.711*10^{-12}$
3	$5.482*10^{-13}$	$5.482*10^{-12}$	$5.771*10^{-12}$
4	$5.090*10^{-13}$	$5.373*10^{-12}$	$4.808*10^{-12}$
5	$5.821*10^{-13}$	$6.099*10^{-12}$	$5.821*10^{-12}$
6	$4.621*10^{-13}$	$5.436*10^{-12}$	$5.436*10^{-12}$

7	$5.331*10^{-13}$	$6.397*10^{-12}$	$6.131*10^{-12}$
8	$2.614*10^{-13}$	$5.491*10^{-12}$	$5.229*10^{-12}$

Based on the obtained data during the experiment, we build the dependence of wear l2 on time t (figure 6.3), the dependence of wear l2 of the eccentric on the diameter d (figure 6.4) and the dependence of wear l2 of the eccentric on force P (figure 6.5) for steel 35L.

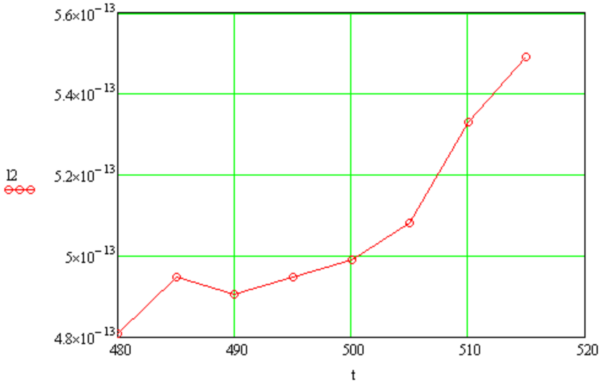


Figure 6.3 - Dependence of wear l2 eccentric on time t

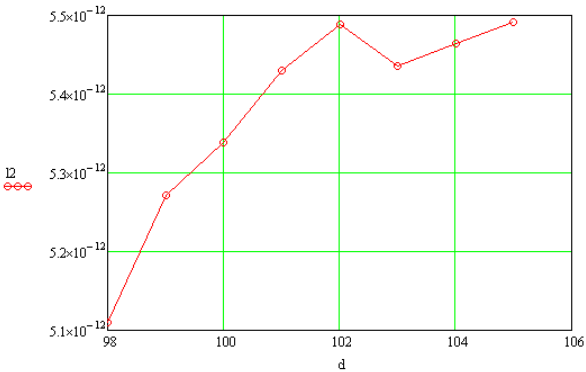


Figure 6.4 - Dependence of wear l2 of the eccentric on the diameter d

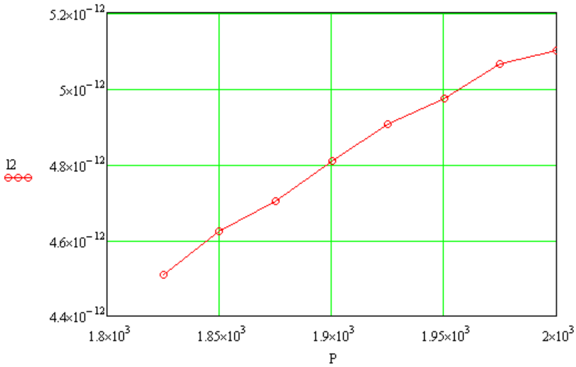


Figure 6.5 - Dependence of wear l2 of the eccentric on the force P

Table 6.8 - The value of wear rate for alloy PL-AN 111

Experiment	Sample 1	Sample 2	Sample 3
1	$3.306*10^{-13}$	$3.606*10^{-12}$	$3.005*10^{-12}$
2	$3.386*10^{-13}$	$3.680*10^{-12}$	$4.122*10^{-12}$
3	$3.491*10^{-13}$	$3.693*10^{-12}$	$4.270*10^{-12}$
4	$3.506*10^{-13}$	$3.704*10^{-12}$	$4.298*10^{-12}$
5	$3.548*10^{-13}$	$3.742*10^{-12}$	$4.352*10^{-12}$
6	$3.588*10^{-13}$	$3.778*10^{-12}$	$4.376*10^{-12}$
7	$3.625*10^{-13}$	$3.838*10^{-12}$	$4.345*10^{-12}$
8	$3.608*10^{-13}$	$3.843*10^{-12}$	$4.366*10^{-12}$

Based on the obtained data during the experiment, we build the dependence of wear l2 on time t (figure 6.6), the dependence of wear l2 of the eccentric on the diameter d (figure 6.7) and the dependence of wear l2 of the eccentric on force P (figure 6.8) for the PL-AN 111 alloy.

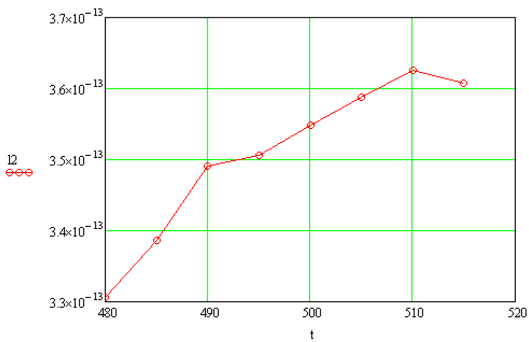


Figure 6.6 - Dependence of wear l2 of the eccentric on time t

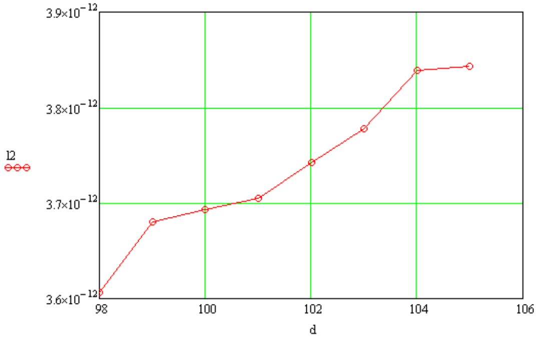


Figure 6.7 - The dependence of wear l2 of the eccentric on the diameter d

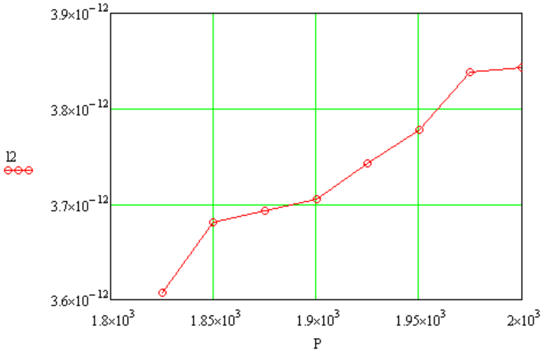


Figure 6.8 - The dependence of wear l2 of the eccentric on the force P

On the basis of the experiment, analyzing the dependencies obtained (Figures 6.3-6.8), we find out that the pressing effect on the intensity of wear of two steel surfaces with radii of curvature close to each other and between which there is a babbit layer is determined by the mass more details.

The wear rate decreases as lapping of coupling parts and then increases with decreasing babbit layer.

6.5 Getting a mathematical model of the object

The purpose of a full-factor experiment is to obtain a description of the object under study in the form of equality (6.5). For convenience, we will use the regression equations, presented in the form of the formula (6.6).

In this case, we obtain independent estimates for *bi* of the corresponding coefficients $\beta_i b_i \rightarrow \beta_i$

The orthogonality of the planning matrix makes it possible to drastically simplify the calculation of the coefficients of the regression equation, which is one of the advantages of such an experimental design. It can be shown [91] that for any number of factors the coefficients will be calculated by the formula:

$$b_i = \frac{\sum_{\vartheta=1}^{n} x_{i\vartheta}\bar{y}_{\vartheta}}{n} \quad (6.6)$$

where b_i is a regression equation coefficient;

i=0, 1, 2,… is factor number

$\bar{y}_{\vartheta}$ is an average response over r experiments at point number *v:*

$$\bar{y}_i = \frac{\sum_{j=1}^{n} y_{\vartheta j}}{n}$$

Zero is written to calculate b0. Since each factor (except x0) varies on two levels +1 and -1, the calculations are reduced to assigning a column for the signs of the column to the corresponding factor and algebraically adding the values obtained. Dividing the result by the number of points in the plan gives the desired ratio.

We calculate the coefficients of the equation for our example (table 6.5):

$$\frac{\sum_{\vartheta=1}^{n} x_{i\vartheta}\bar{y}_{\vartheta}}{n} = 1/8(-0{,}0016 + 0{,}00173 - 0{,}00193 + 0{,}0018 - 0{,}00213 + 0{,}0017 - 0{,}00223 + 0{,}0017) = 5{,}59$$

The values of b2, b3 are calculated in the same way. The calculation of b0 is performed by the same rule:

$$b_0 = \frac{\sum x_{i\vartheta}\bar{y}_{\vartheta}}{n} = \frac{1}{8}(36{,}90 + 44{,}07 + 34{,}83 + 52{,}62 + 18{,}11 + 25{,}62 + 32{,}80) = 34{,}46.$$

Thus, the value of b0 is equal to the average value of the optimization parameter *yv*. So we get: b_0 =1,854167; b_1 =-0,12083, $b_{2=}$ 0,0625, b_3 =0,0875; b_{12} =-0,04583; b_{13} =-0,12083, b_{23} = -0,0375, b_{123} =0,020833

The equation in the converted variables xi will be:

Y= 1,854167-0,12083 x_1 +0,0625 x_2 +0,0875 x_3-0,04583 x_1x_2-0,12083 x_1x_3 -0,0375 x_2x_3+0,020833 $x_1x_2x_3$

To get the equation in natural values of the factors xt, instead of xt, substitute their values in equation (6.5) according to the conversion formula (6.6):

$$x_1 = \frac{\tilde{x}_1 - 1900}{100}, \quad x_2 = \frac{\tilde{x}_2 - 480}{60}, \quad x_3 = \frac{\tilde{x}_3 - 100}{5}.$$

Processing the results of the experiment. The design of the experiment is based on the statistical nature of the dependencies; therefore, the resulting coupling equations are subjected to thorough statistical analysis. The objectives of this analysis are twofold. On the one hand, to extract the maximum of information from the experimental results, on the other hand, to verify the reliability of the obtained dependence and its accuracy [92].

Variance characterizing the error of experience. Each experiment carries some kind of error; in order to reduce it, experiments are repeated under the same conditions, that is, in each row of the planning table. Progressive dispersions are calculated by the formula:

$$s_\vartheta^2 = \frac{\sum_{j=1}^{r} \left(y_{\vartheta j} - \bar{y}_\vartheta\right)^2}{r-1} \tag{6.7}$$

where r is the number of repeated experiments at points of the plan.

The variance of the optimization parameter s^2 *(y)* is the arithmetic mean of the variances of all *n* different experimental variants (averaged variance). When calculating the variance of the optimization parameter, the squared difference between the y_{vj} values in each experiment and the average value of the repeated observations y_v should be summed up by the number of rows in the matrix, and then divided by n (r - 1). So,

$$s^2\{y\} = \frac{\sum_{\vartheta=1}^{n} s_\vartheta{}^2}{n} = \frac{\sum_{\vartheta=1}^{n}\sum_{j=1}^{r} \left(y_{\vartheta j} - \bar{y}_\vartheta\right)^2}{n(r-1)} \tag{6.8}$$

For our case in table 6.5 we have that $\sum_{\vartheta=1}^{n} s_{\vartheta}^{2}$ = 25,6. Then

$$s^2\{y\} = \frac{0{,}723}{8} = 0{,}09$$

If the number of repeated experiments is different (due to the rejection of gross results, lack of materials, etc.), then when averaging the dispersions, the average weighted value of the dispersions should be used, taking into account the number of degrees of freedom:

$$s^2\{y\} = \frac{\sum_{\vartheta=1}^{n} f_{\vartheta} s_{\vartheta}^{2}}{\sum_{\vartheta=}^{n} f_{\vartheta}} = \frac{\sum_{\vartheta=1}^{n} f_{\vartheta} s_{\vartheta}^{2}}{f_E} \qquad (6.9)$$

where s_v is the variance of the response by the results at v point of the plan, where $г._0$ repeated experiments are performed;

$f_{\vartheta}= r_v$ -1 is the number of degrees of freedom for such a dispersion;

f_E is the total number of degrees of freedom for the combined variance s^2\\y\\.

Therefore, it is not possible to use the calculation formulas for the coefficients given above. Before you combine the dispersions, you must ensure that they are homogeneous [92, p.69].

Checking the uniformity of dispersions is performed using various statistical criteria: Fisher, Kochren, Bartlet. Kochren's criterion is suitable for cases when the number of repeated experiments at all points of the plan is the same. Of all variances s_i, the largest s_{lmax} is found, which is divided by the sum of all variances by points. Cochren's criterion is the ratio of the maximum variance to the sum of all variances. In our case, using table 5 [91, p. 75], we find:

$$G = \frac{0{,}37}{25{,}6} = 0{,}014 \qquad (6.10)$$

According to the corresponding table in [92, p.62], we find для f_{vmax} =2, $f_{знам}$ = 8 degrees of freedom and significance level 5%. The critical value is GKP = 0.5157. The hypothesis of homogeneity of dispersions is accepted if, as in our case, the experimental value of Cochren's criterion does not exceed the table value:

$$G < G_{KP}$$
$$0{,}014 < 0{,}5157$$

Regression analysis. Based on the least squares method, a coupling equation or a mathematical model has been found. The method of least squares is used as a computational technique. Now we have to perform statistical estimates of the resulting model.

The usual regression analysis is based on the following assumptions.

1 The results of observations y_u y_2.....$y_,$, optimization parameter in n points of the factor space are independent, normally distributed random variables.

2 The variance of the value y does not depend on the absolute value y and the values of the factors, i.e., the variances at different points of the plan are the same. A check on the fulfillment of this condition was shown above.

3 Factor values are non-random values. In practice, this means that the independent variables *xx*, *x2*,..., *xк* are measured with a negligible error compared with the reproducibility error for these factors. Violation of this condition leads to difficulties in the implementation of the planning matrix and therefore is easily detected in the process of the experiment.

6.6 Testing the significance of model coefficients

The verification of the significance of each coefficient is carried out independently. To do this, you can use the test by student's t-test. When using a full-factor experiment or regular replicas (about them below), the confidence intervals for all coefficients are equal to each other. First of all, we find the variance of the regression coefficient s^2 {ft,}. With a uniform duplication of experiments on points with the number of repeated experiments *г*, it is determined by the formula:

$$s^2\{b_i\} = \frac{s^2\{y\}}{nr} \tag{6.11}$$

$f_E = n\ (r - 1)$ with freedom stages.

In our case:

$$s^2\{b_i\} = \frac{0{,}09}{8 \cdot 3} = 0{,}004\ ;\ s\{b_i\} = \sqrt{0{,}004} = 0{,}063$$

It can be seen from the formula that the dispersions of all coefficients are equal to each other, since they depend only on the experimental error and the number of experiments. Now we calculate the values of the ti-criterion using the formula:

$$t_i = \frac{|b_i|}{s\{b_i\}} \tag{6.12}$$

We get for our task:

$$t_0 = \frac{1{,}85}{0{,}063} = 29{,}37\ ;\ t_1 = \frac{0{,}12}{0{,}063} = 1{,}9;\ t_2 = \frac{0{,}625}{0{,}063} = 9{,}92;\ t_3 = \frac{0{,}088}{0{,}063} = 1{,}397;$$

$$t_{12} = \frac{0{,}46}{0{,}063} = 7{,}302;\ t_{13} = \frac{0{,}12}{0{,}063} = 1{,}9;\ t_{23} = \frac{0{,}38}{0{,}063} = 6{,}032;\ t_{123} = \frac{0{,}02}{0{,}063} = 0{,}317;$$

The critical value t_{KP} is found in the table of work [92, p. 87] with n (r-1) = 16 degrees of freedom and a given level of significance a = 5%. In our case, tKP = 0.17. If $t_i > t_{KP}$, then the hypothesis is rejected and the coefficient bi is considered significant. Otherwise, *bi* is considered statistically insignificant, i.e. βi = 0. In our case, there are no such insignificant coefficients. Now you can build a confidence interval of length 2Δ*bi*, where:

$$\Delta b_i = t_{KP} s\{b_i\} = 0{,}17 \cdot 0{,}004 = 0{,}00068 \tag{6.13}$$

A coefficient is significant if its absolute value is more than half the length of the confidence interval. Orthogonal planning allows defining confidence limits for each of the regression coefficients separately, if any of the coefficients turns out to be insignificant, it can be discarded without recounting all the others [93]. After that, the mathematical model of the object is compiled in the form of the equation of the connection between the output parameter *y* and variables including only significant coefficients. For our example, we get:

$$Y= 1{,}854167-0{,}12083\ x_1 +0{,}0625\ x_2 +0{,}0875\ x_3- -0{,}04583\ x_1x_2-0{,}12083\ x_1x_3 -0{,}0375\ x_2x_3+0{,}020833\ x_1x_2x_3 \quad (6.14)$$

$$Y= 1.175D+0.060P+0.161t-0.00058DP-0.0015Dt-0.000078Pt -120.82179 \quad (6.15)$$

$$b_i = \frac{\ddot{a}y(\tilde{x}_{i0})}{\ddot{a}\tilde{x}_i} \cong 0$$
;

$$R = \sqrt{1 - \frac{\sum_{\vartheta}(\bar{y}_\vartheta - y_\vartheta)^2}{\sum_{\vartheta}(\bar{y}_\vartheta - \bar{y})^2}} = \sqrt{1 - \frac{25{,}6}{25{,}98}} = 0{,}121$$

Table 6.9 – Calculation $\sum(\bar{y}_\vartheta - \bar{y})^2$

№ points v	$\bar{y}_\vartheta$	$(\bar{y}_\vartheta - \bar{y})$	$(\bar{y}_\vartheta - \bar{y})^2$
1	1,6	-0,25	0,065
2	1,73	1,854	3,438
3	1,93	1,871	3,5
4	1,8	1,713	2,933
5	2,13	2,179	4,749
6	1,7	1,821	3,315
7	2,23	2,271	5,157
8	1,7	1,679	2,82
$\bar{y}$ = 1,854		$\sum$ =25,98	

$$s^2_{\grave{a}\ddot{a}} = \frac{r}{n-m}\sum_{\vartheta=1}^{n}(\bar{y}_\vartheta - y_\vartheta)^2 \quad (6.16)$$

$$F_{a\partial}=n-m$$

The Fisher’s criterion allows one to test the null hypothesis about the equality of two general variances $\sigma_{ад}^2$ и σ^2 {*y*} in this case, if the F-criterion is formed as $F = \frac{s^2_{a\partial}}{s^2\{y\}}$ relation. If the calculated criterion value is less than the critical F_{KP} determined by the table in [92, p.88] for the corresponding degrees of freedom:

$$f_{ад} = n - m \quad и \quad f_B — n\ (r - 1)$$

at a given significance level - α%, then the null hypothesis is accepted. Otherwise, the hypothesis is rejected, and the description is considered inadequate to the object. If the sample variance of inadequacy does not exceed the variance estimate of the reproducibility s^2 {*y*}, then F-ratio will be less (or equal) to one and the inequality $F < FK$ for any number of degrees of freedom $f_{ад}$ and f_E that is, the hypothesis does not contradict the sample data $\sigma^2_{a\partial} \leq \sigma^2\{y\}$ and the mathematical model adequately represents the object [94].

Adequacy testing is possible only when $f_{ад} > 0$. If the number of points in the plan is equal to the number of estimated regression coefficients of the coupling equation ($n = ra$), then there are no degrees of freedom left (fad = 0) to test the null hypothesis about the adequacy of the experimental data selected form of approximating polynomial. In this case, you can use the fact that the free member is a joint assessment, i.e. $b_0 \rightarrow \beta_0 + \sum_{i=1}^{k} \beta_{ii}$ If there are repeated experiments in the planning center, i.e. at the point with coordinates (0, 0, 0,..., 0), then the average response gives an unbiased estimate $\bar{y}_0 \rightarrow \beta_0$. Therefore, if the difference b_0 - y_0 turns out to be statistically significant, then this will indicate the inadequacy of the linear model, as well as the model containing the interactions, i.e. that at least some of the coefficients βii are not equal to zero. If some regression coefficients were insignificant or they can be neglected due to their smallness or it is required to prove the validity of a linear approximation in a given variation interval, then the number of terms of the equation being tested in this case will usually be less than the number of points in the plan and one or several degrees of freedom will remain for validation hypothesis testing [95].

We will assess the adequacy in our example, using the data of the calculation table 6.5:

$$s^2_{\grave{a}\ddot{a}} = \frac{r}{n-m}\sum_{\vartheta=1}^{n}\left(\bar{y}_\vartheta - y_\vartheta\right)^2 = \frac{3 \cdot 25{,}6}{8-4} = 19{,}2$$

Since in our case, $s^2_{a\partial} > s^2$ $\{y\}$(19.2> 0.09), we calculate the adequacy of the model by the Fisher’s criterion. Since in our case all the coefficients in the interactions turned out to be significant and, consequently, the number of coefficients of the model m - 8, then there is not a single degree of freedom to assess the adequacy. Then we will resort to using the condition b_0 - $\bar{y}_0$ $\rightarrow$ $\sum \beta_{ii}$ thus, we estimate the significance of the coefficients for the second-order terms, namely:

$$| b_0 - \bar{y}_0 | = | 1{,}854 - 1{,}773 | = 0{,}081.$$

This value is smaller than the experimental error, which means that quadratic effects are negligible and therefore the linear model can be considered adequate [96].

CHAPTER 7. MODELING OF PROCESSES OF THE THERMOFRICTION PROCESSING (TFP)

7.1 Selection of the method of automated analysis of TFP

Modeling numerous physical, biological, and chemical phenomena often leads to solving linear or non-linear equations or systems of partial differential equations. There are traditional mathematical tools that allow one to obtain a solution in certain cases (Fourier analysis, expansion in a series, etc.), but to solve specific problems arising in science and technology, it is impossible to do without using numerical methods. With the increase in computer productivity, numerical simulation takes on special significance, since it allows one to supplement, or even replace, a direct experiment. The latter is often expensive, its formulation can be time consuming or even impossible (modeling the stability of dams, earthquakes, the study of solar phenomena). Currently, there are a number of different methods of automated analysis. Among them, the most popular in CAD are the methods of finite and boundary elements, as well as finite differences [97].

The basis of the boundary element method (BEM) is the solution of partial differential equations by transforming them into boundary integral equations.

Although all BEM have a common origin, they are naturally divided into three different but closely related categories:

Direct version of the BEM. In this version, the unknown functions included in the integral equations are real, physically meaningful variables of the problem. For example, in problems of the theory of elasticity, such a solution of the integral equation should immediately give all the effort and displacement at the boundary, and inside the body they should be obtained from the boundary values by numerical integration. Some of the algorithms developed based on this approach.

Semi-direct versions of BEM. Alternatively, one can compose integral equations for unknown functions similar to stress functions in the theory of elasticity. When a solution is obtained for these functions, a simple differentiation will give, for example, the distribution of internal stresses.

Indirect BEM variants. In the indirect version, the integral equations are fully expressed in terms of the fundamental singular solution of the original differential equations, distributed with unknown density along the boundaries of the considered region. The density functions themselves do not have a certain physical meaning, but when they are found (by numerical solution of integral equations), solution parameter values everywhere inside the body can be obtained from them by simple integration.

In principle, these methods can be applied to any problem for which a differential equation is either linear or linear with respect to increments. In problems that reduce to elliptic differential equations, solutions are obtained immediately, while for parabolic and hyperbolic systems of equations, time advancement processes should be introduced [97, p. 25].

Thus, a very wide class of physical tasks is covered. With the help of direct or indirect formulations of the BEM, for example, problems on steady and unsteady potential flows, problems of static and dynamic theory of elasticity, elastic plasticity, acoustics, etc. can be solved.

Finite difference method [98]. A significant number of problems in physics and technology lead to partial differential equations (equations of mathematical physics). Steady-state processes of different physical nature are described by equations of the elliptic type.

Exact solutions of boundary value problems for elliptic equations can be obtained only in special cases. Therefore, these problems are solved mainly approximately. One of the most universal and effective methods, which are now widely used for the approximate solution of equations of mathematical physics, is the finite difference method or the grid method. The essence of the method is as follows. The area of continuous change of arguments is replaced by a discrete set of points (nodes), which is called a grid or lattice. Instead of a continuous argument function, discrete argument functions are considered that are defined at the grid nodes and are called grid functions. Derivatives of the differential equation and boundary conditions are replaced by differential derivatives, and the boundary problem for the differential equation is replaced by a system of linear or nonlinear algebraic equations (grid or difference equations). Such systems are often referred to as difference schemes. And these schemes are solved with respect to the unknown grid function.

The finite element method (FEM) has now reached such a level of development that many people often doubt whether there can appear at least sometime an equivalent method, not to mention the best one. The range of applicability of finite element methods, their efficiency and the relative ease with which real boundary conditions can be taken into account, indeed make them very serious contenders for any competing method. The advantages of the FEM are flexibility and diversity of grids, standard techniques for constructing discrete problems for arbitrary regions, ease of taking into account the natural boundary conditions and. etc. In addition, the FEM mathematical analysis is simpler, its methods are applicable to a wider class of initial problems, and error estimates for approximate solutions, as a rule, are obtained under less stringent restrictions than in the finite difference method. At the same time, it is necessary to emphasize that the basis for the study of the FEM has created fundamental results related to the study of the convergence and stability of finite difference schemes, projection methods, and generalized solutions. Its weakest side is that it is an idea of the whole body discretization scheme, and this inevitably leads to a very large number of finite elements, especially in three-dimensional problems with remote boundaries, within each of which not all unknown variables change continuously.

The finite element method generally consists of 3 steps:

Sampling. The considered solution domain is divided into finite subregions or finite elements.

Approximation. Using the approximating polynomial, we associate a continuous function with the desired discrete function.

Algebraization. Substitution of the approximation into the defining equation. After substitution, we obtain a system of algebraic equations for a discrete function. Solving the system, we obtain the values of the discrete function, i.e. approximate solution of the problem.

Comparing these two methods, we can say that each of the methods has its advantages and disadvantages. Disadvantages of the boundary equation method:

- the complexity of solving problems in the case of an inhomogeneous solution domain, the presence of nonlinearities

- lack of solution under insufficient boundary conditions give the right to use the finite element method for the implementation of the task.

Comparative analysis of FEM and BEM:

BEM allows to reduce the dimension of the problem by an order and is effective for external tasks;

The influence matrix in the MGE is completely filled and asymmetric, unlike the stiffness matrix in the FEM. Therefore, the calculation of the coefficients of the matrix of influence G is much more difficult;

The scope of BEM is related to solving problems with infinite areas (geomechanics, acoustic waves).

FEM, sometimes called finite element research, is a numerical method for finding approximate solutions of partial differential equations as well as integral equations. This solution method is based on decomposition of entire differential equations, or the expression of partial differential equations in an approximate system of ordinary differential equations that are numerically integrated using standard methods such as the Euler method, Runge-Kutta method, etc. When solving differential equations with partial derivatives, an equation is initially created that approaches an equation that can be investigated by numerical mixing, meaning that errors in the input data and in intermediate calculations do not accumulate and cannot cause meaningless output.

The finite element method, in order to simplify the calculation of the problem, can be implemented by means of the DEFORM 3D program. This software package of FEM is based on the modeling process of a system designed for analyzing a variety of shaping and heat treatment processes used in OMD and related to industry. This is a modern tool that allows you to design and develop by modeling computer processing. Operations simulated in DEFORM 3D: forging, extruding, drawing, machining, upsetting, pressing, rolling, drawing, draft.

Based on the finite element method, DEFORM software products have proven their efficiency and accuracy by more than twenty years of application in various enterprises. The powerful system solver is capable of analyzing metal flow and temperature indicators of the workpiece and tool during deformations of any size with very high accuracy.

The automatic grid generator allows you to create a finite element grid, the dimensions of which, in different parts of the model, will vary depending on the specificity of the analyzed process. This significantly reduces the overall task dimension and hardware requirements. In addition, the user of the DEFORM ™ - 3D system has the ability to adjust the grid density and the finite element size ratio in a "manual" mode.

Despite the fact that DEFORM ™ - 3D allows for the modeling of very complex processes, the interface of this system is extremely simple and easy to learn. In addition, using DEFORM ™ - 3D, you can easily, without the help of third-party CAD systems, build geometric models of workpieces and tools.

With the help of the DEFORM ™ - 3D system, it is possible to simulate, as well, separation operations and mechanical processing. In this way. DEFORM ™ - 3D is a software package that allows you to perform a comprehensive analysis of metalworking, starting with the operations of the section for hire for workpieces, ending with the operations of final machining.

DEFORM ™ - 3D is widely used in industry and research around the world. The development and technical support of the DEFORM ™ - 3D system is provided by Scientific Forming Technologies Corporation (SFTC). For many years, engaged in the introduction of modeling of technological processes in production. To ensure the successful implementation of DEFORM ™ SFTC and its representatives regularly hold conferences, user seminars and update versions.

7.2 Planning of machine experiments in modeling

In modeling, just as with any other method of analyzing and synthesizing a system, the question of its effectiveness is very significant. The effectiveness of simulation modeling can be assessed by a number of criteria, including accuracy and reliability of simulation results, construction time and work with the model, machine resource costs [99].

As a rule, simulation models (SM) contain random events, quantities, processes. Therefore, modeling is a selective experiment, the analysis of the results of which has statistical aspects. The latter are associated with the stages of modeling:

- at the stage of setting the task, it is necessary to determine the goal (comparison of options based on a point estimate of the indicators, determination of the functional dependence of the indicator and factors, determination of the optimal combination of factors);
- at the stage of collecting and processing data about an object, it is necessary to solve the main problems of mathematical statistics (determining the distribution laws of random variables, testing the likelihood of hypotheses or determining distribution parameters using statistical data) and choose initial conditions for studying a transitional or steady state;
- at the stage of model development, it is necessary to choose factors and combinations of their levels for experimentation in accordance with the objectives (planning experiments);
- at the stage of implementing the model and interpreting the results, the sample is manipulated to reduce the error variance and the sample size is determined on the basis of a given statistical reliability.

After the simulation model is implemented on a computer, it is necessary to perform a model test, study its properties and draw up a plan for conducting simulation experiments on a computer.

In the study of the properties of the model, it is necessary to establish the range of variation of the model response when each component of the parameter vector changes. Depending on the range of variation of responses, a strategy for planning experiments on SM is determined. If at a significant amplitude of changes in some component of the model parameter vector, the response changes slightly, then this means that the accuracy of the representation of this component in SM does not play a significant role. In addition, in planning simulation experiments this component will not be used as the main one. If the response of the model turns out to be highly sensitive to changes in some component of the vector, then this indicates the need to represent it in the model with the highest possible accuracy.

7.3 Development of the model in the preprocessor

Three-dimensional modeling of the modes when cutting metals in the process TFP. The system can be used to simulate TFP processes with some assumptions. We start the development of the model with the introduction of models of interacting objects. In our case it will be a disk tool and an eccentric billet. Calculation of cutting forces (the process that occurs during the thermal friction treatment, conventionally, cutting, as plastic deformation occurs), cutting temperature, tool shape, wear and durability of the tool is made by the system during the analysis. We study the effects of such process parameters as cutting speed, feed rate and depth of cut, depending on the process. DEFORM3D ™ supports special proposed samples, which simplifies the description of the model and uses the engineering language in the design process. The basic information necessary for modeling are: the data of the plastic flow of the material for the working sample and the geometric data of the tool. The data is the plastic flow stress of the material, which can reveal the strain rate, the strain, and the temperature interval for the metal cutting process. For most materials, the strain rate is typically between 0 - ~ ~10^6/ s, the interval for stretching is 0 - 5, and the temperature is 20 - 1200 ° C. For the technological characteristics of special materials, it is necessary to address these ranges when loading installations. The insertion of a geometric model can be made in STL form, made in any CAD system.

Models can include as a detailed description of the process data, downloadable material from the library. Through the precise definition of special simulated data, the user creates the final data necessary for the analysis. This stage of the analysis is the initial unsteady state of the analysis. After performing the simulation and the formation of a sufficient number of chips, we calculate the steady state characteristics of the process, which includes forecasting the steady temperature characteristics and geometry of the chips. The data of the thermal characteristics of this stage are multivalued, which is sufficient at computational time, and this is not a deviation from the norm, which is associated with unsteady analysis. At this stage, data on wear and durability of the tool are important. Machining samples are used together with a set of library files to insert geometries. We can use any other tool geometry and save it later from the system library for later use [99, 100].

The data entry wizard for processing can be opened as a basic unit module, as well as a special preprocessor, by installing mechanical processing tasks.

Here, we set the typical settings for the calculation process as shown below.

Material used: AISI 1045 Steel, initial temperature 20ºC.

Instrument used: disk-instrument (instrument model made in Compass 3D, which will be converted to STL format)

Modes: n = 2500; 3000; 3500; 4000; 4500; 5000 min $^{-1}$

After the preprocessor is opened, we set the SM units of measurement, indicate the name of the task / project and the type of process. Specify an ambient temperature 20 ° C, 0.5 coefficient of friction for cutting and a 45.0 N / Sec / mm / C constant heat transfer coefficient.

Initially, the tool is determined by the user and can be checked by the basic parameters of this tool, the base materials are detailed and described if they occur.

We select the linear density ratio as 4, and use the generated 45,000 tetrahedron elements for the tool. Information about the cutting edge is available in the data on the tool, the automatic master applies the exact mesh (grid generation relative to the entire surface of the tool, thickening it in the areas of contact of the tool and the workpiece) near the cutting zone. After this stage, to check for thermal boundary conditions, we perform complete mixing. The edge surface relative to the cutting surface is set with special temperature conditions.

Installs the details of the working sample. The pending diameter of the working sample, the user can install any single-level model or solve the problem in the form of a curve. We will display the generated sample in the solution domain. For this case, we use a simplified model with a length 10 mm.

After generating the working specimen geometry, a grid of elements is generated with a linear density ratio 7, and a minimum element size 0.06 mm. In the next step, load the material of the working sample from the library. For example, we downloaded ‘AISI 1045 (machining)’ from steel categories.

Setting the simulation control, including the number of steps (1000), save steps (25) and cutting length (3.5 mm) to start the launch of the Lagrange function. Although we have described the length of the number of steps, the modulator will select a criterion based on the length of the cut. Next, check for wear parameters of the tool. Now the system only supports the model used. The utilization factor in this model is determined on the basis of experimental verification, since they depend on the calculation of the process and the material for the correct result. As, for example, for this case we used a = 0.0000002 and b = 650.5.

After calculating the simulation, we can view the results by selecting the “Post” function.

To perform the simulation, we will use the DEFORM 3D machining preprocessor, where we will select a milling process in which we can enter TFP modes. And to verify the correctness of the results, we introduce the parameters of the working sample for steel 20, the quality of which surfaces after the TFP has been studied in some detail. Geometrical model of the tool and the working sample made in the CAD - system, and made in STL form.

After performing the simulation for the above steel, verify the adequacy of the output data by running the post-processor using the DEFORM 3D POST and DEFORM microstructure.

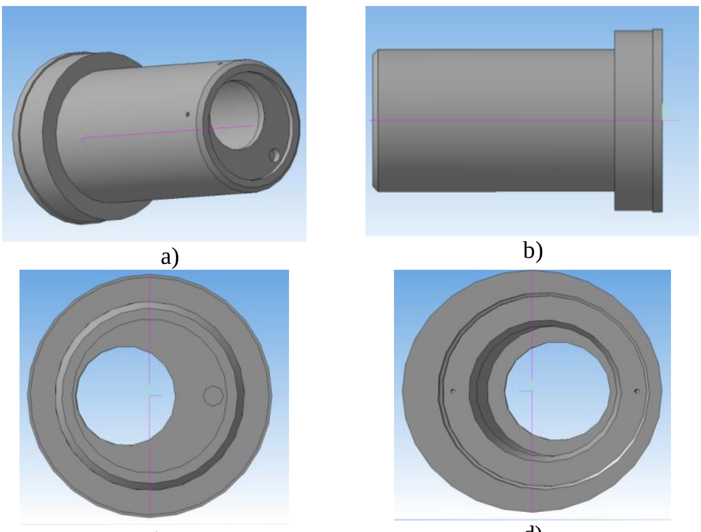
7.4 Prototyping the original geometric forms in STL format

The abbreviation STL stands for STereoLithography (that is, volume lithography). The STL format and its specifications were created by the Albert Consulting group, which developed the first layer processing algorithm for 3D Systems. For all layered systems, it is necessary for the 3D model to be “sliced” into horizontal slices, so that its geometry can be reproduced as a physical model layer by layer. In 1987, 3D Systems committed an act that was completely uncharacteristic for most technology companies - it openly published the STL format (apparently, this was done in order to provide it with support from CAD companies working in the field of 3D design). Thus, STL quickly became the standard for transmitting data to prototyping installations, a large variety of which we see today.

STL is a “mosaic” format in which a sequence of triangles (facets) is used to represent the shape of a digital 3D model. Three-dimensional geometry in leading 3D CAD-systems is described by high-order surfaces, and when triangulated, the surface of the model is divided into small triangles. As you can guess, each facet is described by four data sets: the XYZ coordinates of each of the three vertices and the normal vector, which describes the orientation of the facet, indicating, as in other formats, the outward direction of the model.

There are other factors. Thus, the specification specifically states that all coordinates of the vertices of the facets within the system must belong to the positive octant. In simple terms, the coordinates of the vertices cannot be in the space of negative values, and all values of the X, Y, and Z coordinates of each facet must be positive. In addition, each facet should have two common vertices with each of the adjacent facets. This is necessary to ensure the creation of an airtight model without cracks and gaps [98, p. 56].

As for storing data in STL files, there are two ways to be indicated in the official specification - ASCII format (in this case normal, rather bulky text is written) and binary format (much more efficient). It should also be noted that some equipment manufacturers introduce their own STL format extensions to transmit color information. For example, Z Corporation in its Z406 machines and new installations of the Z510 uses an extension of the STL format, in which information about the color of each triangle is stored using the RGB (Red-Green-Blue) color scheme (Figure 7.1).



a) b)

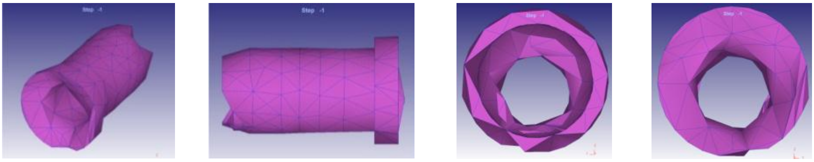
c) d)

a) and b) are frontal view of the eccentric; c) and d) are top view

Figure 7.1 - Modeling an eccentric with a CAD system

The minimum size of the elements depends primarily on the geometry of the part. It should not be more than 1/3 of the smallest radius, otherwise it is not possible to accurately describe its shape. Naturally, it makes no sense to break the entire billet into evenly smaller elements. It is necessary to create mesh thickenings, creating density windows and changing the weight of such factors as surface curvature or degree of deformation.

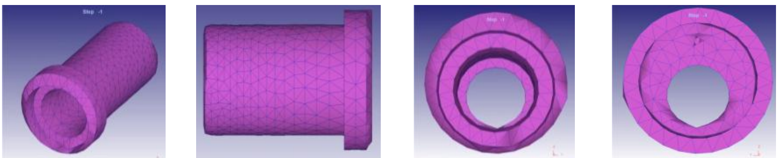
But the calculation step depends on the size of the item. In one step, the tool should not pass more than half the length of the smallest element, otherwise contact of the tool with the workpiece may be lost (Figures 7.2-7.4).



a) b) c) d)

a) type of eccentric model in space; b) model in y axis;
c) model in x axis; d) model in z axis.

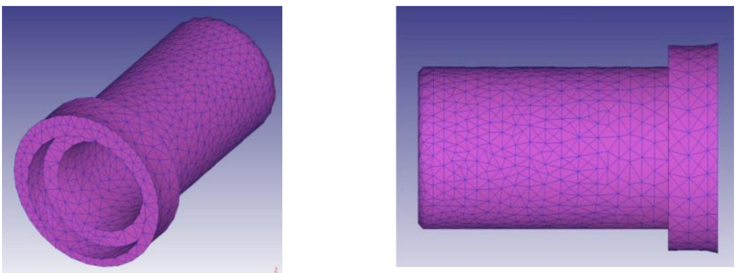
Figure 7.2 - Simulation of the eccentric with the number of elements 2000



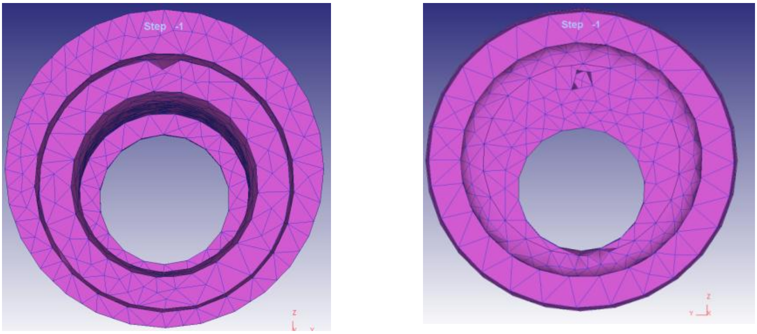
a) b) c) d)

a) type of eccentric model in space; b) model in y axis;
c) model in x axis; d) model in z axis.

Figure 7.3 - Simulation of the eccentric with the number of elements 5000



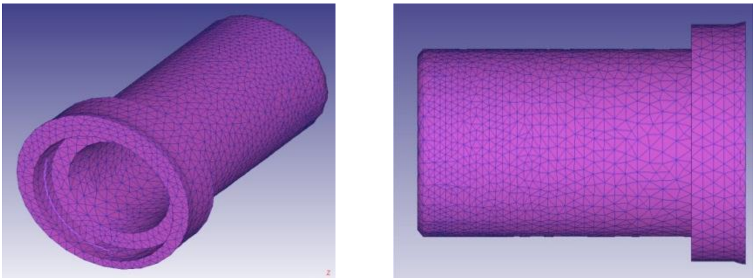
a) b)



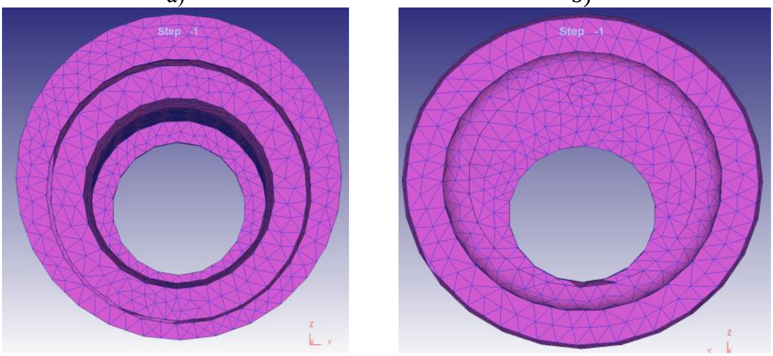
c) d)

a) type of eccentric model in space; b) model in y axis;
c) model in x axis; d) model in z axis.

Figure 7.4 - Simulation eccentric with the number of elements 10.000



a) b)



c) d)

a) type of eccentric model in space; b) model in y axis;
c) model in x axis; d) model in z axis.

Figure 7.5 - Simulation of the eccentric with the number of elements 20.000

When modeling an eccentric with the number of elements 2000 (Figure 7.2), it can be said that only the largest surface (outer) is described correctly, the remaining surfaces are described incorrectly. The deviation from the true dimensions due to the size of the elements is in the smallest point of the order of 9/10, which is completely unacceptable for calculations.

When modeling an eccentric with the number of elements 5000 and 10000 (Figure 7.3), all surfaces are described correctly except for the ø10mm hole. The curvature of the surfaces is sufficient, while at the same time there is a lack of elements on the collar (one element per 1/12 circle).

When modeling an eccentric with a number of elements 10.000 (Figure 7.4), the hole ø10mm accurately describes, the inner hole for the eccentric is described with a slight defect on the side of the wall having a great thickness, but the deviation from the correct curvature is about 1/20 and does not exceed 5% which is quite acceptable.

When modeling an eccentric with the number of elements 20.000 (Figure 7.5), all surfaces are described correctly, the number of defects is one, but this defect is located on the thinnest side. At the same time, the calculation with such a large number of elements takes a lot of machine time.

From the proposed models, we choose a number of elements equal to ≈10000, which quite accurately describes the hole ø10mm, the inner hole for the eccentric is described with a slight defect on the side of the wall having a great thickness, but the deviation from the correct curvature is about 1/20 and does not exceed 5% which is quite acceptable.

7.5 Output Management

The first thing you should pay attention to is the process of surface triangulation. Replacing an exact 3D surface with a triangulated polygonal mesh always requires a certain approximation and data transformation. The key question here is whether the accuracy you require is ensured.

Such a factor as resolution is perhaps the most critical. To manage this indicator, there are several key parameters. The difficulty lies in the fact that in each system these parameters are managed somewhat differently. But, basically, you can control the size of the triangles, as well as how the system handles the roundings on the model. For example, Pro / ENGINEER offers two options for controlling triangulation: Chord Height and Angle Control. These parameters, respectively, set the dimensions of the triangles as a function of the overall size of the model and determine how the system triangulates non-planar surfaces (such as fillets, holes, etc.).

The SolidWorks system also offers two variables to the user - Deviation and Angle Tolerance. They are associated with the same triangulation factors, but use a different language and a slightly different system of measurements and related quantities. In other systems, a different set of parameters is used, which, in turn, are related to other factors that also affect the quality of the output and the functionality (or limitations) of each particular system.

In addition, noteworthy is the ability of the system to display STL files for building models.

Here there are two ways:

The entire node can be output to one STL file, which contains the selected parts in the form of separate bodies or shells;

The system processes the build model and displays each part in a separate STL file.

7.6 Support for STL output in CAD systems

Inventor Professional packages support the output of STL files at the kernel level of the system; however, in comparison with other systems, the available tools do not seem to be flexible enough. The ability to preview the grid is missing. You can only display individual mesh parts, but not assemblies. It is necessary to expend efforts in order to export the entire assembly to the STL file, extracting the parts and the assembly one by one, and this cannot be done with the STL tools available in the system core. As far as resolution control is concerned, there are three basic presets –Low, Medium and High, but changing them is associated with significant difficulties. In order to do this, it is necessary to edit the register of the Windows operating system. Table 1 summarizes the information about the tools included in the system to facilitate the rapid prototyping process.

At the kernel level, CATIA V5 offers basic STL output in ASCII format only. It is possible to output files of individual parts, and both output modes of assemblies are supported (both as separate part files and as a single file with multiple bodies). The system does not use preset parameters, but users have the ability to control two key values: Sag Value (sets the chord height and it can be set even less than 0.10 microns) and Step (sets the maximum length of the triangle face) [97, p. 76].

In addition, there are two STL-related modules - TL1 and STL in the CATIA V5 system. Essentially, TL1 offers the ability to output in binary STL format and contains some grid editing capabilities. The STL module is a higher level, it adds more advanced tools for the repair and optimization of the grid. This module includes tools for checking the quality of the grid, which display and "clear" the grid automatically remove distorted and duplicated triangles, isolated triangles, etc. There is also a module for automatically filling holes in the grid, grid regeneration tools (a high-quality 3D grid generator for complex shaped parts), smoothing tools. There are functions such as splitting, trimming, merging individual parts of a grid, equidistant displacement (offsetting) and decimation of a grid. A special function called Flip Edge makes it possible to change the docking of the vertices of the triangles to improve the quality of the shape, especially on sharp edges and rounding.

Of course, the question inevitably comes up: how much will you have to pay for this additional functionality? As we have said, output in ASCII codes is included in the core of the system. The next level is the TL1 module. It is already available for the P1 platform (that is, for all V5 users) and costs $ 3,500. To have a higher level STL tool, you must be a user of the P2 or P3 platform, and the module itself will cost $ 7,000. None of these modules are not included in any CATIA configuration (which Dassault and IBM call module groups or bundles) - both products are system extensions (add-ons) [98, p. 80].

The UGS NX package supports STL output at the system kernel level and this feature is available at no extra charge in all package configurations. Speaking of opportunities, it should be noted that the system allows you to display files of parts, as well as selected surfaces (although the applicability of this in rapid prototyping is limited).

As for assemblies, NX allows you to export them as a single model, in which each part is presented as a separate volume. To control the user is not offered a set of any presets, as is done in many other systems, as you can fully control the process. The base variable Triangle Tolerance determines how accurately the triangles approximate the boundaries of the surfaces. You can view the triangles created to output the file in STL-format. The Local Coordinate System command allows you to make sure that after automatic placement all elements are in the region of positive numbers.

Other options are related to the export of surface models. The first thing to do is to mention the parameter Adjacency Tolerance, which allows you to set the accuracy of the mating surfaces. When the calculated distance between the boundaries of the two surfaces is less than a specified value of Adjacency Tolerance, then the two boundaries are treated as coincident, and the two surfaces are adjoined along this boundary. In addition, there are tools with which you can make sure that all the normal issues in the STL file are oriented correctly [99].

The UGS I-deas package supports the output of STL files in basic configuration, but only for individual parts. Before output, the grid can be viewed graphically, but there are no presets. You can control the parameter Facet Deviation, which determines the maximum distance from the surface to the front plane of the facet that approximates this surface. The parameter values can be selected from a set of predefined parameters depending on the size of the prototyping machine.

STL output files of PTC company in the Pro / ENGINEER package is standard for the entire range of configurations and modules. It is possible to export both individual parts and assemblies. Regarding the set of variables and control, users can control the coordinate system associated with the part, select the type of STL file (ASCII or Binary), and also allow or prohibit the use of negative values (this applies to the requirement that all parts be located in the octant coordinates).

To control the resolution are two parameters (with default values): Chord Height and Angle Control. When triangulating the surface of models, Chord Height acts as a global variable. It sets the maximum distance between the chord and the surface. The smaller the selected chord height value, the smaller the deviation from the actually existing surface of the part. The Angle Control parameter controls additional triangulation along surfaces with small radii — the smaller the radii — the smaller the radii, the greater the number of triangles used in the approximation. Pro / ENGINEER provides the ability to preview when splitting the surface into triangles, which allows you to choose the best values of the parameters to achieve the desired result.

To display the assembly details as 1 separate STL files, use the Pro / Batch function, which is included in the basic configuration of the package. It allows you to display entire catalogs of parts and assemblies instead of processing each object separately. This tool also allows you to set the output quality for each object, which can be useful for products with parts of different sizes.

UGS's Solid Edge package provides support for STL data output at the system's kernel level, and this feature is available in various package configurations. Models in the STL format can be generated for both parts and assemblies; however, an assembly can only be output as a general STL file that contains all the parts included in it. According to UGS representatives, separate STL files can be generated from the assembly, but to do this, you must use an open application programming interface (API) and scripts written in Visual Basic. Solid Edge does not provide the ability to render or preview a grid before exporting it.

The tools for STL output have the following options. The Conversion Tolerance parameter limits the distance between the surface of the model and the facets that approximate it. Its value is entered from the keyboard and is an important factor determining the global accuracy with which CAD geometry is presented after triangulation as an STL file. Other parameters include the Tolerance Unit, which sets the units of change for the Conversion Tolerance, as well as the Surface Plane Angle, the value of which determines the allowable deviation between the surface and its approximating facets. The STL file can be output in ASCII or in binary format. During operation, the system generates a protocol containing warnings and information about the files involved in the process.

The Dassault Systўmes SolidWorks package in all its configurations supports STL output for both parts and assemblies. In this case, the entire assembly can be displayed in one STL-file or each part in its own file. Provides a preview of the grid (if this setting is enabled) with two options for display quality, which are given by two predefined values: “coarse” (Coarse) and “exactly” (Fine). You can also change the values of deviation (Deviation) and angular tolerance (Angle Tolerance), which, respectively, control how the system triangulates the part as a whole and its individual elements of small size.

In addition, the user can set the unit of measurement and choose between outputting a file in binary format or in ASCII. Interestingly, when working with assemblies, SolidWorks offers an option such as checking for contact or intersection of bodies. The system also allows you to control the orientation of coordinate systems, automatically translating (or moving) parts into the space of positive coordinate values.

Finally, SolidWorks offers Print3D, a web portal where users can contact companies that offer rapid prototyping and parts manufacturing services. Here you can place requests for pricing and even make an order.

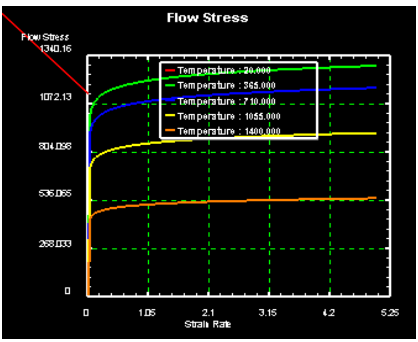
In Alias' StudioTools, STL output is supported at the kernel level (in both binary and ASCII format) and does not require any additional costs. Since StudioTools is a surface modeling system, the division into parts and assemblies is not used. Alias claims that StudioTools does not work directly with the details, but it can work with several models in one file. At the same time, the system can export any individual models that are “stitched” together.

In addition, users of advanced configurations of StudioTools (Studio, Surface Studio and AutoStudio) can use Alias' Spider software, which provides several ways to repair STL models that have holes. Selecting the Coarse installation will cause the hole to be filled with the minimum number of polygons. The Taut option allows you to close any found hole with a flat "lid" of polygons. Finally, the Faired option serves to seal the gap with a triangulated surface that smoothly continues the shape of the surfaces around the hole.

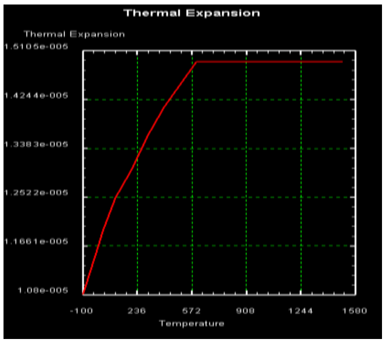
McNeel's Rhino package supports a wide range of STL output functions. However, since this is mainly a surface modeling system, there is no point in talking about parts and assemblies.

As far as management is concerned, Rhino stands out for its flexibility and wide user options, mainly due to the fact that it is a surface modeling system. The user can control the output simply by moving the slider control. In addition, all variables affecting the STL grid can be controlled. These include the parameters of triangles (angles of aspect ratio, length of edges), controls for the translation of jagged edges and the imposition of textures on the surface [99, p.88].

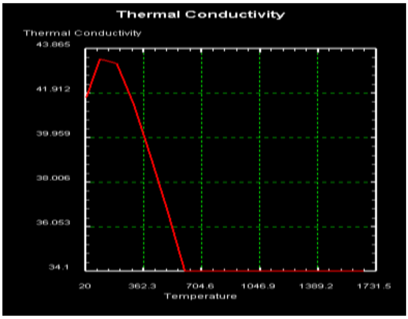
The configuration of the part and the number of elements was determined, then we proceed to the description of the physical-mechanical properties of the material used for the workpiece 35L according to State Standard 977-65. To describe its properties, select steel 35 (35NCD16_Steel (machining) _000008s) from the material library. Where, according to, we change the material's fluidity and elasticity during thermofriction treatment and obtain graphs of the physical and mechanical properties of steel 35L (Figure 7.6, a. b, c, d, e).

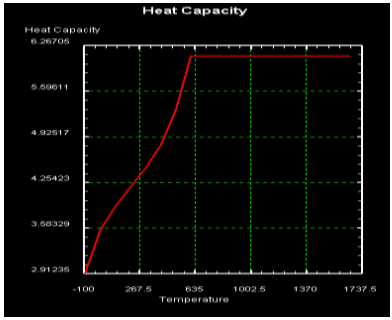


a)

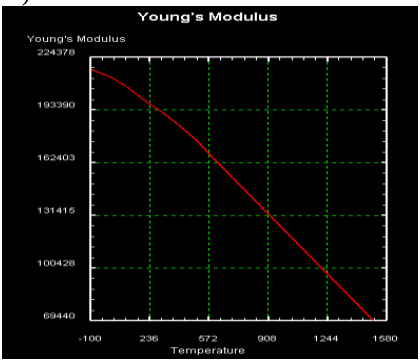


b)





c) d)



e)

a) dependence of the flow rate on plastic deformation;
b) temperature dependence on stretching; c) temperature dependence on conductivity; d) temperature dependence on heat capacity;
e) the dependence of temperature on the modulus of longitudinal elasticity
Figure 7.6 - Physical and mechanical parameters of the workpiece

7.7 Obtaining results modeling of the TFP process and interpretation of results. Preparation of TFP modeling

One of the main methods of solving the problem of quality assurance is the creation of optimal thermomechanical parameters of the process to maximize the use of the natural deformation properties of steel and alloys, as well as the implementation of more advanced heat balance schemes when changing. The determination of the characteristics of heat fluxes by calculation or by calculation and experimentally by the deformation zone allows the use of modern forecasting models for the quantitative assessment of metal damage by macrodefects. However, at the moment, methods for calculating heat are approximate, semi-empirical, based on the methods of the theory of heat balance. In this connection, it is necessary to conduct a numerical study of heat in the workpiece and the tool under the conditions of their manufacture and operation based on modern approaches using the defining relations of the theory of plasticity and elasticity [100].

The study of the heat of the workpiece in the process TFP. For TFP modeling, a software product of the finite-element analysis Deform 3D was used, which is specialized for the calculation of metal forming processes.

The blank is a cut-out from the plane with the following dimensions: 10x2x1 mm. In order to continue the calculation, we will produce a mesh in the result of which we obtain a blank with the required number of elements (Figures 7.7-7.9).

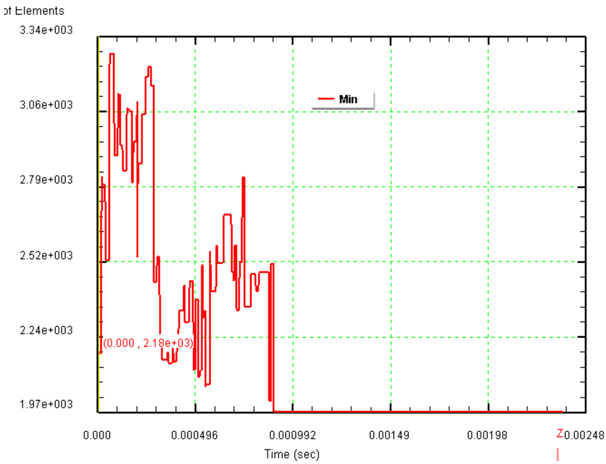


Figure 7.7 - The number of items to calculate

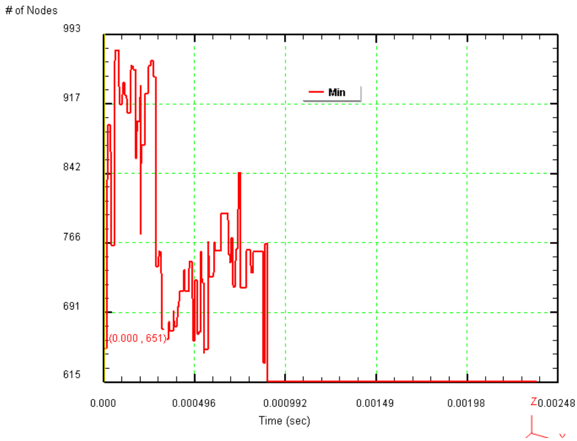


Figure 7.8 - The number of nodes to calculate

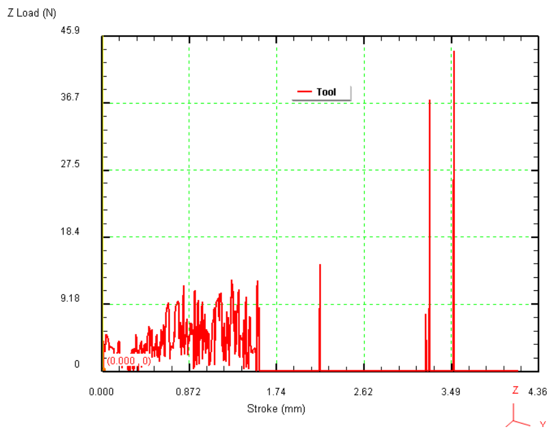
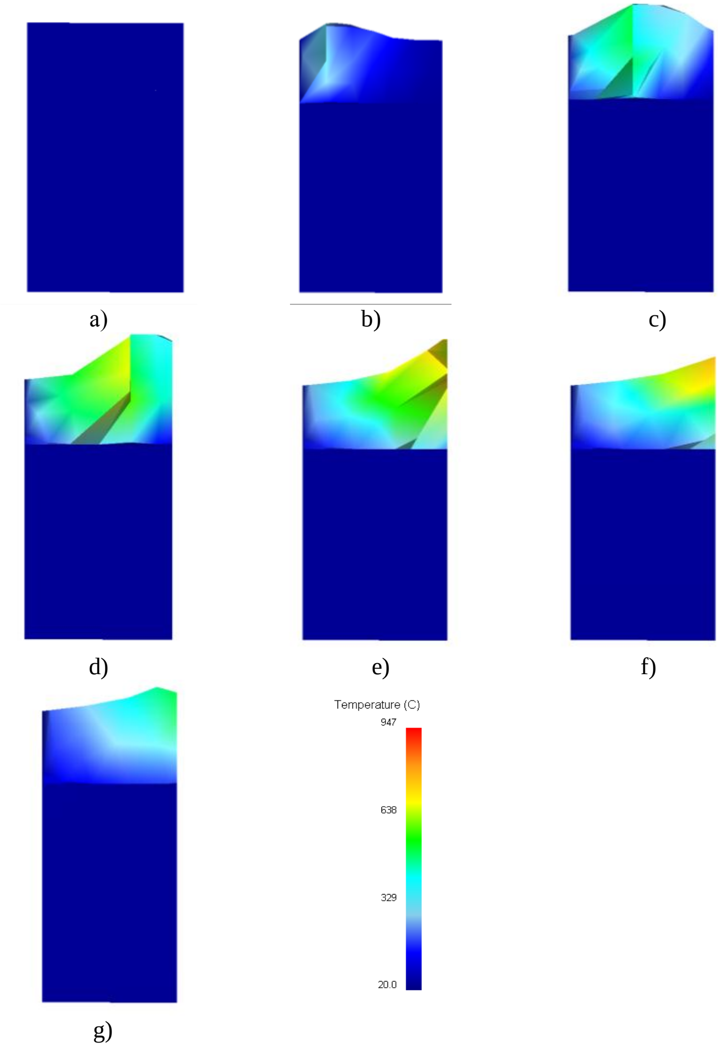


Figure 7.9 - The amount of loading eccentric

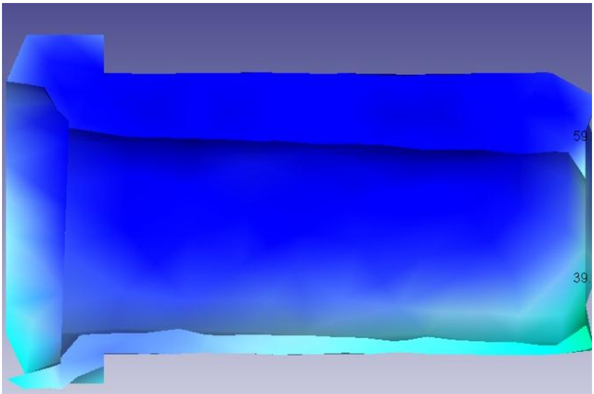
The simulation of the TFP process is shown in Figure 7.10. If we conditionally divide the operation of the TFP into components, then it can be seen that, due to the configuration of the instrument, the process takes place on each tooth separately. We will simulate this process as shown in Figure 7.10, the dynamics of the impact of the tooth resembles smoothing with deformation of the surface layer.



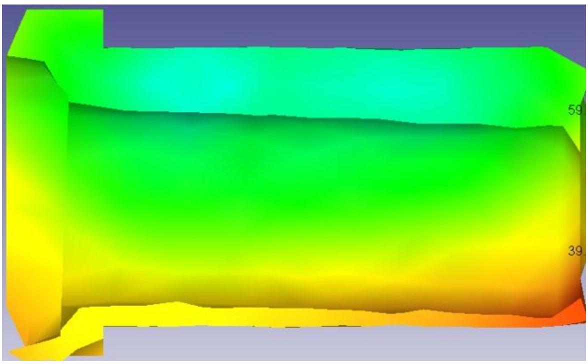
a) before processing; b) embedding tool; c) introduction of the first tooth; d) metal removal; e) and e) tooth exit from zone g) surface layer after treatment

Figure 7.10 - Dynamics of the TFP process for the eccentric site

It is impossible to show the TFP process without breaking into teeth, since it requires very large computing resources of a PC. Therefore, in order to have a complete picture, we will model the main indicator of TFP thermal effect on the workpiece. Heat distribution has the following trajectory (Figure 7.11), numerical indicators of this trajectory are presented in Figure 7.12



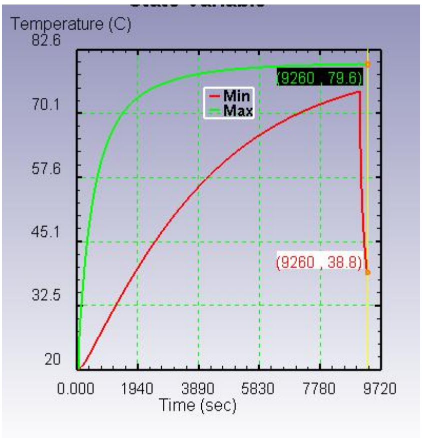
a)

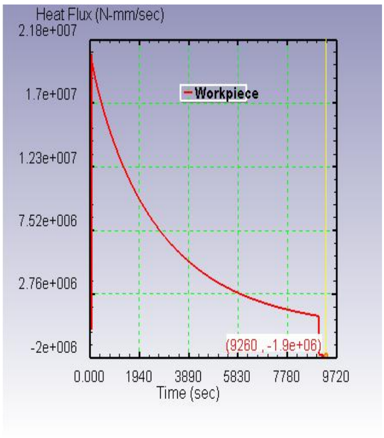


b)

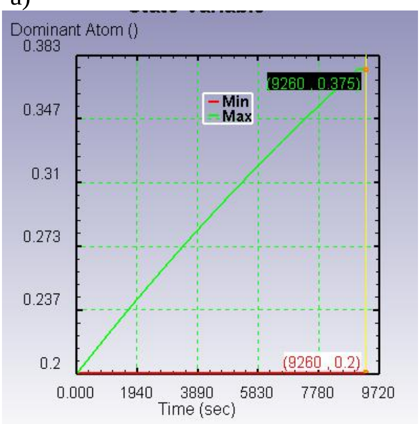
a) at the beginning of processing; b) in the middle of processing

Figure 7.11 - Dynamics of the process of propagation of heat flows through the body of the eccentric at TFP





a) b)



c)

a) temperature dependence on time; b) the dependence of loading on time; c) the dependence of the surface layer on time

Figure 7.12 - Thermal indicators on the body of the eccentric

Next, we calculate the actual deformations, displacements, stresses, the temperature at the contact area and the size of the layer to be removed for one tooth contact.

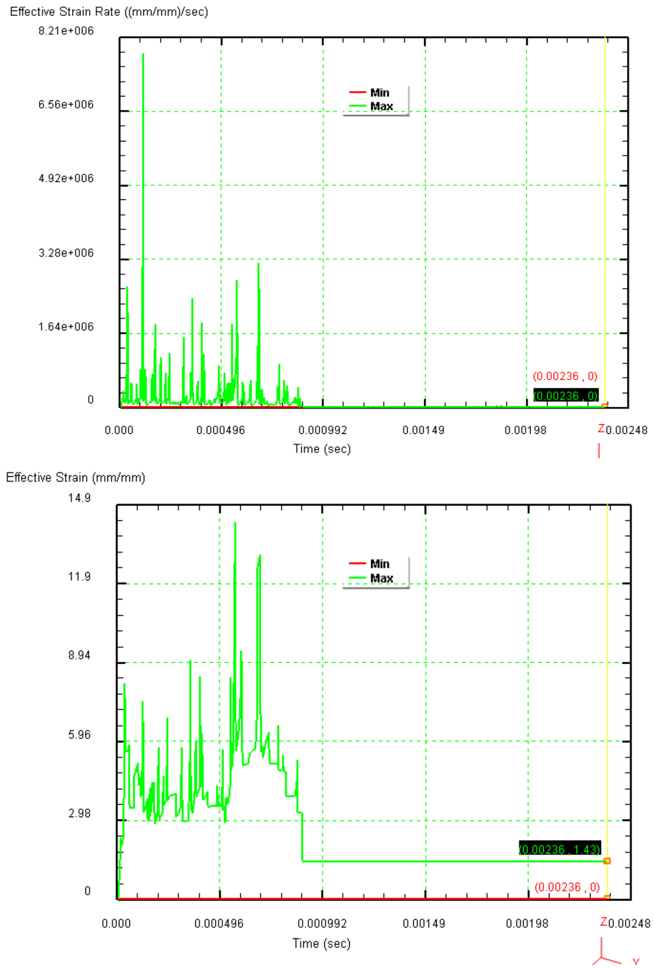


Figure 7.13 - Values of the actual deformation and displacement at the contact area

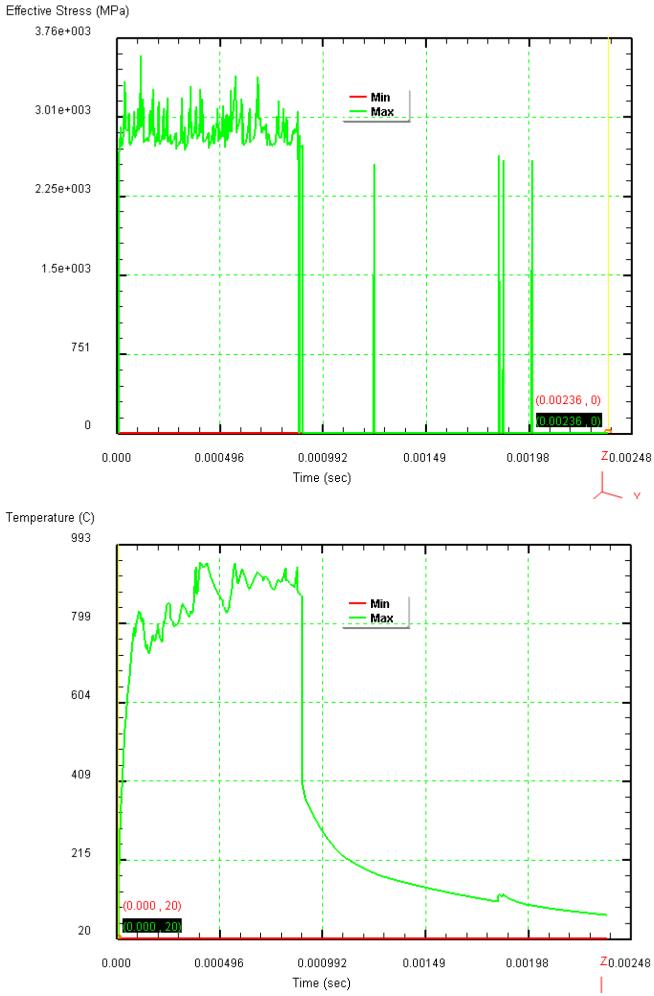


Figure 7.14 - Values of actual voltage and temperature in the contact zone

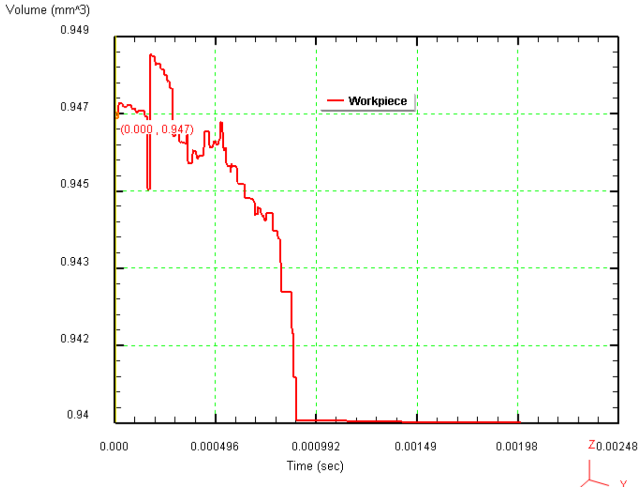


Figure 7.15 - The size of the layer to be removed for one contact of the tool and the workpiece

The results of the calculations are shown in Figures 7.13 - 7.15. Analyzing these data, we find out that the process time for a single tooth when rotating an instrument of 3000 rpm is about 0.0028 s, which is consistent with the practical results. The magnitude of the maximum deformation is sufficient for plastic deformation of the material (Figure 7.13). Along with this, thermal processes occur that are associated with deformation (Figure 7.14), that is, heat flows are influenced by the deformation energy, and not the energy of mutual slip. Figure 7.15 shows the process of hardening the surface layer during thermofriction treatment. The change in the volume of the part coincides with the dynamics of the process and no elastic deformation is observed.

The maximum temperature of the recovery process using thermofriction treatment of the outer side of an eccentric cone crusher is 928 ° C, which corresponds to the lower point of recrystallization, but since the heating and cooling times are respectively 0.0028, the recrystallization process does not occur as the amount of heat does not significantly penetrate the surface layer. The deformable stress at the area of contact between the tooth and the surface to be treated is 3.76 MPa.

REFERENCES:

1. Lynch A. R. Crushing and grinding cycles. Modeling, optimization, design and management. - M.: Resources, 1981. - p. 383.
2. Analysis and planning of the operation of the technological sections of the crushing in the automatic mode / V.M. Kurkin, etc. // Mining Journal: Publishing house of universities - 2002. - № 2. - p. 85-90.
3. Rudnev V. D. Cone crushers medium and fine crushing. - M.: Mechanical engineering, 1981. - p. 120.
4. Vinogradov V. N., Sorokin G. M., Albagachiev A. Yu. Wear on impact. -M.: Mechanical Engineering, 1992. - p.192.
5. Chervyakov S. A., Muyzemnek Yu. A. Modern trends in improving the workflow in cone crushers // Mining Journal. - 2000. - №3. - p. 53-55.
6. Muyzemnek Yu. A., G. A. Kalyunov and others. Cone crushers. – M.: Mechanical Engineering, 2000, – p. 232.
7. Banatov P. S. Wear and durability of mining machines. – M.: Resources, 1980. – p. 214.
8. Rakov Ye. F. Investigation of the causes of destruction of the main units of cone crushers and increase their durability // Mining Journal. - 1989. - №2. - P. 45-48.
9. Chervyakov S. A., Muyzemnek Yu. A. Features of the design and operation of cone crushers // Mining industry. - 1997. -Number 3. - p. 33-36.
10. Maslennikov V. A., Nosyreva E. M. Investigation of the performance of the crusher CMTC-2200 // Mining Journal. - 1980. - №12. - P. 48-49.
11. Sorokin G. M. Influence of mechanical characteristics of steel on its abrasive wear resistance // Mechanical Engineering Proceedings. - 2002. - №5. - p. 35-38.
12. Donchenko A. S., Donchenko V. A. Operation and repair of crushing equipment. –M.: “Resources”, 1972. – p. 320.
13. Improving the wear resistance of mining equipment: Ed. N.S. Penkina. – M.: “Resources”, 1992. – p. 265.
14. Bykov V. I. and others. Operation and repair of equipment crushing factories. -M.: “Resources”, 1973. – p. 321.
15. Muyzemnek Yu. A. Possible criteria for optimal conjugation of cone crushers for medium and fine crushing // Mining Journal. - 1997. - №7. - p. 68-71.
16. Ryzhov E. V. Technological methods to improve the wear resistance of machine parts. – Kiev: Naukovo Dumka, 1982. - P. 271.
17. Ryzhov E. V. and others. Technological support of operational properties of machine parts. – M.: Mechanical Engineering, 1989. -

P. 176.
18. Fadeyev L. L., Albagachiev A. Yu. Improving the reliability of machine parts. -M.: Mechanical Engineering, 1999. - p. 96.
19. Increase of durability and reliability of machine parts with technological processing methods. // Collect. article / ed. A. A. Mikhailov. – M.: All-Union Machine-Building Institute, 1989. volume15. - p. 120.
20. Korchanov I. E., Yakovlich E. A. Technology and organization of repair of machinery and equipment. - M.: "Resources", 1996. – p. 421.
21. Grokholsky N. F. Restoration of machine parts and mechanisms of welding and welding. -2 ed. - M.: Mechanical engineering, 1966. - P. 275.
22. Pokrovsky B. S. Increasing the durability of machine parts using powder tape welding. -M.: Mechanical engineering, 1969. - P. 76.
23. Hasui A. Surfacing and spraying. Per.s Japanese. –M.: Mechanical engineering, 1985. - P. 240.
24. Shnyrev A. P. Technological bases of welding processes. – M.: Agar, 2002. – P. 152.
25. Welding materials for repair and building-up: Reference book / translation from English. -Minsk: Skakun Publishing House, 2001. – P. 123.
26. Theoretical and technological bases of surfacing. Surfacing materials / ed. doctors tech. Sciences I. I. Frumina. – Kiev, 1988. – p. 271.
27. Equipment for mechanized arc and electroslag welding and surfacing / ed. doctors tech. Sciences A. I. Chvertko. - M.: Mechanical engineering, 2000. – p. 240.
28. Klimenko Yu. V. Electrocontact surfacing. - M.: Metallurgy, 1978. – p. 165.
29. Zarubitsky E. U. Thermofriction processing of steel parts // - M.: Mechanical engineering, 1996. - № 2, - p. 25.
30. Babey Yu. I. et al. Hardening of the surface layers of steel and cast-iron parts by friction machining. Vestnik Mech.eng. - 1987. -№10. - p. 39-40.
31. V. Lebedev friction welding: Handbook. -L.: Mechanical Engineering. 1987. - p. 236.
32. Kvaginidze V.S. Metal technology and welding. - M.: MSTU, 2004.- P. 566.
33. Belfort M. G. Equipment for automatic and semi-automatic welding and surfacing. Album. -M.: Higher School, 1967. - P. 170.
34. Kolganov L. A. Welding work: Welding. Cutting. Soldering. Surfacing. -3rd ed. -M.: Damikov I.K., 2007. - P. 408.

35. Lapidus V. A. Electrodes for surfacing. - M.: Mashgiz, 1987. - p. 232.
36. Shakhter S. Ya. Surfacing of metals. -M.: Mechanical Engineering, 1982. - p. 72.
37. Pokrovsky B. S. Fundamentals of industrial equipment repair technology. –M.: ACADEMA, 2006. – p. 175.
38. Surfacing materials. Bibliographic Index of Domestic and Foreign Literature (1997... 2003) –Kyiv, 2003. –p.121.
39. Volovik V. L., Frutgina M. M., Bovbas V. I., Uchaikin T. P., Tsydypov N.D. Technological recommendations on the application of methods for the restoration of machine parts. -M.: GOSNITI, 1976. – p. 412.
40. Gorokhov V. A., Rudenko P. A. Repair and restoration of crankshafts. - M.: Kolos, 1978. – p. 265
41. G. Dotsenko. New in the technology of repairing automotive parts by welding and welding. -M.: Higher School, 1971. –p. 65.
42. Klimenko Yu. V. Electrocontact surfacing. - M.: Metallurgy, 1978. – p. 390.
43. Kravtsov T. G. Electric arc welding with an electrode tape. - M.: Mechanical Engineering, 1978. – p. 71.
44. Kostikov V. I., Shesternin Yu. A. Plasma coatings. - M.: Metallurgy, 1978. – p. 612.
45. Nassonov V. S., Gorchakov A. I., Ulman I. E. Automatic vibration-arc surfacing. - M.: Kolos, 1972. – p. 121.
46. The use of plasma surfacing to restore machine parts. - M.: Rosselkhozizdat, 1976. – p. 265.
47. Recommendations for the restoration of worn-out parts of machines by chrome plating and zinc. -M.: Rosselkhozizdat, 1976. –p. 96.
48. Recommendations for the use of new tools for cleaning machines and parts during repair. -M.: GOSNITI, 1975. –p. 165.
49. Specialized rates for recovering parts. "Catalog-Maloyaroslavets. -1978. – p. 119.
50. Theoretical and technological bases of surfacing. Surfacing materials / ed. doctors tech. Sciences I. I. Frumina. - Kiev, 1978. – p. 205.
51. Khomyak B. S., Ponomarenko A. M. Cutting of the weld surfaces // In. Sat NIINFORMTYAZHMLHSH Technology, organization and mechanization of mechanical assembly production. - M.: Mechanical engineering, 1972. –p. 165.
52. Tsvetkov V. I. Repair of metallurgical machines parts. - M.: Metallurgy, 1979. – p. 341.
53. Petruha N. G. and others. Cutting difficult-to-cut materials. - M.: -

Machine Engineering, 1999. - p. 912.
54. Gurevich N. L. and other. Cutting modes of difficult-to-cut materials. - M.: Mechanical engineering, 1989. –p. 265.
55. Nechaev K. N. Analysis of the technological capabilities of the methods of thermofriction metal processing // Tool and technology. - SPb.: Mechanical Engineering Institute, 2002. - № 9-10. - p. 182-186.
56. Suslov A. G. Engineering technology. -M.: Mechanical engineering, 2004. –p. 400.
57. Nechaev K. N. Thermofriction processing - a promising technological direction of processing and assembly of parts // Tool and technology. - SPb.: Institute of Mechanical Engineering, St. Petersburg: SPb IM Publishing House, 2005. - № 17-18. - p. 157-162.
58. Sherov K. T. Analysis of methods and methods of thermofriction processing // Science Bulletin of the Kazakh Agrotechnical University. S. Seifullin. -Astana: KazAU Publishing House, 2009. -№1 (52). - p. 466-471.
59. Sherov K. T., Buzauova T. M., Imasheva K. I. Study of the method of thermofriction smoothing of functionally connected surfaces // Proceedings of the international scientific-theoretical conference "III Toraigyrov readings". - Pavlodar: PGU Publishing House, 2009. - p. 475-482.
60. Sherov K. T., Buzauova T. M., Sherov A. K., Ualiev D.Sh. and etc. Method for performing thermo-friction cutting and strengthening treatment of cylindrical surfaces of workpieces by a friction disk / Patent № KZ25649-A4. Derwent: 2019-31750G.
61. Sherov, K. T., Sikhimbayev M. R., Sherov A. K., Mazdubay A. V., Rakishev A. K. et al. Matematical modeling of thermofrictional milling process using ANSYS WB software / Journal of Theoretical and Applied Mechanics, Sofia, Vol. 47, No. 2 (2017) pp. 24-33. https://doi.org/10.1515/jtam-2017-0008 (in Eng.).
62. Sherov, K. T., Sikhimbayev M. R., Donenbayev B. S., Ainabekova S. Experimental Research of Rotational-and-Frictional Boring of Big Holes in Large Parts / Journal of Theoretical and Applied Mechanics, Sofia, Vol. 47, No. 4 (2017) pp.23-36. https://doi.org/10.1515/jtam-2017-0018 (in Eng.).
63. Sherov K. T., Buzauova T. M., Imasheva K. and etc. Method for thermo-clutch processing of plane of metal workpieces by friction disks, involves detecting smooth working surfaces by specific holes for supplying lubricating fluid on contact area of periphery of friction disk/ Patent № KZ22998-A4. Derwent: 2019-36801W.

64. Pavlov P. A. Mechanical condition and strength of materials. - L.: Publishing house of the Leningrad State University, 1979. - p. 176.
65. Grabsky M. V. Structural superplasticity of metals / translation from Polish. - M.: Metallurgy, 1975. -p.270.
66. Gubkin S.I. Plastic deformation of metals. - M.: Metallurgizdat, 1951.- volume. 2. - p. 355.
67. Gulyaev A. P. Metal science. -M.: Metallurgy, 1978. - p. 648.
68. Danielyan A. M. Cutting of heat-resistant steels, alloys and refractory metals. - M.: Mechanical Engineering, 1965. - p. 308.
69. Zarubitsky E. U. Thermofriction processing of steel parts. -M.: Mechanical Engineering. 1996. -№2. - p. 25
70. Kascheev V. N. Processes in the friction contact zone in metals. -M.: Mechanical Engineering, 1978. - C. 213.
71. Lyulenkov V. I. Cut of metal rolled. -M: Mashgiz, 1959. – p. 163.
72. E. Savchenko. Improving the quality of friction cutting: Abstract.Cand. tech. sciences. -Odessa, 1992. – p. 25.
73. Nechaev K. N. Thermal friction processing of flat surfaces // Metalworking. 2004.- №1. - p. 2-3.
74. Zarubitsky E. U. Processing of flat surfaces of parts with a friction disk // Shipbuilding. -1983. -№ 10. -P. 39-40.
75. Zarubitsky E. U. Thermofriction processing of parts. -M.: Mechanical engineering, 1989. - №11. - p. 30-31.
76. Sherov K. T. Quality Management in Thermofriction Cut with High-Frequency Cooling: Cand. tech. sciences. - Tashkent: Tashkent State Technical University, 1999. - p. 114.
77. Poduraev V. N. Automatically adjustable and combinable cutting processes. - M.: Mechanical Engineering, 1977. - p. 304.
78. Larin M. N. Fundamentals of speed milling / / Sat. Monitomash "High-speed methods of metal processing." -Mashgiz, 1949. – p. 65.
79. Golubev N. P. Determination of the degree and depth of work piece work hardening // Machines and tools. -1962.- №4. - p. 105.
80. Murashkin S. L. Engineering technology. The basics of engineering technology. -M.: High School. 2003. –#1. – p. 278.
81. Zorev N. N. Questions mechanics of cutting metals. -M.: High School. 1982. - p. 279.
82. Kushnazarov I. K., Sherov K. T., Altynbaev R. R. Thermofriction milling technology with high-frequency cooling // Visoki tekhnologii ї in machine-drilling: Zbirnik naukovih Prats NTU "KhPI". - Harkiv, 2007. - Vip.2 (15). - p. 134-139.
83. Yakubov F. Ya. The energy ratio of the process of machining of metals.

Tashkent: FAN, 1985. – p. 104.

84. Tretyakov A. V. Mechanical properties of steels and alloys during plastic deformation. -M.: Mechanical engineering, 1971. – p. 217.
85. Sherov K. T., Mardonov B. T., Makhmudov L. N., Altynbaev R. R., Saidov O. B. Investigation of the thermal regime in the heating zone during the thermofriction section with high-frequency cooling // Interuniversity collection of scientific papers "Actual issues in the field of technical, socio-economic and humanities." -Tashkent: Publishing House of Tashkent State Technical University, 2002. - Vol. 3.- p. 12-17.
86. Kushnazarov, I. K., Sherov, K. T., Mardonov, B. T. Control of the average temperature in contact with the thermofriction segment with high-frequency cooling // «Ізденіс-Поиск». A series of natural and technical sciences. Almaty: MES RK, 2001. - № 4, 5. – p. 239-243.
87. Methods of testing for friction and wear: Ref. Ed. / L.I. Kuksenova, V.G. Laptev, A. G. Kolmakov, L. M. Rybakova. - M.: "Internet Engineering", 2001. - P. 152
88. Zarubitsky E. U., Pokintelitsa N. I., Kostina T. P. Investigation of force dependences during thermofriction processing of stepped planes // Physical processes during metal cutting. -1988. - P. 43−46.
89. Khrushchev M. M., Babichev M. A. Metal wear research. - M.: Science, 1980. - p. 612.
90. Katsev A. P. Statistical research methods of cutting tools. -2 ed. reclaiming and add. -M.: Mechanical engineering, 1974. - p. 548.
91. Bolshev L. N., Smirnov N. V. Tables of mathematical statistics. –M.: Science publishing, 1965. – p. 754.
92. Novitsky P. V., Zograf E. N. Estimation of measurement errors. - L.: Energy, 1983. - p. 380.
93. Planning an experiment in the study of technological processes // K. Hartman, E. Letsky, V. Shefer, and others. -M.: Mir. 1977.- p. 552
94. Adler Yu. P., Markova E. V., Granovsky Yu. V. Planning of an experiment in the search for optimal conditions. -M.: Science, 1976. - p. 279.
95. Novitsky P. V., Zograf E. N. Estimation of measurement errors. - L.: Energy, 1983. p. 380.
96. Basova K., Ansys in examples and problems. - M.: Word, 2001. – p. 200
97. Nikishkov G. P., Morozov E.M. The finite element method in fracture mechanics. - M.: Science, 1980. – p. 256.
98. ANSYS Commands Reference: User’s Manual. -ANSYS, Inc.. -2000. – p. 165.

99. ANSYS Elements Reference: User's Manual. - ANSYS, Inc... 2000. – p. 205.
100. Sergey Lezhnev, Yevgeny Panin. The use of software complex DEFORM 2D / 3D in scientific work and the educational process // CAD and graphics. – M.: Publishing house Kompyuterpress, 2009. - № 5 (151). - p. 345.

MONOGRAPH

Buzauova Toty Meirbekovna,
Sherov Karibek Tagayevich,
Algazy Zhauyt,
Turusbekova Ainur Serikbolovna

STUDY OF WEAR AND RESTORATION OF THE MINING MACHINES PARTS

Subscribe to print 12/11/2019. Format 60×90/16.
Edition of 300 copies.
Printed by “iScience” Sp. z o. o.
Warsaw, Poland
08-444, str. Grzybowska, 87
info@sciencecentrum.pl, https://sciencecentrum.pl

ISBN 978-83-66216-16-7