МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

АЕРОКОСМІЧНИЙ ФАКУЛЬТЕТ

КАФЕДРА ПІДТРИМАННЯ ЛЬОТНОЇ ПРИДАТНОСТІ ПОВІТРЯНИХ СУДЕН

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
канд. техн. наук, доц.
_______________О.В. Попов
«_____»_____________2021 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ
«МАГІСТР»

ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема: «Дослідження зносостійкості плазмових покриттів при вібраціях та односпрямованому терті»

Виконав: __________ **М.С. Нікітенко**

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Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

AEROSPACE FACULTY

AIRCRAFT CONTINUING AIRWORTHINESS DEPARTMENT

PPERMISSION TO DEFEND
Head of the department
Ph. D., Assoc. Professor
_____________ O. V. Popov
«____”_______________ 2021

MASTER’S DEGREE THESIS

(EXPLANATORY NOTE)

GRADUATE OF EDUCATIONAL DEGREE

«MASTER»

FOR EDUCATIONAL-PROFESSIONAL PROGRAM
«MAINTENANCE AND REPAIR OF AIRCRAFT AND AVIATION ENGENS»

Topic: «Research of wear resistance of plasma coatings in vibrations and unidirectional friction»

Created by: _____________**M.S. Nikitenko**

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Advisers on Individual Sections:

Labour precaution: Ph. D., Assoc. Professor _____________**V.V. Kovalenko**

Environmental protection: Ed. D., Professor _____________**T.V. Sayenko**

Standards Inspector: _____________

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Faculty: Aerospace faculty
Aircraft Continuing Airworthiness Department
Educational and Qualifications level: «Master Degree»
The specialty: 272 «Aviation transport»
Educational-professional program «Maintenance and Repair of Aircraft and Engines»

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«____”_______________ 2021

Graduate Student's Degree Work Assignment

NIKITENKO MYKYTA SERGHIYOVYCH

1. The topic of the work: **« Research of wear resistance of plasma coatings in vibrations and unidirectional friction»** approved by the Rector's order of October 11, 2021 № 2196/ст.
2. The work fulfillment terms: since October 25, 2021 until December 31, 2021.
3. Initial data for the project (thesis): analysis of the damage of titanium alloys details and durability of refurbished details by means of thermal spraying aircraft parts.
4. The content of the explanatory note: analysis of damage to components of aircraft due to wear, application of coatings in aviation, analysis of methods for repairing parts in aviation, conducting experiments, processing of experimental results, analysis of safety and environmental protection.
5. The list of mandatory graphic materials: Theme; List of tasks; methods of aviation components repair; implementation of sprayed coatings; fretting problem; analysis of methodologies on conducting tests; МФК-1 installation; wear measurement; wear resistance results; friction surfaces fractography; surface topography; conclusions and recommendations.

6. Calendar schedule

Task	Fulfillment term	Completion mark
Literature review of materials for degree work	25.10.2021-30.10.2021	
Analysis of technological process of work fulfillment	01.11.2021 – 10.1.2021	
Preparation of necessary equipment for research carrying out	11.11.2021 – 14.11.2021	
Work on a special part of degree work	15.11.2021 – 20.11.2021	
Processing of research results	21.11.2021 – 30.11.2021	
Fulfillment of individual sections of degree work	01.12.2021 – 04.12.2021	
Processing of master's degree work	05.12.2021 - 20.12.2021	

7. Advisers on individual sections

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labour precaution	Ph. D., Assoc. Prof. V. V. Kovalenko		
Environmental protection	Ed. D., Professo T.V. Sayenko		

8. Assignment issue date «_____»___________ 2021.

Degree work supervisor: ___________________ A.M. Khimko
(signature)

Assignment accepted for fulfillment ____________________ M.S. Nikitenko
(signature)

ABSTRACT

The explanatory note to master's degree work « Research of wear resistance of plasma coatings in vibrations and unidirectional friction »:

87 pages, 23 figures, 2 tables, 36 literature sources.

Object of study - coatings deposited on titanium alloy.

Subject of study – processes of wear resistance of coatings under unidirectional and reverse friction.

The purpose - analysis of thermal coatings damages which are a result of fretting corrosion and unidirectional friction-sliding.

Research method - laboratory studies of thermal coatings damages after unidirectional and cyclic friction.

The complex analysis of the methods for details restoration was conducted. The complex study on qualitative and quantitative parameters of mating surfaces friction, on thermal spray coatings wear resistance testing was conducted.

All these issues are described as fully as possible, thesis is completed in accordance with all requirements of the degree works fulfillment, the specifics of specialty is taken into account.

The results of degree work can be recommended for the departments that deal with the wear resistance issues of different materials under different types of friction and also for the educational divisions during training courses of tribology.

FRETTING-CORROSION, UNIDIRECTIONAL FRICTION, WEAR, DAMAGE ANALYSIS, FRACTOGRAPHY, MOLIBDENUM, TITANIUM

LIST OF ABBREVIATIONS

APS – air plasma spray

BACT – best available control technology

CAA – clean air act

CMC– ceramic-matrix composites

COF - coefficient of friction

EBPVD – electron beam physical vapor deposition

ESAVD – electrostatic spray assisted vapour deposition

GTE - gas turbine engines

HEPA – high-efficiency particle absorption

HVOF - high velocity oxygen fuel

MACT – maximum achievable control technology

NAAQS– national ambient air quality standards

PTWA - plasma transferred wire arc

RCRA – resources conservation and recovery act

SPPS – solution precursor plasma spray

TBC – thermal barrier coatings

USZ – ultra-stabilized zirconia

CONTENT

INTRODUCTION

In any sphere where machines, mechanisms and different devices are used, the tasks of increasing their efficiency and durability are initial. Reliability and duration of that type of units where interaction between their parts are structurally embedded are caused by such phenomenon as friction and wear. Wear leads to interruption of mechanism units tightness, accuracy of details' arrangement and also to their mutual displacements. As the result, wedging, impacts, vibration are appeared. Eventually, they lead to failures of mechanisms. Friction, in its turn, causes the loses of energy, reheating of the mechanism units and as the result - the reducing of their effective work. Phenomenon of friction and wear are interconnected: friction leads to wear, and wear of the detail surfaces causes the changes of friction.

One of the ways of technical level increasing and increasing of quality of the machinery construction products is providing the parts of machine and assemblies of modern machinery with reliability and durability. This problem is especially actual for friction assemblies, because 80 % of machine's parts, mechanisms, instruments and technological equipment break down are caused by destroying of working surfaces.

Nowadays a huge variety of testing equipment in manufacturing are developed and exploited, they are machines for testing the material on stretching and compression, bending, share, torsion, wear, impact, devices for determination of hardness elastic constants of materials, means for technological testing of materials, investigation of climatic factors, etc. Developing of units for carrying out the investigations of assemblies and separate parts for wear resistance gets the first-priority importance for different machines and mechanisms exploited at hard working conditions.

Work resource of mechanism units is usually limited by the premature wear or destruction of the contacting parts. These appear as the result of development of damages which are caused by such processes as one-directed and reversal friction. The mentioned above processes are subspecies of such a phenomenon as friction sliding. It's necessary to mark the special type of corrosion-mechanical wear under the alternating friction. It's name is fretting-corrosion. This process usually is observed in the immovable connections which exposed the vibration. Under the fretting-corrosion the cyclical micro displacements in contacts of the details lead to deformations, intensive accumulation of structural defects, appearance of micro- and macro-cracks.

At the identical conditions of alternating and one-directed friction sliding the properties of the working surfaces differ. As the result, alternation of friction affects on the wear resistance of the machine details.

In techniques, low speeds under friction sliding are widespread. For example, in hinges of units, machine pillars, places where the vibration takes place and other. As the result of vibration under the action of fretting-corrosion the wear process appears. That’s why, it will be interesting to compare the material damages in case of alternating and one-directed friction sliding. These types of friction siding are parts of one process, but at the same time have their own peculiarities. It’s important to mark, that wear at fretting-corrosion and friction sliding – are the different types of surfaces wear. So, the comparative analyses should be done by certain criterions.

PART 1.
ANALYSIS OF THE USE OF COATINGS IN AVIATION

1.1 General terms of friction and wear

Friction is a part of our everyday life. Nearly every movement we make involves friction, and we have instinctively learned to take advantage of friction, or the lack of friction, since our childhood.

Simple devices that rely on friction are everywhere around us. Scientists and engineers have been studying friction and its effects for a very long time. Engineers in particular have a real “love-hate” relationship with friction. For many jobs, an engineer must fight against friction and its effects through careful, clever design. Roughly speaking, the scientist's role is to understand friction, what causes it and how those causes can be controlled. The engineer's role is to anticipate friction's part in the task at hand, and to use friction to the best advantage in the design of materials, machines, and experiments.

The work done by friction can transform into deformation, wear, and heat that can affect the contact surface properties (even the coefficient of friction between the surfaces). This can be beneficial as in polishing. The work of friction is used to mix and join materials such as in the process of friction welding. Excessive erosion or wear of mating sliding surfaces occurs when work due frictional forces rise to unacceptable levels. Harder corrosion particles caught between mating surfaces in relative motion exacerbates wear of frictional forces [1]. Bearing seizure or failure may result from excessive wear due to work of friction. As surfaces are worn by work due to friction, fit and surface finish of an object may degrade until it no longer functions properly [2].

Problem of wear as a result of friction and sliding often occurs in aviation.

Aerospace Tribology is the science and technology that is related to surfaces interacting in relative motion, and it includes the study of friction, lubrication and wear [3]. Being able to evaluate surfaces that touch each other are of vital importance to a failure investigation. For example, the unwanted fretting and wear of hinges, tracks, bearings, and gearboxes in airframes and engines is a constant problem in aircraft, because it induces failures and jamming [1]. Aviation Tribology Experts understand how to evaluate the failures caused by the different types of wear and friction that can be imparted on an aircraft component.

1.1.1 Notions of friction

Friction is the force that opposes sliding motion. It is the resistance to the movement of one body in relation to another body with which it is in contact. For example, if we try to slide a wooden block across a table, then friction acts in the direction opposite to the movement of the block.

When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into heat. This property can have dramatic consequences, as illustrated by the use of friction created by rubbing pieces of wood together to start a fire [4]. Kinetic energy is converted to heat whenever motion with friction occurs, for example when a viscous fluid is stirred. Another important consequence of many types of friction can be wear, which may lead to performance degradation and/or damage to components [5]. Friction is a component of the science of tribology.

Friction is not itself a fundamental force but arises from fundamental electromagnetic forces between the charged particles constituting the two contacting surfaces. The complexity of these interactions makes the calculation of friction from first principles impractical and necessitates the use of empirical methods for analysis and the development of theory.

The classic rules of sliding friction were discovered by Leonardo da Vinci (1452–1519), but remained unpublished in his notebooks. They were rediscovered by Guillaume Amontons (1699). Amontons presented the nature of friction in terms of surface irregularities and the force required to raise the weight pressing the surfaces together. This view was further elaborated by Belidor (representation of rough surfaces with spherical asperities, 1737) and Leonhard Euler(1750), who derived the angle of repose of a weight on an inclined plane and first distinguished between static and kinetic friction. A different explanation was provided by Desaguliers (1725), who demonstrated the strong cohesion forces between lead spheres of which a small cap is cut off and which were then brought into contact with each other.

The understanding of friction was further developed by Charles-Augustin de Coulomb (1785). Coulomb investigated the influence of four main factors on friction: the nature of the materials in contact and their surface coatings; the extent of the surface area; the normal pressure (or load); and the length of time that the surfaces remained in contact (time of repose). Coulomb further considered the influence of sliding velocity, temperature and humidity, in order to decide between the different explanations on the nature of friction that had been proposed. The distinction between static and dynamic friction is made in Coulomb’s friction law (see below), although this distinction was already drawn by Johann Andreas von Segner in 1758. The effect of the time of repose was explained by Musschenbroek (1762) by considering the surfaces of fibrous materials, with fibers meshing together, which takes a finite time in which the friction increases.

John Leslie (1766–1832) noted a weakness in the views of Amontons and Coulomb. If friction arises from a weight being drawn up the inclined plane of successive asperities, why isn't it balanced then through descending the opposite slope? Leslie was equally skeptical about the role of adhesion proposed by Desaguliers, which should on the whole have the same tendency to accelerate as to retard the motion. In his view friction should be seen as a time-dependent process of flattening, pressing down asperities, which creates new obstacles in what were cavities before.

Arthur Morrin (1833) developed the concept of sliding versus rolling friction. Osborne Reynolds (1866) derived the equation of viscous flow. This completed the classic empirical model of friction (static, kinetic, and fluid) commonly used today in engineering.

The focus of research during the last century has been to understand the physical mechanisms behind friction. F. Phillip Bowden and David Tabor (1950) showed that at a microscopic level, the actual area of contact between surfaces is a very small fraction of the apparent area. This actual area of contact, caused by “asperities” (roughness) increases with pressure, explaining the proportionality between normal force and frictional force. The development of the atomic force microscope (1986) has recently enabled scientists to study friction at the atomic scale.

There are several types of friction [6]: like fluid friction, dry friction, and sliding friction:

- dry friction resists relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into static friction (“stiction”) between non-moving surfaces, and kinetic friction between moving surfaces;
- fluid friction describes the friction between layers within a viscous fluid that are moving relative to each other;
- lubricated friction is a case of fluid friction where a fluid separates two solid surfaces;
- skin friction is a component of drag, the force resisting the motion of a fluid across the surface of a body.

Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation.

In the reference frame of the interface between two surfaces, static friction does not work, because there is never displacement between the surfaces. In the same reference frame, kinetic friction is always in the direction opposite the motion, and does negative work. However, friction can do positive work in certain frames of reference. One can see this by placing a heavy box on a rug, then pulling on the rug quickly. In this case, the box slides backwards relative to the rug, but moves forward relative to the frame of reference in which the floor is stationary. Thus, the kinetic friction between the box and rug accelerates the box in the same direction that the box moves, doing positive work.

The work done by friction can transform into deformation, wear, and heat that can affect the contact surface properties (even the coefficient of friction between the surfaces) [7]. This can be beneficial as in polishing. The work of friction is used to mix and join materials such as in the process of friction welding. Excessive erosion or wear of mating sliding surfaces occurs when work due frictional forces rise to unacceptable levels. Harder corrosion particles caught between mating surfaces in relative motion (fretting) exacerbates wear of frictional forces. Bearing seizure or failure may result from excessive wear due to work of friction [5]. As surfaces are worn by work due to friction, fit and surface finish of an object may degrade until it no longer functions properly

The elementary property of sliding (kinetic) friction were discovered by experiment in the 15th to 18th centuries and were expressed as three empirical laws:

Amontons’ First Law: The force of friction is directly proportional to the applied load;

Amontons’ Second Law: The force of friction is independent of the apparent area of contact;

Coulomb’s Law of Friction: Kinetic friction is independent of the sliding velocity.

Dry friction resists relative lateral motion of two solid surfaces in contact [7]. The two regimes of dry friction are “static friction” (“stiction”) between non-moving surfaces, and kinetic friction (sometimes called sliding friction or dynamic friction) between moving surfaces.

Coulomb friction, named after Charles-Augustin de Coulomb, is an approximate model used to calculate the force of dry friction. It is governed by the model:

$$F_\mathrm{f} \leq \mu F_\mathrm{n} \tag{1.1}$$

where: F_f is the force of friction exerted by each surface on the other. It is parallel to the surface, in a direction opposite to the net applied force.

μ is the coefficient of friction, which is an empirical property of the contacting materials,

F_n is the normal force exerted by each surface on the other, directed perpendicular (normal) to the surface.

The Coulomb friction F_f may take any value from zero up to μF_n, and the direction of the frictional force against a surface is opposite to the motion that surface would experience in the absence of friction. Thus, in the static case, the frictional force is exactly what it must be in order to prevent motion between the surfaces; it balances the net force tending to cause such motion. In this case, rather than providing an estimate of the actual frictional force, the Coulomb approximation provides a threshold value for this force, above which motion would commence. This maximum force is known as traction.

The force of friction is always exerted in a direction that opposes movement (for kinetic friction) or potential movement (for static friction) between the two surfaces. For example, a curling stone sliding along the ice experiences a kinetic force slowing it down [8]. For an example of potential movement, the drive wheels of an accelerating car experience a frictional force pointing forward; if they did not, the wheels would spin, and the rubber would slide backwards along the pavement. Note that it is not the direction of movement of the vehicle they oppose, it is the direction of (potential) sliding between tire and road.

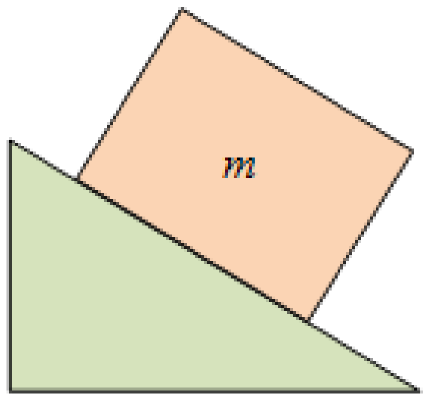


Figure 1.1 – Block on a rump

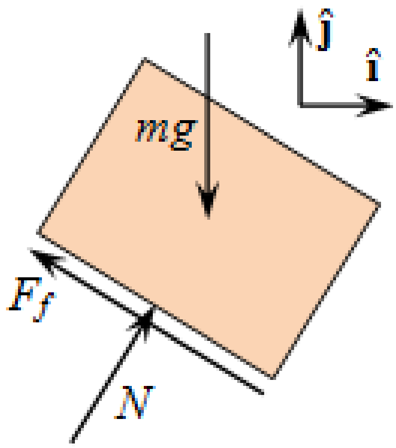


Figure 1.2 – Free body diagram of just the block

Free-body diagram for a block on a ramp is shown on Figure 1.1. Arrows are vectors indicating directions and magnitudes of forces. N is the normal force, mg is the force of gravity, and Ff is the force of friction.

The normal force is defined as the net force compressing two parallel surfaces together; and its direction is perpendicular to the surfaces, you can see this on Figure 1.2. In the simple case of a mass resting on a horizontal surface, the only component of the normal force is the force due to gravity, where $N = mg$. In this case, the magnitude of the friction force is the product of the mass of the object, the acceleration due to gravity, and the coefficient of friction. However, the coefficient of friction is not a function of mass or volume; it depends only on the material. For instance, a large aluminum block has the same coefficient of friction as a small aluminum block. However, the magnitude of the friction force itself depends on the normal force, and hence on the mass of the block.

If an object is on a level surface and the force tending to cause it to slide is horizontal, the normal force N between the object and the surface is just its weight, which is equal to its mass multiplied by the acceleration due to earth's gravity, g. If the object is on a tilted surface such as an inclined plane, the normal force is less, because less of the force of gravity is perpendicular to the face of the plane. Therefore, the normal force, and ultimately the frictional force, is determined using vector analysis, usually via a free body diagram. Depending on the situation, the calculation of the normal force may include forces other than gravity [9].

The coefficient of friction (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction. Coefficients of friction range from near zero to greater than one.

For surfaces at rest relative to each other $\mu = \mu_\mathrm{s}$, where μ_s is the coefficient of static friction. This is usually larger than its kinetic counterpart.

For surfaces in relative motion $\mu = \mu_\mathrm{k}$, where μ_k is the coefficient of kinetic friction. The Coulomb friction is equal to F_f, and the frictional force on each surface is exerted in the direction opposite to its motion relative to the other surface.

Arthur Morin introduced the term and demonstrated the utility of the coefficient of friction [10]. The coefficient of friction is an empirical measurement – it has to be measured experimentally, and cannot be found through calculations. Rougher surfaces tend to have higher effective values. Both static and kinetic coefficients of friction depend on the pair of surfaces in contact; for a given pair of surfaces, the coefficient of static friction is usually larger than that of kinetic friction; in some sets the two coefficients are equal, such as teflon-on-teflon.

Most dry materials in combination have friction coefficient values between 0.3 and 0.6. Values outside this range are rarer, but teflon, for example, can have a coefficient as low as 0.04. A value of zero would mean no friction at all, an elusive property – even magnetic levitation vehicles have drag. Rubber in contact with other surfaces can yield friction coefficients from 1 to 2. Occasionally it is maintained that μ is always < 1, but this is not true. While in most relevant applications $\mu < 1$, a value above 1 merely implies that the force required to slide an object along the surface is greater than the normal force of the surface on the object. For example, silicone rubber or acrylic rubber-coated surfaces have a coefficient of friction that can be substantially larger than 1.

While it is often stated that the COF is a "material property", it is better categorized as a "system property" [11]. Unlike true material properties (such as conductivity, dielectric constant, yield strength), the COF for any two materials depends on system variables like temperature, velocity, atmosphere and also what are now popularly described as aging and deaging times; as well as on geometric properties of the interface between the materials. For example, a copper pin sliding against a thick copper plate can have a COF that varies from 0.6 at low speeds (metal sliding against metal) to below 0.2 at high speeds when the copper surface begins to melt due to frictional heating. The latter speed, of course, does not determine the COF uniquely; if the pin diameter is increased so that the frictional heating is removed rapidly, the temperature drops, the pin remains solid and the COF rises to that of a "low speed" test.

As of 2012, a single study has demonstrated the potential for a negative coefficient of friction, meaning that a decrease in force leads to an increase in friction. This contradicts the everyday experience that an increase of normal force improves friction. This was reported in the journal Nature in October 2012 and involved the friction encountered by an atomic force microscope stylus when dragged across a graphene sheet in the presence of graphene-adsorbed oxygen [12].

As we already know one of the types of friction is static friction.

Static friction is friction between two or more solid objects that are not moving relative to each other. For example, static friction can prevent an object from sliding down a sloped surface. The coefficient of static friction, typically denoted as μs, is usually higher than the coefficient of kinetic friction.

The static friction force must be overcome by an applied force before an object can move. The maximum possible friction force between two surfaces before sliding begins is the product of the coefficient of static friction and the normal force:

$$F_{max} = \mu_s F_n \tag{1.2}$$

When there is no sliding occurring, the friction force can have any value from zero up to F_{max}. Any force smaller than F_{max} attempting to slide one surface over the other is opposed by a frictional force of equal magnitude and opposite direction. Any force larger than F_{max} overcomes the force of static friction and causes sliding to occur. The instant sliding occurs, static friction is no longer applicable—the friction between the two surfaces is then called kinetic friction.

An example of static friction is the force that prevents a car wheel from slipping as it rolls on the ground. Even though the wheel is in motion, the patch of the tire in contact with the ground is stationary relative to the ground, so it is static rather than kinetic friction.

The maximum value of static friction, when motion is impending, is sometimes referred to as limiting friction, although this term is not used universally. It is also known as traction.

Another type of friction is kinetic friction.

Kinetic (or dynamic) friction occurs when two objects are moving relative to each other and rub together (like a sled on the ground). The coefficient of kinetic friction is typically denoted as μk, and is usually less than the coefficient of static friction for the same materials [14].

New models are beginning to show how kinetic friction can be greater than static friction. Kinetic friction is now understood, in many cases, to be primarily caused by chemical bonding between the surfaces, rather than interlocking asperities; however, in many other cases roughness effects are dominant, for example in rubber to road friction.

Surface roughness and contact area, however, do affect kinetic friction for micro- and nano-scale objects where surface area forces dominate inertial forces.

In the reference frame of the interface between two surfaces, static friction does not work, because there is never displacement between the surfaces. In the same reference frame, kinetic friction is always in the direction opposite the motion, and does negative work [13]. However, friction can do positive work in certain frames of reference. One can see this by placing a heavy box on a rug, then pulling on the rug quickly. In this case, the box slides backwards relative to the rug, but moves forward relative to the frame of reference in which the floor is stationary. Thus, the kinetic friction between the box and rug accelerates the box in the same direction that the box moves, doing positive work.

1.1.2 Notions of wear

The work done by friction can translate into deformation, wear, and heat that can affect the contact surface properties (even the coefficient of friction between the surfaces). This can be beneficial as in polishing. The work of friction is used to mix and join materials such as in the process of friction welding. Excessive erosion or wear of mating sliding surfaces occurs when work due frictional forces rise to unacceptable levels. Harder corrosion particles caught between mating surfaces in relative motion exacerbates wear of frictional forces. Bearing seizure or failure may result from excessive wear due to work of friction. As surfaces are worn by work due to friction, fit and surface finish of an object may degrade until it no longer functions properly.

Problem of wear as a result of friction and sliding often occurs in aviation.

Aerospace Tribology is the science and technology that is related to surfaces interacting in relative motion, and it includes the study of friction, lubrication and wear. Being able to evaluate surfaces that touch each other are of vital importance to a failure investigation. For example, the unwanted fretting and wear of hinges, tracks, bearings, and gearboxes in airframes and engines is a constant problem in aircraft, because it induces failures and jamming. Aviation Tribology Experts understand how to evaluate the failures caused by the different types of wear and friction that can be imparted on an aircraft component. Some of the more common types of wear include the following:

Abrasive wear is due to hard particles or hard protuberances that are forced against and move along a solid surface Figure 1.3. Abrasive wear is commonly classified according to the type of contact and the contact environment. The type of contact determines the mode of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear Figure 1.4. Two-body wear occurs when the grits or hard particles remove material from the opposite surface.

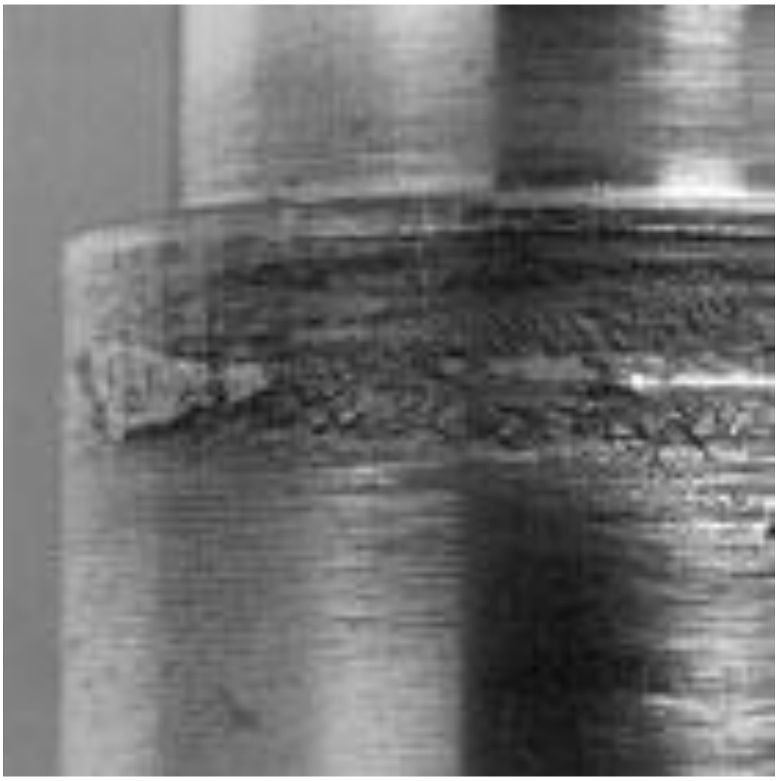


Figure 1.3 – Detail damaged by abrasive wear

The common analogy is that of material being removed or displaced by a cutting or plowing operation. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface. The contact environment determines whether the wear is classified as open or closed. An open contact environment occurs when the surfaces are sufficiently displaced to be independent of one another.

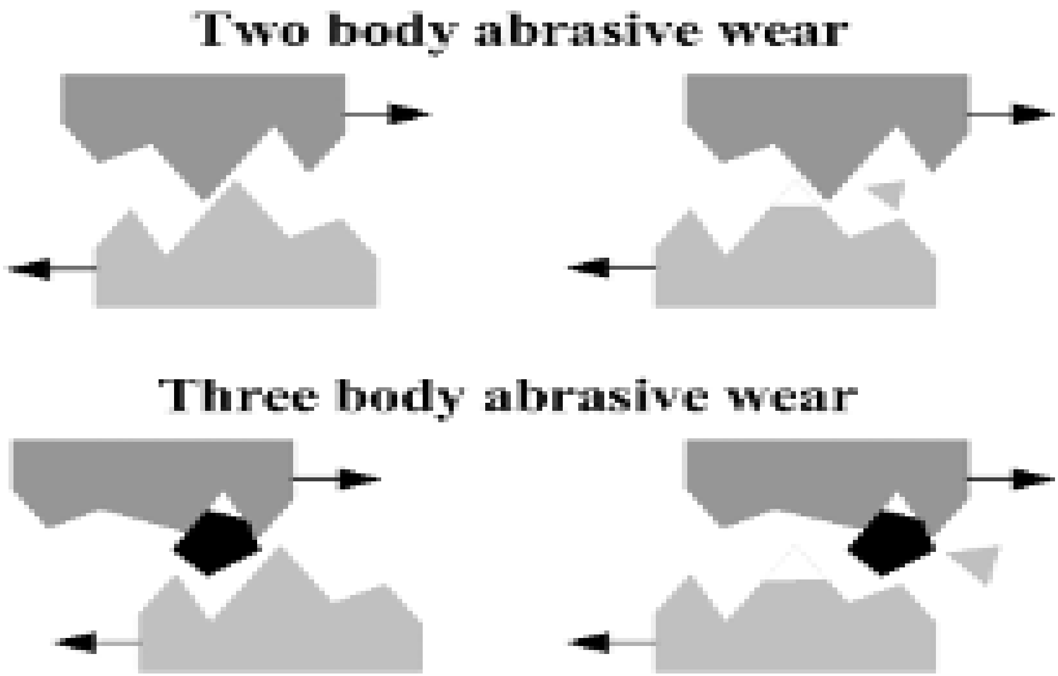


Figure 1.4 – Modes of abrasive wear

Adhesive wear can be found between surfaces during frictional contact and generally refers to unwanted displacement and attachment of wear debris and material compounds from one surface to another Figure 1.5. Generally, adhesive wear occurs when two bodies slide over or are pressed into each other, which promote material transfer. This can be described as plastic deformation of very small fragments within the surface layers. The asperities or microscopic high points or surface roughness found on each surface, define the severity on how fragments of oxides are pulled off and adds to the other surface, partly due to strong adhesive forces between atoms but also due to accumulation of energy in the plastic zone between the asperities during relative motion. There are several major types of adhesive wear. Sliding wear: any solid sliding on any other solid; Galling: severe form of adhesive wear; Scoring/scuffing wear: grooves and scratches in the sliding direction; Oxidative wear: mild wear in hard/hard unlubricated ferrous systems. In addition, there are four types of relative sliding motions to consider: unidirectional continuous, reciprocating, complex (slide, roll, etc.), and intermittent.

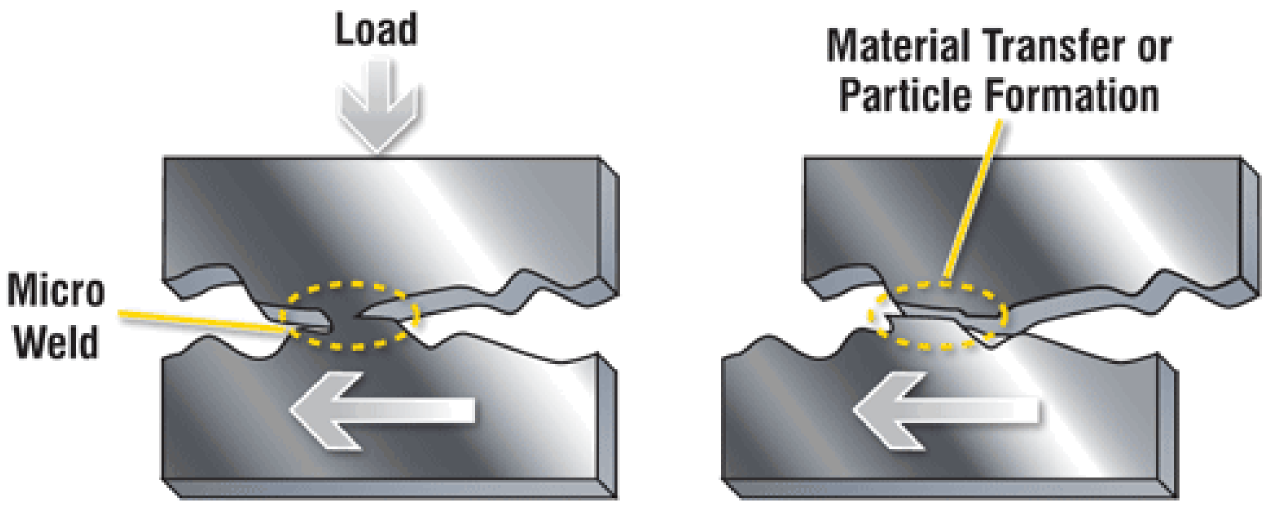


Figure 1.5 – Typical scheme of the adhesive wear

Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, impact velocity and impingement angle are primary factors along with the properties of the surface being eroded [15].

Erosive wear can be described as an extremely short sliding motion and is executed within a short time interval. Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. It is a widely encountered mechanism in industry. A common example is the erosive wear associated with the movement of slurries through piping and pumping equipment.

The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, impact velocity and impingement angle are primary factors along with the properties of the surface being eroded. The impingement angle, which is shown on Figure 1.6, is one of the most important factors and is widely recognized in literature. For ductile materials the maximum wear rate is found when the impingement angle is approximately 30°, whilst for non ductile materials the maximum wear rate occurs when the impingement angle is normal to the surface.

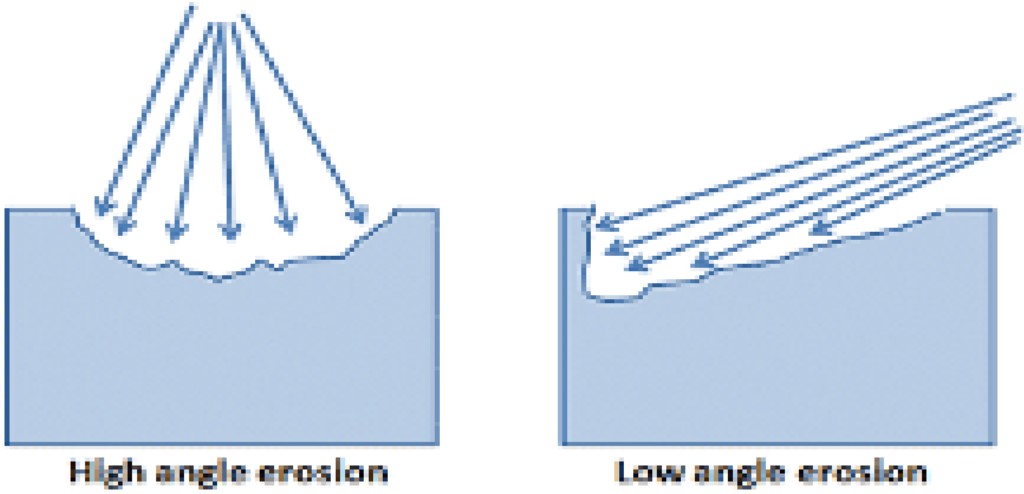


Figure 1.6 – The impingement angle is very important factor of erosive wear

In materials science, fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture Figure 1.7. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.

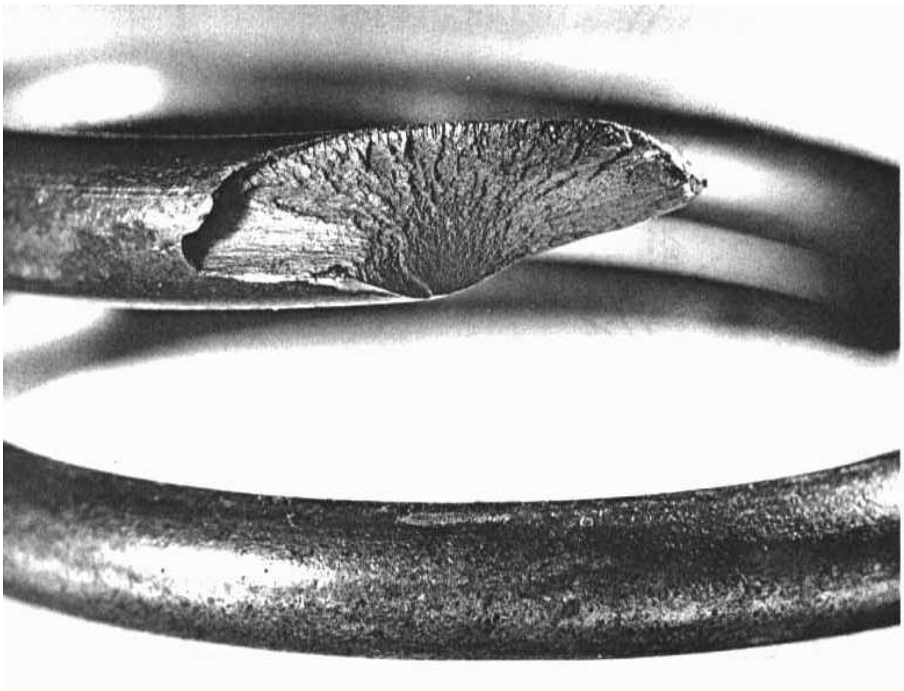


Figure 1.7 – Fatigue of the structure as a result of cracks

1.2 Analyses of methods of aviation details repairing

During determining the repair method, the following factors should be taken into account: the nature of the defect and its causes, modes of the repaired object, material and structural shape of the part. Considering these factors, repair technology of the aircraft or helicopter set rejection factors, ie, quantitative and qualitative characteristics of defects that require replacement, enhancing or restoring certain parts or structural elements.

Replacement (total or partial) of parts, assemblies or components should be in accordance with the reason for rejection in case: found unacceptable damage; detected defect size exceeds the set limit, worked out the assigned resource, items included in the list is constantly being replaced during repair.

Consider a few examples. Detection of cracks in bolts, axles, shafts, referred to unacceptable damage caused by the need to replace these parts. The presence of any mechanical damage to the pipe in the nipple joint is not allowed, and the pipeline must be replaced. Salvage pitting of the stringer section, especially in connection with a shell should be replaced, since no repair methods can prevent corrosion. Bearing with released for the permitted limits Axial and radial runout cannot be allowed to further exploitation and it is replaced. Cracked, peeled paint on the outer surface of an airplane or helicopter is removed and completely replaced [14].

Replacements during repairs are carried out not only in the presence of defects, but also after working out by some details or units of assigned resource. For example, all the rubber sleeves, O-rings, gaskets have limited calendar lifetime, and they are replaced during repair. The same applies to the flexible hoses and tubes.

In some cases, a specific resource is defined for screws, brackets, rails and flaps etc. This restriction is based on the results of advanced test design or operating statistics and repair facilities. For certified units designated resource is defined after work out of which their replacement is produced [13]. For all types of lock repair parts (cotter pins, spring washers, wire backlight, etc.) is replaced regardless of their condition. In repair technological guidelines are constantly replaced parts.

Currently, a significant proportion of the cost of repair is the cost of replacement parts and new units, manufacturing of parts and structures. Meanwhile, the recovery efficiency of aircraft parts made of expensive and scarce materials, rational technology of repair will give a major economic effect [17]. Technological possibilities of restoration of details on aircraft repair company are expanded through the development of advanced methods of processing metals, the introduction of technology application and other types of metal coatings, promising types of welding, soldering, bonding.

Regenerative repair is performed in the following cases: the presence of defects and damages of allowable sizes for detail and structural elements; violation of established plantings due to wear of mating parts movable and fixed joints [18].

Depending on the nature of the defect all the processes of the details recovery are grouped into two main groups: the restoration of the parts with mechanical damages and restoration of details with worn surfaces (with changing sizes of working surfaces parts). The first group includes methods for recovery of parts with cracks, holes, deformation and corrosion damage, the second - with changed dimensions and geometric shapes of working surfaces in the form of oval, conical, corset, etc.

Application of a method of recovery also depends on the material from which the restored item was made. The most common ways of details renewal are: welding and surfacing Figure 1.8. These methods recover about 60% of the parts [16]. Widespread use of welding and surfacing is due to the simplicity of the technological process and equipment, the possibility of the restoration of parts of the most used metals and alloys, high performance and low cost.

Figure 1.8 – Detail restoration by welding

During restoration of the details the following types of items and methods of welding and surfacing are used: manual arc welding, gas welding, semi-automatic welding in carbon dioxide, semi-automatic welding by wire Panch-11, semiautomatic welding by flux cored wire welding, automatic submerged arc welding, electro contact welding.

Very promising is the way to restore the parts by applying thermal spray coatings with a thickness of 0.03 to a few millimeters. The essence of the process consists in melting the raw material (powder or wire) and transfers it to the retracted surface of the detail by stream of gas (air) without causing overheating of the metal. During detail restoring various kinds of fitting and machining are used. Processing of details to the repair size recover reduced geometric shape of their working surfaces. Statement of additional repair parts ensures restoration of the worn surfaces to the size of new items [19]. Details are also reduced by plastic deformation (edited), which is based on the use of the plastic properties of the work piece material. Depending on the design of parts used such types of plastic deformation, as compression, knurled, draft, hood, etc.

Thermal spray coatings can be engineered using most metals, carbides, ceramics, and plastics to create a coating with the optimum properties for your application. Thermal spray coatings can be applied to a broad range of materials, from metals to composite materials.

Examples of thermal spray applications within the aerospace industry Figure 1.9:

Turbine Blades - Thermal spray coatings protect engine turbine blades from the extreme temperatures they experience, and ensure increased reliability for extended periods of time.

Jet Engines - There are over 100 applications for thermal sprays coatings within a single jet engine, such as crank shafts, cylinders, piston rings and abrasive coatings to ensure a sealing surface between the turbine blade and their housing.

Landing Gear - thermal sprays have recently replaced hard chrome plating as the preferred method of coatings used in aircraft landing gear to protect this equipment from the extreme forces experienced during take-off and landing.

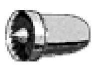
Industry	Surface Requirement	Component	Thermal Spray Coatings
Aerospace 	Thermal Barrier	Rocket Combustion Chamber	Zirconium Oxide
	Resist Fretting	Compressor Air Seals	Aluminum Bronze
	Particle Erosion	Missle Nose Cones	Calcium Zirconate
	Shielding	Missle Systems	Pure Aluminum
	Oxidation Resistance	High Pressure Nozzles	Cobalt-Molybdenum
Turbine Engines 	Fretting-Hi Temperature	Turbine Air Seals	Chromium Cobalt
	Corrosion Resistance	Fuel Nozzles	Aluminum Oxide
	Fretting-Low Temperature	Compressor Stators	Tungsten Carbide
	Particle Erosion	Turbine Vanes	Chromium Carbide
	Abradable Coating	Engine Compressor Stages	Nickel Graphite

Figure 1.9 - Thermal spray coatings usage in aerospace industry

Coatings range from engine to landing-gear applications. Thermal spray coatings protect engine turbine blades from extreme temperatures, and ensure increased reliability for extended periods of time. In landing-gear applications, these coatings are replacing hard chromium plating as the preferred coating method to provide improved performance. Applications in these and other aerospace applications may include:

• Landing gear (bearings, axles, pins, etc.)

• Jet engines (blades, vanes, combustion liners, compressor casings, nozzles, etc.)

• Actuation systems (pistons, pumps, flaps, etc.)

• Engine cowling, wing structures

More and more polymeric materials are used during details repair: the elimination of mechanical damage of the parts, during compensation of wear of the working surfaces of the parts (compositions based on epoxy resin) and connecting parts for bonding, such as gluing of friction linings.

A large number of parts are recovered by deposition of galvanic coverage, based on metal deposition on the item of electrolytes. In repair practice most widely used electrolytic metalizing and electrofriction.

Galvanic coating is a metal film with thickness from a fraction of a micron to tenths of a millimeter, applied to the surface of nonmetal and metal products using electroplating to give them hardness, wear resistance, corrosion-resistant, anti-friction, decorative properties. The industry now pays special attention to the development of new fully non cyanide electrolytes for application shiny plating.

1.3 Fretting wear

At present, research in the field of tribology and mechanics of contact fracture of elements and units at variable load modes represents current direction. It causes significant amount of operational failures of technical objects of various purposes.

Fretting takes up to 50 % of wear of aircraft parts.

According to [20], among the main operational defects in domestic and foreign aircraft gas turbine engines (GTE), fretting takes up to 60 % of all types of wear. Fretting develops in GTE in various elements of connection:

– bolted;

– spline;

– dowel joints;

– in different press fittings of elements, hinged places of locking connections;

– on contact surfaces of shroud flanges of blades, fittings of turbine and compressor blades, including fittings of fan blades.

Destruction due to fretting is observed in the form rubbing, dents, caverns, microcracks and pits filled with powder-like products of wear. All materials in almost all kinds of environment and conditions are subjected to the influence of fretting.

One of the most important aircraft units which often suffer from fretting wear are aircraft wing mechanization units, which are designed to create additional lift at such responsible stages of flight as takeoff and landing.

Fretting is a combined form of wear, fatigue and corrosion that can lead to premature mechanical failure at loads well below structural design limits. It is a time-based failure that will require increased attention as the transport-category aircraft fleet continues to age.

The basic requirements for fretting are relative motions between two surfaces in contact; some mechanical load applied to the surfaces; and a load vector sufficient to cause slip between the surfaces.

Fretting can result in excessive wear, surface fatigue, component fracture, loss of clamping pressure and jamming (by generated debris). Although most reports of fretting damage involve metals, composite materials and ceramic materials also are susceptible to fretting damage [21, 22].

In its nature fretting is a process in which two bodies in contact are subjected to relative motion of an amplitude small enough to allow resulting debris to be trapped between the contacting (faying) surfaces. Because the faying surfaces and debris are subject to corrosion as well as wear, the process is sometimes called fretting corrosion. When one or both of the bodies also undergo cyclic tensile (fatigue) loading, the process is called fretting fatigue. The simultaneous action of wear, corrosion and fatigue mechanisms often results in a synergistic degradation of the components with a reduction in life which can be an order of magnitude more than would be expected based upon the operation of only one of the three mechanisms.

Fretting fatigue is increasingly being recognized in the aircraft industry as a major cause of failure. It is a failure mechanism which frequently leads to high maintenance and inspection costs and could potentially lead to catastrophic failure of aircraft components. Thus, it represents both a durability and a safety problem. Costs associated with fretting fatigue are significant. The 1988 Aloha Airlines disaster focused new attention on fretting in the aircraft industry as it was thought fretting could have played an important role in that failure. Fretting can be present in any area of an aircraft structure (e.g. engines, aircraft primary and secondary structure, and landing gear components) in which small amplitude cyclic slip between adjacent contacting materials is possible [23, 24]. Rivets and mechanically fastened joints in general are particularly susceptible to fretting and fretting fatigue multiple-site damage. This damage can link up in aircraft structures and create catastrophic results. Thus, it is imperative to understand the role of fretting and fretting fatigue in producing multiple-site damage in riveted aircraft joints.

Fatigue wear of a material is caused by a cycling loading during friction. Fatigue occurs if the applied load is higher than the fatigue strength of the material.

Fatigue cracks start at the material surface and spread to the subsurface regions. The cracks may connect to each other resulting in separation and delamination processes of the material pieces from surface Figure 1.10. One of the types of fatigue wear is fretting wear caused by cycling sliding of two surfaces across each other with a small amplitude (oscillating). The friction force produces alternating compression-tension stresses, which result in surface fatigue. Fatigue of overlay of an engine bearing may result in the propagation of the cracks up to the intermediate layer and total removal of the overlay.

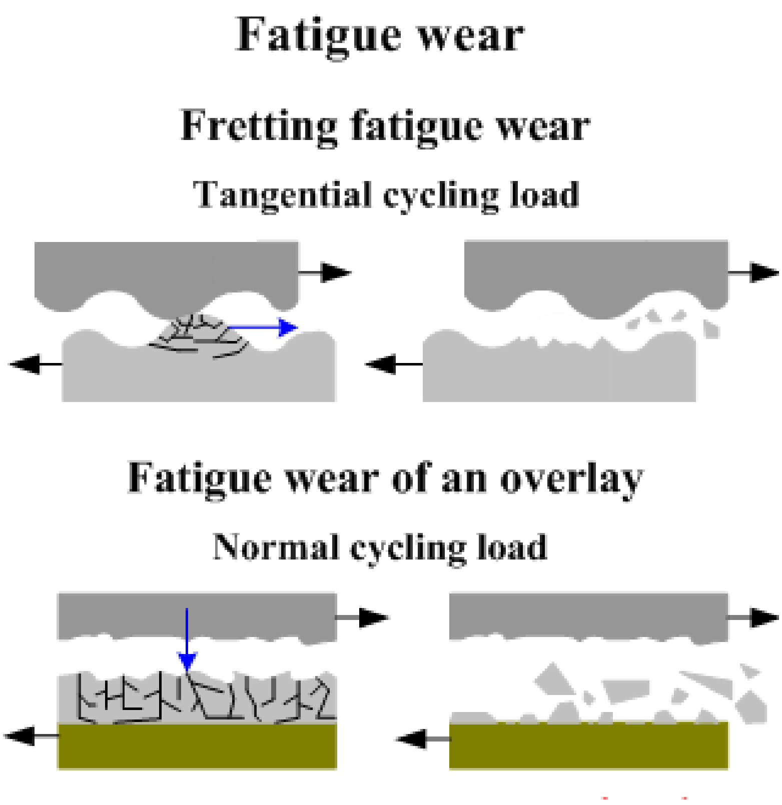


Figure 1.10 – Fretting fatigue wear types

Fretting corrosion is caused by a slight vibration, friction, or slippage between two contacting surfaces that are under stress and heavily loaded. It is usually associated with machined parts. Examples of these parts are the area of contact of bearing surfaces, two mating surfaces, and bolted or riveted assemblies. At least one of the surfaces must be metal. In fretting corrosion, the slipping movement on the contacting surface destroys the protective films that are present on the metallic surface. This action removes fine particles of the basic metal. The particles oxidize and form abrasive materials, which further agitate within a confined area to produce deep pits. Such pits are usually located in an area that increases the fatigue failure potential of the metal. Early signs of fretting corrosion are surface discoloration and the presence of corrosion products in lubrication. Lubrication and securing the parts so that they are rigid are effective measures to prevent this type of corrosion.

1.4 Thermal spray coatings

In the aerospace industry, thermal spray coatings are used in a large number of applications including airframe and propulsion for meeting high performance levels and high quality requirements. These coatings include ceramic, metal, cermet and composite materials.

Coatings range from engine to landing-gear applications. Thermal spray coatings protect engine turbine blades from extreme temperatures, and ensure increased reliability for extended periods of time. In landing-gear applications, these coatings are replacing hard chromium plating as the preferred coating method to provide improved performance. Applications in these and other aerospace applications may include:

- Landing gear (bearings, axles, pins, etc.)
- Jet engines (blades, vanes, combustion liners, compressor casings, nozzles, etc.)
- Actuation systems (pistons, pumps, flaps, etc.)
- Engine cowling, wing structures

In the defense industry, thermal spray coatings are used across the various branches to enhance and protect components on military platforms (aircraft, surface ship, submarine, etc.), and in machinery and weapon systems.

The demand for thermal spray coatings and engineered surfaces looks promising in the aerospace and military/defense industry for decades to come. The goal of surface engineering is to extend the life of parts and thus save time, energy, and money. Perhaps the biggest challenge is solving wear problems. Wear may be minimized by modifying the surface properties of a material or by application of a "surface engineering" process.

Metal and Metal Alloy Thermal Spray Coatings:

- Metal alloys can be used as bond coatings for other thermal spray coatings
- Nickel and Ni alloys such as NiAl are commonly used for dimensional buildup of parts for ease of machining.
- Stainless steel, NiCr, etc. can be used to restore dimensions or to put an improved surface for wear and corrosion.
- Stellite, Triballoy, and other tribological materials can be used for improved performance over an easily fabricated base material.

- Molybdenum (Mo) and other refractory metals can be used for high temperature wear resistance, for sliding wear, and applications requiring lubricity.
- Cobalt (Co), Tantalum (Ta), Chromium (Cr), Tungsten (W) and similar types of materials offer specialized properties.
- Copper (Cu) and Aluminum (Al) based materials are used for corrosion resistance, electrical conductivity, thermal conductivity, and other applications.
- MCrAlY's, such as CoCAlY, NiCrAlY, CoNiCrAlY and NiCoCrAlY, are used for hot oxidation protection and corrosion protection in gas turbine applications and in high temperature wear and corrosion up to 1000°C. They are also excellent bond coat materials.

Chromium carbide based thermal spray coatings are widely used in high temperature wear applications. In these extreme environments, several phenomena will degrade, oxidize, and change the microstructure of the coatings, thereby affecting wear behavior. There is necessity to develop a better understanding of the effect of spray parameters on resulting chromium carbide coating microstructure after high temperature operation and high temperature sliding wear properties.

As it mentioned, beside main types of thermal spray coatings the molybdenum coatings has the best characteristics for sliding friction wear resistance. Thermal sprayed molybdenum has been shown to bond very well to metals, especially steel, and has several desirable material properties.

Several general characteristics of molybdenum are high thermal conductivity, low thermal expansion and excellent wear resistance. When molybdenum is sprayed, oxides are produced inside the coating. These oxides are beneficial for service performance because they have a low friction coefficient and contribute to overall coating hardness. Wear is the removal of material from a solid surface by the action of another material. There are five principal wear mechanisms: abrasive, adhesive, surface fatigue, fretting, and erosion. Wear by abrasion is due to hard particles that are forced against and move along a solid surface and is the most costly and damaging of the wear mechanisms. Adhesive wear occurs when a surface and its complementary component come into contact and move relative to one another. Under the proper conditions the two surfaces may fuse together locally. In extreme cases the surfaces will seize or weld to each other causing considerable surface damage. This phenomenon is referred to as galling. If the load has a cyclic component the parts may fail by contact fatigue. If the load contains a vibratory component then fretting wear may occur. Erosion wear is the loss of material that results from repeated impact of small particles. These mechanisms do not include dimensional losses of parts due to plastic deformation or corrosion which are usually associated with wear damage. The severity of wear damage is dependent on load, temperature and oxidation tendency of the material.

In an effort to improve wear, industry has often employed the use of specialty steels by alloy additions. Typically, the component is placed in an application where the crack resistance of the alloy is poor, which in turn limits the effectiveness. This limitation has led to molybdenum deposition on metal substrates, where higher hardness and low friction coefficient are needed to offset the wear mechanisms. On steel substrates no traditional bond coat material such as NiAl is required; in addition molybdenum has successfully been applied to titanium and aluminum. As a further advance, pure molybdenum has been alloyed with specific elements. For example, carbon additions form carbides within the molybdenum matrix which can improve erosion resistance. Depending on the industry and part configuration, molybdenum has been deposited by several combustion and plasma processes. The prime user of this coating has traditionally been the aerospace industry Figure 1.11, other industries have begun to utilize this coating as well.

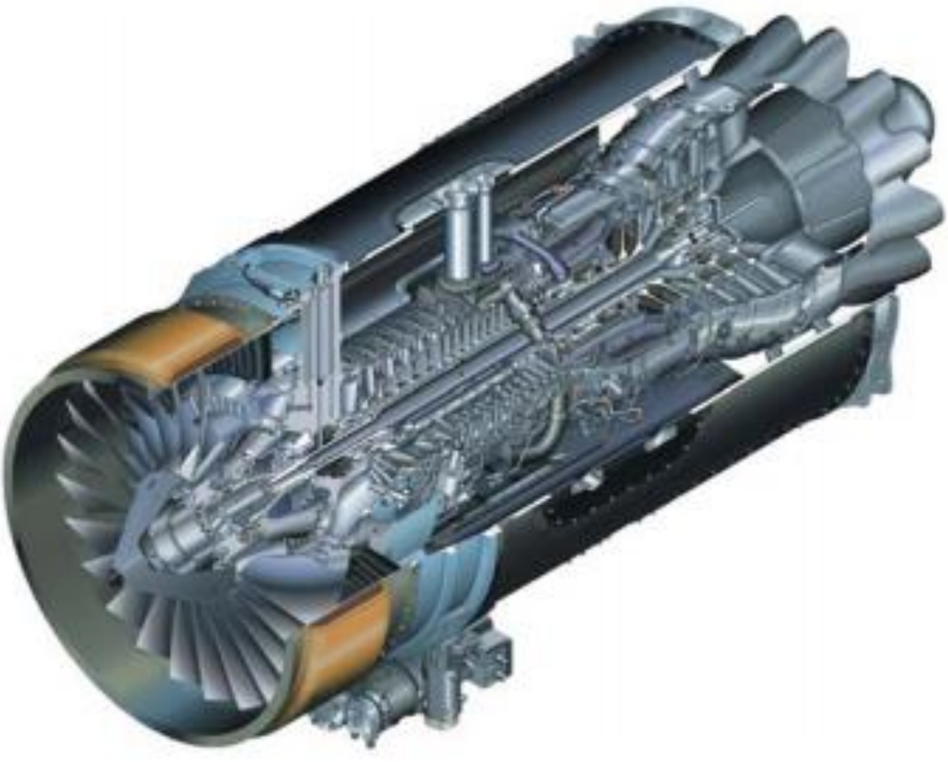


Figure 1.11 - Cutaway view of an AE 3007 engine. Moly coatings are generally used for a range of applications in the "cold" sections of a gas turbine.

Operating limits for pure molybdenum in oxidizing conditions is about 300°C. In reducing environments temperature exposure can be increased. Plasma sprayed molybdenum coatings are used in aerospace, automotive, marine, and numerous heavy industry applications. The coating is sufficiently porous to operate under lubrication and can be impregnated with oil after spraying. Molybdenum based coatings are used on journal and bearing shafts, piston rings, valves, cylinder rods and gears.

Thermal Spray at Boeing

Thermal spray technology at The Boeing Co. dates back to 1968 when the first thermal spray specification, "Plasma Flame Spray Coating," was released. The company continued to develop thermal spray technology by participating in the Hard Chromium Alternative Team activities in the 1990s. As a result, Boeing led the aerospace industry in adapting and implementing the use of thermal spray coatings as an alternative for hard chromium plating on numerous structural components used in the 767-400 main landing gear. Since the first Boeing thermal spray specification was released, over 19 thermal spray vendors have been qualified nationally and internationally to coat parts for the company. Based on Boeing's diverse portfolio of products (commercial aircraft, military aircrafts, and rotorcrafts, space, and satellite vehicles), the use of thermal spray technology has gained significant attention, specifically in past decade.

With a focus on lower operating costs and production, delivery of the game-changing 787-8 and 787-9 demanded a lighter structure using aluminum alloys, titanium alloys, and carbon laminates Figure 1.12. Dramatic changes in structural material and design of next-generation aircraft and rotorcraft requires unconventional coating/substrate system design that meets new demanding requirements. Some of the challenges for coating design are:

- Design and processes for next-generation environmentally friendly, damage-tolerant (wear, corrosion, and fatigue resistant) coatings.
- Design of multifunctional surfaces with high surface quality to combat erosion and abrasion.
- Integration of communication antennas, loading, and damage-sensing functionalities into the structure.

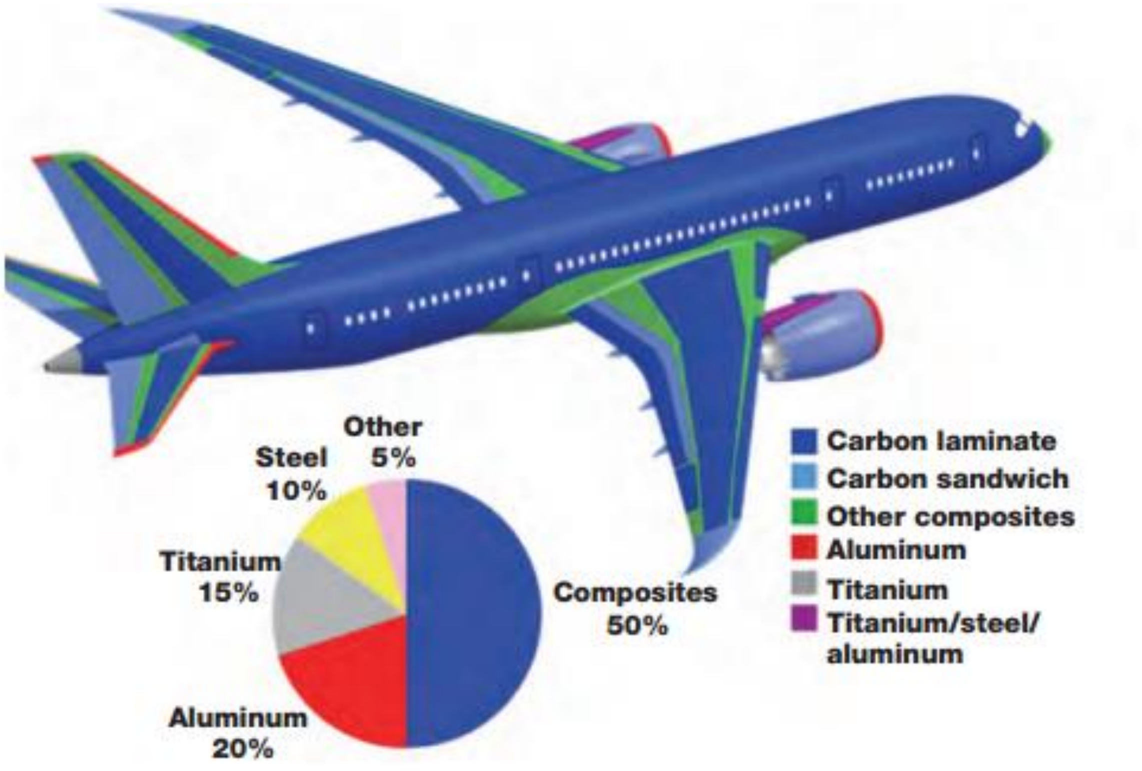


Figure 1.12 - Materials used in Boeing 787 airplane

Boeing Research and Technology's Chemical Technology group is staffed with a balanced mix of high-performing technicians, engineers, and world experts developing novel, high impact technology solutions. Within that group, the thermal spray team is rapidly developing state-of-the-art material and process solutions for novel, differentiated products.

The team has extensive experience in materials engineering and thermal spray process technologies, with educational backgrounds in material science, chemical engineering, and metallurgy. The Boeing Research and Technology thermal spray team strategically collaborates with industry, universities, and research centers nationally and internationally.

Conclusion to part 1

Friction is one of the most widespread factions, connected with the work of the machines and mechanisms. Friction can lead to the wear of the surface. Mainly all mechanisms are subjected to the wear of surfaces. Thus, this is the major factor defining the durability and the longevity of the elements.

One of the most dangerous and widespread types of materials and coatings friction damages is fretting. Fretting wear occurs when repeated loading and unloading causes cyclic stresses which induce surface or subsurface break-up and loss of material.

There are a range of the methods and repair techniques to restore of the worn out surfaces. The most relevant method is using the vacuum-arc coverages. According to the performances they have almost the similar structure with the galvanic ones. The galvanic coverages are widely used in the aviation as the protective covering. Thermal spray coatings have and are used in a very broad range of wear resisting surfaces and for the repair of wear resisting surfaces. The main advantage being that thermal spray coating can provide the surface properties and the component substrate material can be chosen from the bulk requirements be it strength, weight or cost without the need to consider it's inherent wear resistance or other surface properties.

These coatings do provide the best solution to many applications, but they are certainly not universally suited to all applications. Selection of the best coating for an application is not often straight forward and must consider different factors, such as loads and speeds, coasts, abrasives, coefficient of friction and so on. Below, in next chapters, we will determine what kind of coatings have better wear resistance characteristics during reverse and unidirectional friction.

PART 2

METHODOLOGY OF THE EXPERIMENT CONDUCTION

2.1 Testing methodology of the materials and coverages under fretting-corrosion and friction-sliding motion

The important reason that should be taken into account while developing the friction machines is the economy and overall dimensions of the unit. Specimens for the friction must have as small dimensions as possible, but also be sufficient enough for necessary type of friction implemented by the unit.

During the investigations it is necessary to carry out the development of the procedures in correspondence with two requirements. Fistly, imitation of sliding friction under the laboratory conditions must approach the conditions in the real structures. Secondly, the procedure must give the possibility to carry out the comparison with received data of other works.

The main task is the development of materials and coverings test procedure in the conditions of butt sliding friction at low speeds sliding.

It is necessary to take into account that the wear from the sliding friction and fretting are different types of surface wear and it is necessary to make a comparison based on certain criteria. As comparative criteria the way of friction and mean speed of sliding of specimen were chosen.

On the base of the unit for materials testing for fretting МФК-1 the unit for material testing for sliding friction was developed. The unit allows to carry out the comparative tests of steels, alloys, coverings, composit materials at low speeds of sliding in different liquid and gas environments at different temperatures.

The feature of the unit is the replacement of reciprocating motion of collet of МФК-1 unit in which a tested specimen is fastened on the directed rotation with the set speed.

The unit fretting tests is designed by the scheme contact of plane- plane in accordance with ГОСТ 23.211-80. Essence of the procedure is that a cylindrical movable specimen (tested specimen) which comes into contact with a butt end with an immobile cylindrical specimen at the set pressure is set in reciprocating motion with set amplitude and frequency.

The appearance of the unit for materials testing for the sliding friction is represented on a Figure 2.1. The unit works in the following way (Figure 2.2): electric motor *2* transmits the rotation motion to the reduction gear box *3*. Frequency of rotation and amount of revolutions is registered by the instrument *1*. Reduction gear box *3* by means of crank *4* transmits the motion to the tested specimen *5*.The immovable specimen *6* fastened in a self-centering collet *8*, set on the movable stock shaft *9*. The loading of the specimen is carried out by a loading device *12*, *13*. The value of axle loading on specimens is registered by the dynamometer of ZIP 02-79 type - DOSM-3-0,2 (ГОСТ 2283-79) with the limits of measuring from 0,2 to 2 kN. Registration of the friction force is made by an instrument NO71.5M *11* through the amplifier 8-ANCH-7M 10 with the help of strain beam *9*.

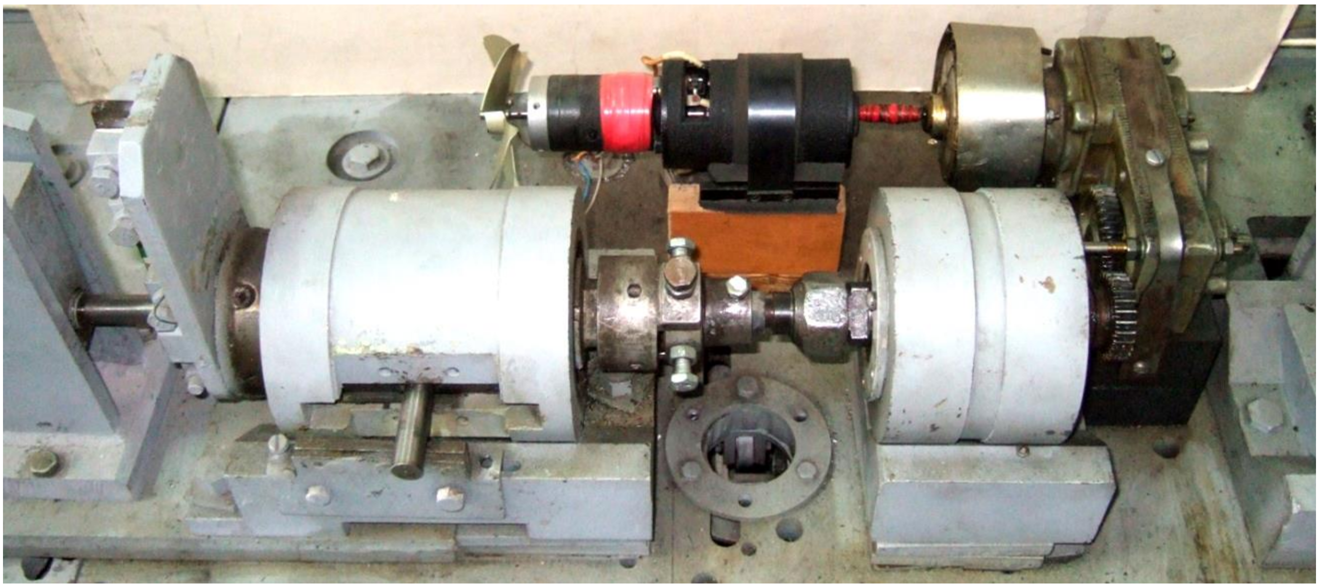
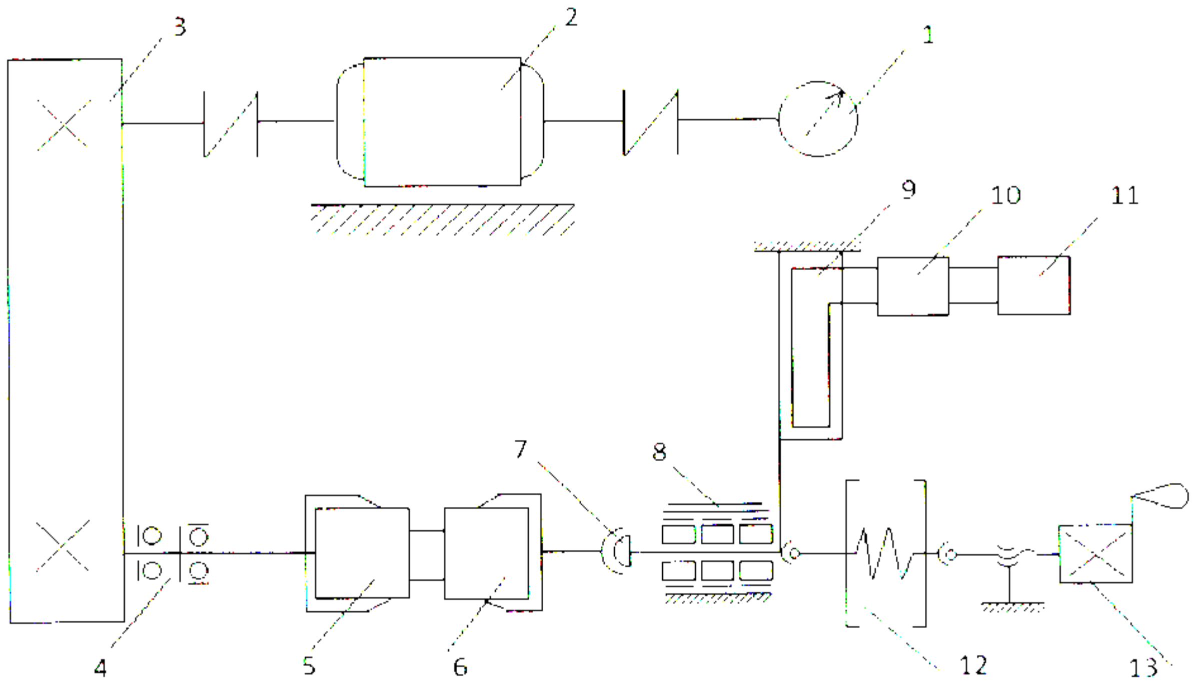


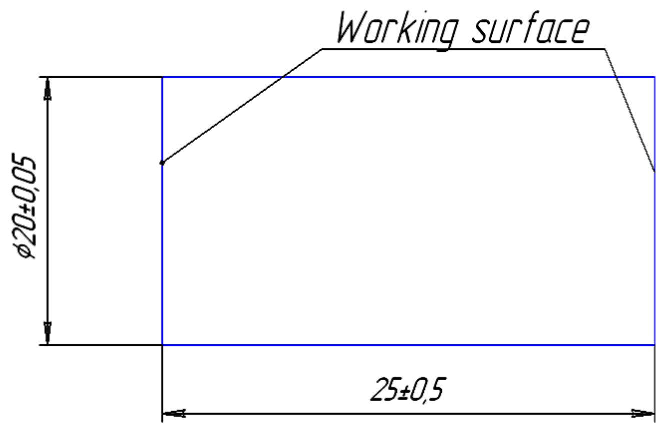
Figure 2.1 - The appearance of the unit for materials and coverings testing at the low speeds of sliding

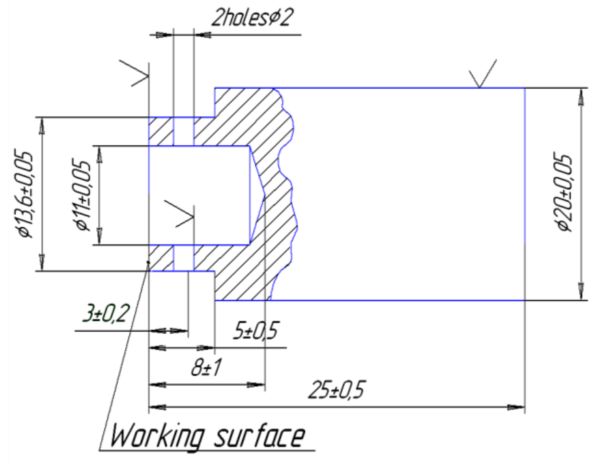


1 – revolution counter; *2* – electro motor; *3* – reduction gear box; *4* – crank;
5 – movable specimen; *6* – unmovable specimen; *7* – self-centering collet;
8 – movable stock; *9* – strain beam; *10* – amplifier; *11* – registration equipment;
12 – dynamometer; *13* – loading device.

Figure 2.2 - Scheme of the unit for material testing at low speeds of sliding

Large advantage of the developed unit is a complete accordance of specimens for tests on unit МФК-1 with a unit for materials testing at friction sliding. It gives a certain economic effect and adequacy of comparison of wear results from fretting with the results of wear from the sliding friction. Specimens for tests are represented on a fig. 2.3 and they are cylindrical rollers with the diameter of 20 mm manufactured from a necessary alloy or steel. The conjugation of the tested specimens is carried out on a surface, being the closed ring with the nominal contact area of 0,5 sm^2, internal diameter of 11 mm and external diameter of 13,6 mm.



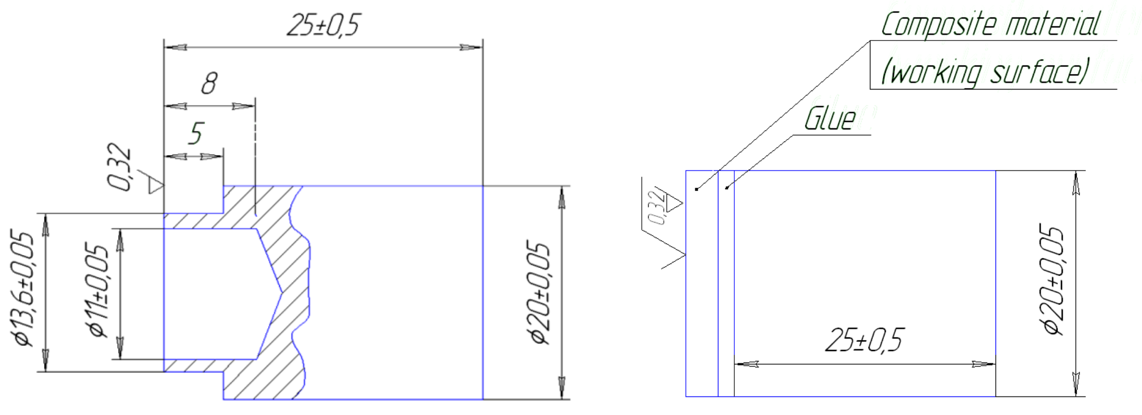


a *b*

a – specimen, *b* – tested specimen.

Figure 2.3 - The scheme of the specimens for materials and coverings testing in liquids and gas environments

The presented specimens enable to carry out the experiments at different liquids and gas environments. The present openings on the tested specimen are intended for more fast access of working environment to the internal cavity of friction specimens. During the materials and coverings testing in air without liquid and aggressive gas environments it is possible to produce specimens without openings. During the tests of composite materials it is necessary to paste the cut out by necessary form fragments of composition materials to the butt ends of specimen Figure 2.4. During the tests of the wearproof sheetings it is necessary on the workings surfaces of specimens and if necessary tested specimens to apply the layer of wearproof coverage.



a *b*

a – tested specimen, *b* – specimen

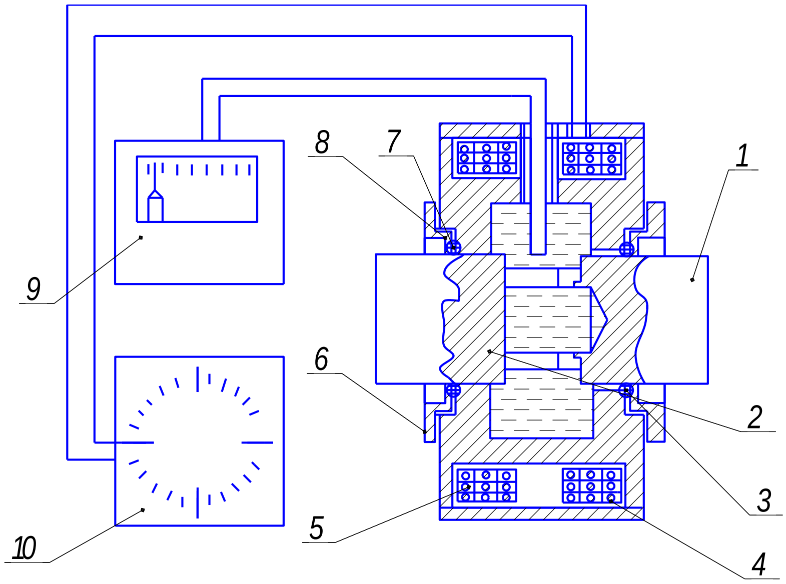
Figure 2.4 - The scheme of the specimens for composite materials testing

For the tests of materials in different liquids and gas environments the special chambers are developed Figure 2.5, Figure 2.6.

For the materials testing in liquid environments the special heating chamber is used, that provides the possibility of supply and withholding liquid environments in the contact area of the specimens, The scheme of the chamber for metals and coverings tests in liquid environments is represented on a figure 2.5. The specimens for tests *1*, *2* fastened in the unit collets, set in the round openings of chamber *4*, provided with the sealing *7*, manufactured from heat-resistant rubber. The leakage of working environment from a chamber is prevented with a help of sealing regulators *6*.

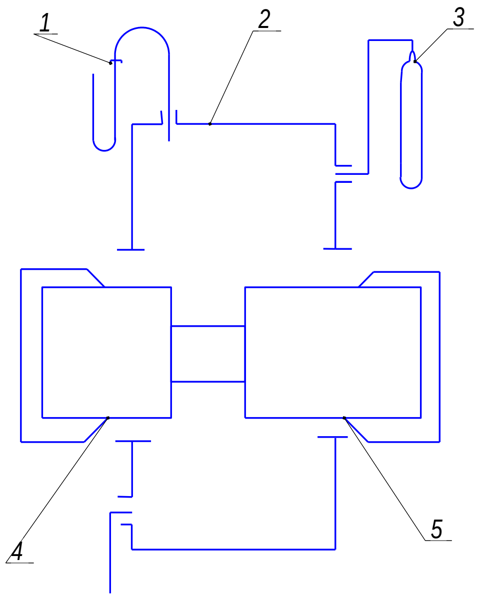
The control of the temperature of working environment is provided by a thermocouple and pointer of temperature *9* with accuracy ±2 °C, working range of temperatures of chamber 0…200 °C. The set temperature of tests is achieved with the help of a heating element *5* and temperature regulator *10*.

A chamber allows to carry out the experiments in oils and plastic greasings at the temperature from 0 to 200 degrees. Heating is carried out by the increase of tension on latra *10* and heating of nichrome coil *5*. The control of temperature of the liquid environment is carried out through the temperature sensor *8* and milliammeter *9*. The impermeability of the chamber internal cavity is carried out with the help of two rubber temperature and oil resistant sealings *8*.



1, 2 – tested specimens, *3* – lubricating materials, *4* – frame of the chamber, *5* – heating element, *6* – sealing regulator, *7* – sealing, *8* – thermocouple, *9* – pointer of temperature of liquid environment, *10* – temperature regulator

Figure 2.5 - The chamber for the materials and coverings testing in different liquid environments and temperatures



1 – manometer, *2* – chamber, *3* – vessel with gas, *4, 5* – tested specimens

Figure 2.6 - The chamber for the materials and coverings testing in different gas environments

The scheme of materials testing in different gas environments is presented on a Figure 2.6. A chamber is put on the specimen *2*, through which the gas is skipped. The surplus pressure of gas in a chamber is controlled by an aquatic manometer *1*. During carrying out of the experiments a gas chamber must be cleaned from air by blowing off by the tested gas, equal to 15-20 volumes of chamber, that provides its complete cleaning. The chamber allows to carry out the experiments in the environment of nitrogen at negative temperatures to -50 degrees.

2.2 Metallography and fractography

Metallography is the study of the physical structure and components of metals, typically using microscopy.

Ceramic and polymeric materials may also be prepared using metallographic techniques, hence the terms ceramography, plastography and, collectively, materialography.

The surface of a metallographic specimen is prepared by various methods of grinding, polishing, and etching. After preparation, it is often analyzed using optical or electron microscopy. Using only metallographic techniques, a skilled technician can identify alloys and predict material properties [25].

Mechanical preparation is the most common preparation method. Successively finer abrasive particles are used to remove material from the sample surface until the desired surface quality is achieved. Many different machines are available for doing this grinding and polishing, which are able to meet different demands for quality, capacity, and reproducibility.

A systematic preparation method is the easiest way to achieve the true structure. Sample preparation must therefore pursue rules which are suitable for most materials. Different materials with similar properties (hardness and ductility) will respond alike and thus require the same consumables during preparation.

Metallographic specimens are typically "mounted" using a hot compression thermosetting resin. In the past, phenolic thermosetting resins have been used, but modern epoxy is becoming more popular because reduced shrinkage during curing results in a better mount with superior edge retention. A typical mounting cycle will compress the specimen and mounting media to 4,000 psi (28 MPa) and heat to a temperature of 350 °F (177 °C). When specimens are very sensitive to temperature, "cold mounts" may be made with a two-part epoxy resin [26]. Mounting a specimen provides a safe, standardized, and ergonomic way by which to hold a sample during the grinding and polishing operations.

After mounting, the specimen is wet ground to reveal the surface of the metal. The specimen is successively ground with finer and finer abrasive media. Silicon carbide abrasive paper was the first method of grinding and is still used today. Many metallographers, however, prefer to use a diamond grit suspension which is dosed onto a reusable fabric pad throughout the polishing process. Diamond grit in suspension might start at 9 micrometres and finish at one micrometre. Generally, polishing with diamond suspension gives finer results than using silicon carbide papers (SiC papers), especially with revealing porosity, which silicon carbide paper sometimes “smear” over. After grinding the specimen, polishing is performed. Typically, a specimen is polished with a slurry of alumina, silica, or diamond on a napless cloth to produce a scratch-free mirror finish, free from smear, drag, or pull-outs and with minimal deformation remaining from the preparation process.

After polishing, certain microstructural constituents can be seen with the microscope, e.g., inclusions and nitrides. If the crystal structure is non-cubic (e.g., a metal with a hexagonal-closed packed crystal structure, such as Ti or Zr) the microstructure can be revealed without etching using crossed polarized light (light microscopy). Otherwise, the microstructural constituents of the specimen are revealed by using a suitable chemical or electrolytic etchant.

Fractography is the study of fracture surfaces of materials. Fractographic methods are routinely used to determine the cause of failure in engineering structures, especially in product failure and the practice of forensic engineering orfailure analysis. In material science research, fractography is used to develop and evaluate theoretical models of crack growth behavior.

One of the aims of fractographic examination is to determine the cause of failure by studying the characteristics of a fracture surface. Different types of crack growth (e.g. fatigue, stress corrosion cracking, hydrogen embrittlement) produce characteristic features on the surface, which can be used to help identify the failure mode. The overall pattern of cracking can be more important than a single crack, however, especially in the case of brittle materials likeceramics and glasses.

An important aim of fractography is to establish and examine the origin of cracking, as examination at the origin may reveal the cause of crack initiation. Initial fractographic examination is commonly carried out on a macro scale utilising low power optical microscopy and oblique lighting techniques to identify the extent of cracking, possible modes and likely origins. Optical microscopy or macrophotography are often enough to pinpoint the nature of the failure and the causes of crack initiation and growth if the loading pattern is known.

Common features that may cause crack initiation are inclusions, voids or empty holes in the material, contamination, and stress concentrations. “Hachures” are the lines on fracture surfaces which show crack direction. The broken crankshaft shown at right failed from a surface defect near the bulb at lower centre, the single brittle crack growing up into the bulk material by small steps, a problem known as fatigue. The crankshaft also shows hachures which point back to the origin of the fracture. Some modes of crack growth can leave characteristic marks on the surface that identify the mode of crack growth and origin on a macro scale e.g. beachmarks or striations on fatigue cracks. The areas of the product can also be very revealing, especially if there are traces of sub-critical cracks, or cracks which have not grown to completion. They can indicate that the material was faulty when loaded, or alternatively, that the sample was overloaded at the time of failure.

Fractography is a widely used technique in forensic engineering, forensic materials engineering and fracture mechanics to understand the causes of failures and also to verify theoretical failure predictions with real life failures. It is of use in forensic science for analysing broken products which have been used as weapons, such as broken bottles for example. Thus a defendant might claim that a bottle was faulty and broke accidentally when it impacted a victim of an assault. Fractography could show the allegation to be false, and that considerable force was needed to smash the bottle before using the broken end as a weapon to deliberately attack the victim. Bullet holes in glass windscreens or windows can also indicate the direction of impact and the energy of the projectile. In these cases, the overall pattern of cracking is vital to reconstructing the sequence of events, rather than the specific characteristics of a single crack. Fractography can determine whether a cause of train derailment was a faulty rail, or if a wing of a plane had fatigue cracks before a crash.

Fractography is used also in materials research, since fracture properties can correlate with other properties and with structure of materials.

2.3 Methods of wear determination between sliding surfaces

The most common and affordable method for determining the amount of wear is the method of micrometer measurements. This method is most commonly used during the condition of large absolute values of wear. It is based on the measurement of parts with a help of mechanical, contact or any other devices before and after the test for wear.

Measurement accuracy depends on what kind micrometric tool is used. Usually, it is 0.01 mm [27]. Application is very accurate, it gives an opportunity to make measurements with an accuracy of 1 micron, provides a measure of the amount of wear with an accuracy of less than 5 microns.

This is explained by the fact that measurements are made at different times and under different temperature conditions, etc.

Micrometric method has some errors, reasons of them are the following:

- if both sides between which measurements are performed (e.g., shaft or hole of the cylinder) are worn, with a help of micrometry changes in diameter are determined, however the amount of linear wear of the initial surface cannot be established. This disadvantage is partially eliminated by the use of special indicator devices allowing usage of measurement of the distance from the wall of the elements to a constant non-wearing base;

- if simultaneously with wear can occur deformation of the detail, than by micrometric method simultaneous change in dimensions from this two reasons is defined;

- repeated measurements cannot be made exactly by the same direction.

Gravimetric method is commonly used to determine the wear of small parts. They are weighed before and after testing [28]. Before weighing, parts must be thoroughly washed, dried, and after testing samples must be washed out from the wear products, lubricants, etc. Weighing allows determine with great accuracy the wear of very small samples. In analytical balance ВЛА-200 with a full load 200 g permissible error ± 0,2 mg.

Determination of the linear wear weight loss is accomplished by calculations based on the assumption that the wear occurs evenly over the friction surface. In this case, the wear is converted into a linear formula:

$$Ih = \frac{Q}{S \cdot j \cdot L \cdot 10^{-8}} \tag{2.1}$$

where: Q- the wear, mg;

S- area of the friction surface, cm^2;

j- specific weight, g/cm^3;

L- friction path, km.

It is not recommended to determine amount of wear by gravimetric method when changes in item's sizes occurred not only because of the separation of particles, but also due to plastic deformation. Gravimetric method is unacceptable in determining the amount of wear of porous materials washed with oil.

Measurement of the amount of wear by the method of artificial bases is to determine by calculating the distance from the friction surface to the bottom of the deepening, which is artificially made on this surface. The deepening does not violate the service properties of details and its depth is greater than the expected value of the linear wear. After we determine the distance from the surface to the bottom of the deepening (which serves as an artificial base) before and after testing, we can define wear with a help of difference in the depth of wear [28]. The main advantage of the artificial bases is that in this case wear is determined by the local surface wear of the detail. The second is that it doesn't have such errors as micrometric methods got. Here it is possible to have the high accuracy of wear determination. Also determination of the distribution of wear on the whole friction surface is possible.

Methods of artificial bases, depending on the kind of deepening application are divided into the method of prints, method of drilled deepening; method of cut holes.

The method of prints consists in the following. On the test surface by any indenter we did an imprint of a known form. Indenter material is preferably a diamond, but it can be hard alloy and even hardened steel.

Measuring of specimens wear can be carried out with the help of profilograph-profilometer by the removal of profilogram of 8 equidistant areas of specimen working surface in radial direction Figure 2.7.

During researches the specimen wear h_i was calculated by the formula:

$$\boldsymbol{h_i = \frac{\sum_{1}^{8} h_i}{8}} \tag{2.2}$$

where: $\boldsymbol{h_i}$ is the distance of friction path on the profilogram between the middle lines of profile of initial and working surface concordantly to ГОСТ 2789-73.

Important advantage of wear determination by the linear method is that the size of wear does not depend on a specific weight of material and possible changes of mass of specimens.

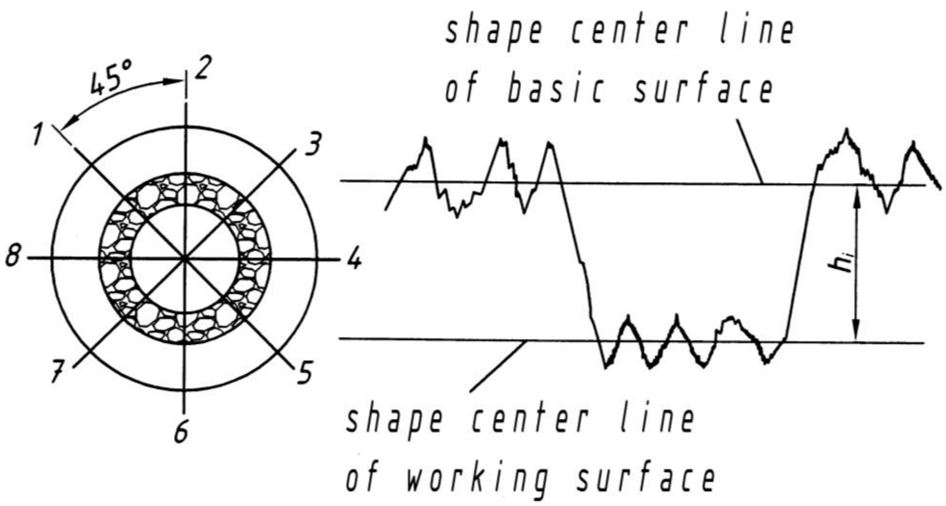


Figure 2.7 - Scheme of specimens wear determination.

Conclusion to part 2

The unique unit based on МФК-1 for materials wear resistance testing at the friction of sliding is developed. The unit enables to carry out the comparative tests of friction of sliding and fretting of steels, alloys, coverings and composite materials in different liquid and gas environment. Using the standard specimens for fretting - ГОСТ 23.211-80 the unit allows to provide tests in the range of loading from 1 to 40 MPa and in the wide range of sliding speeds.

With the help of the unit it comes possible to carry out the comparative tests between fretting and sliding friction at the use of identical ways of friction, speed of sliding and specific pressure and also testing of materials for sliding friction at low speeds of sliding in different liquid and gas environments.

PART 3.

TESTING ON WEARABILITY OF COVERAGES IN SLIDING FRICTION CONDITIONS

3.1 Analysis of the obtained results

The experiment was performed on the unit based on the МФК-1.

The specimens are the cylindrical rollers with the diameter of 20 mm on which by means of plasma method the coverings ВКНА, Mo, ПС and ПГ were applied. The thickness of coverings equaled to 400mcm. Except of this, comparisons were made on the titanium alloy ВТ-22, which was thermo-treated by the adopted in aviation regime of three-stages processing. This processing is stabilizing dropped and soft hardening on the air with the following aging. The specimens were made from the alloy 95Х18Ш.

The specimens with the plasma coverings and titanium alloys were used during the tests. The choice of materials is explained by the following: these materials are widely used in the aviation techniques.

As the comparative criterions during the experiment were taken into account the following: 1) way of friction and 2) sliding speed.

Investigations at the cyclical friction sliding were made under the loading of 20 MPa and amplitude of 50mcm. Oscillation frequency remained constant and was 30Hz. Tests bases was $5\cdot10^5$ cycles.

Under one-directed friction sliding as the confirmative criterions between researches at the cyclical and one-sided friction sliding were taken average speed of sliding, which was 3mm/s, and way of friction – 50m. The tests were made in such way, that work during al experiments was constant. Investigations of the change of linearity and intensity of wear of colored alloys were conducted on the air during the friction and without oil material.

The linear wear of the immovable specimen was determined with the help of the vertical type optimeter ИКВ by the given number of cycles, the values of which determine the wear resistance of investigation material. The amount of experiments were three per each point.

The results of the researches

The results of the researches are shown on the Figure 3.1 [29] and Figure 3.2.

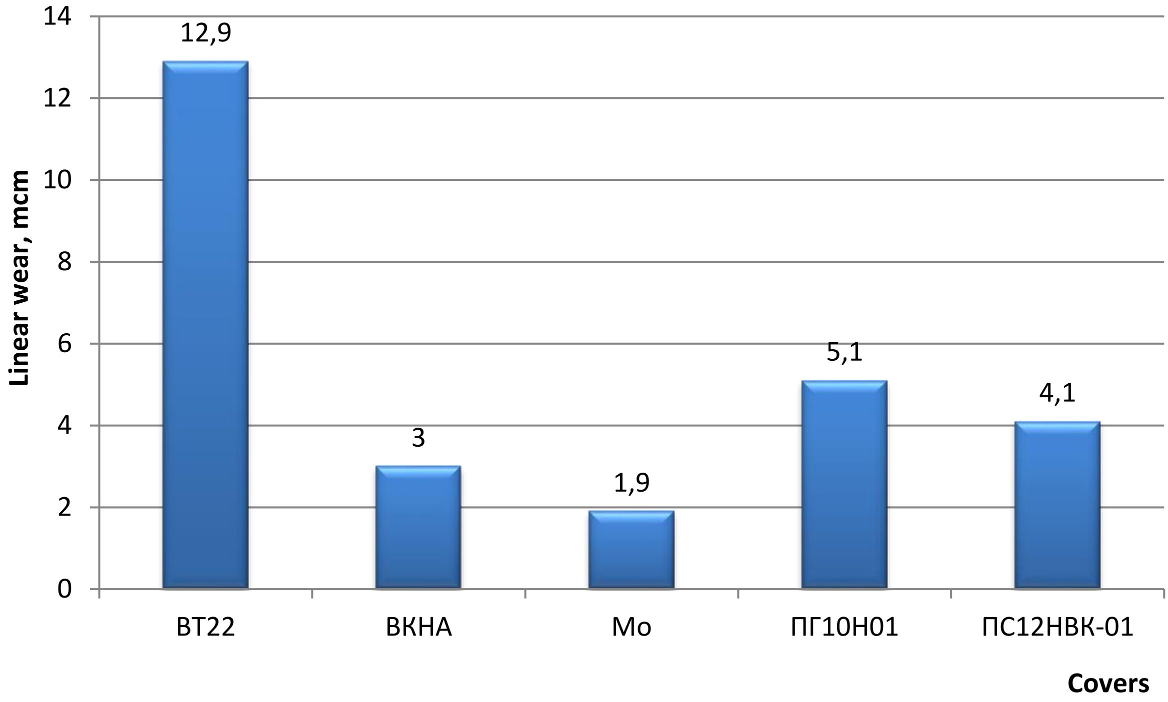


Figure 3.1 - Histograms of the changes of linear wear of plasma coverings and titanium alloy BT-22 at the reversal friction (fretting-corrosion)

Making the analyses of histograms of wear resistance of materials, we can talk about that fact that wear of materials at the one-sided friction is in ten times greater then at the reversal friction. That's why, it's very interesting fact that at the one-sided friction sliding wear resistance of titanium alloy BT-22 can be compared with the wear resistance of plasma covering ПГ10Н01 та ПС12НВК-01. I.e., at the realization of the similar condition of work in techniques, the titanium alloy does not require any coverings at all. Wear of titanium alloy and coverings ПГ10Н01, ПС12НВК-01 is practically the same.

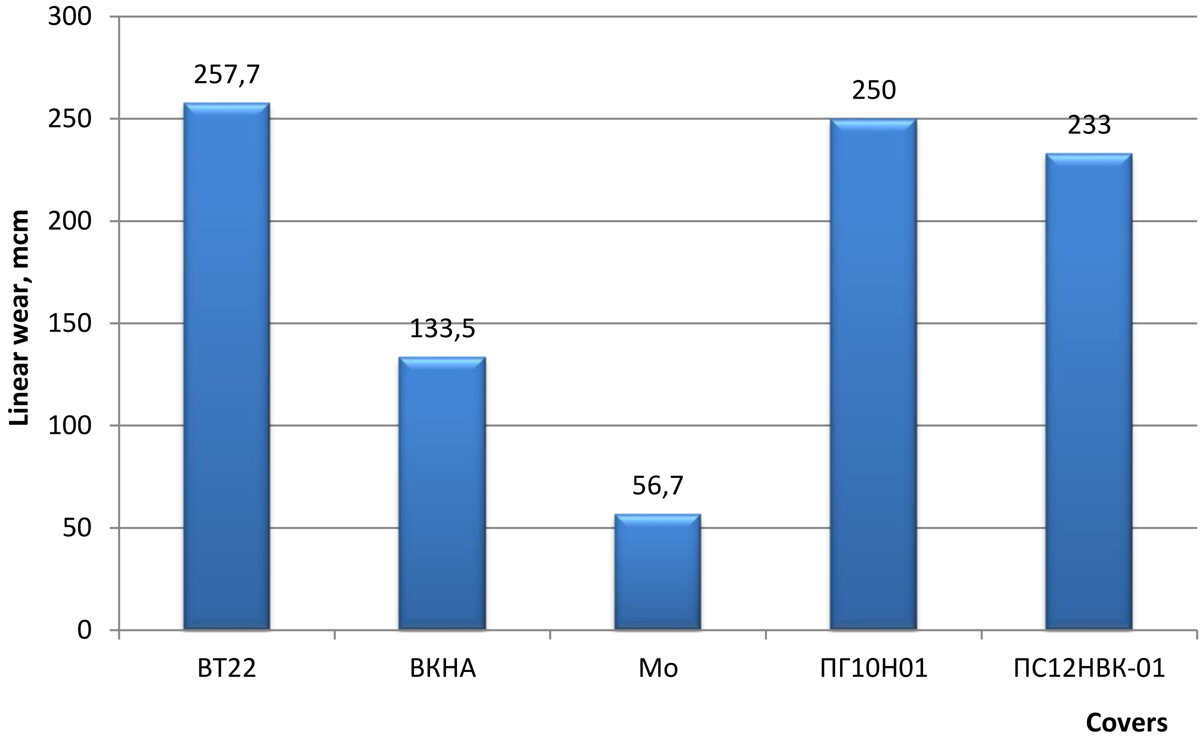


Figure 3.2 - Histograms of the changes of linear wear of plasma coverings and titanium alloy BT-22 at the one-directed friction

The high wear of coverings ПГ10Н01 and ПС12НВК-01 is explained by their chemical composition and structure. Covering of the self-fluxing powder ПГ10Н01 is the alloy from parts of chromium, silicon and iron in the nickel matrix. Covering ПС12НВК-01 consists of three main phases, the main elements which determine the distribution of this phase are nickel 76 % and chromium 18%, the rest is tungsten. At the one-sided friction sliding the solid parts of chromium and tungsten, which are inside the covering, crimp and intensively destroy the surface, like the abrasive material. Micro hardness of chromium parts and tungsten in the coverings is $H_{м50}$ = 13,7 GPa. [30]. This is confirmed by the topographies of coverings' surfaces of friction which are illustrated on the pic.3.

Wear resistance of the titanium alloy BT-22 at the one-sided friction is approximately in 20 times less, than at the reversal friction sliding. During one-sided friction the gradual smearing of the titanium alloy on the material of contra-specimen 95X18 is appeared. Subsequently, the transferred titanium on the contra-specimen becomes harder and its micro hardness becomes higher in comparison with initial material. I.e., at one-sided friction appears the constant transfer of the titanium alloy BT-22 on the contra-specimen 95X18, it's explained by the high ability of the titanium alloy to anointing. On the pic.3k is shown the surface of the contra-specimen with the anointing hardened titanium alloy BT-22.

At the reversal friction of the titanium alloy BT-22 with the 95X18 appears the intensive oxidation of the surface of both materials and formation of corrosion products. In this case wear intensity of the titanium alloy is usually proportional to the pressure, the friction coefficient obtains the values, which are closer to its values in case of friction titanium on titanium. The friction has the character of gripping. Rupture, of the improved by deformation and gassy bridges of welding, appears in the depth of surface of titanium specimens. As the result the surface of the steel contra-specimen becomes covered with the parts of adhering titanium alloy and the oxidation with the formation of TiO_2 takes place. This oxides at the reversal friction sliding work as the hard oil material, which create the space between two surfaces of friction. At the one-sided friction sliding the oxides which appears during the experiment pour from the friction zone, and it leads to creation of the new sites of settings.

The least wear between tested coverings at one-sided and reversal friction sliding has the molybdenum covering (see Figures 1, 2). The high wear resistance of plasma molybdenum covering is explained be the specific of this covering. During the spraying inside the covering the hard small parts of nitro-oxides of molybdenum are appeared, their micro hardness is 13 GPa. I.e., in the covering the "Sharpie's rule" is realized. There exist the soft matrix for damping impacts during friction and the hard blotches for high wear resistance.

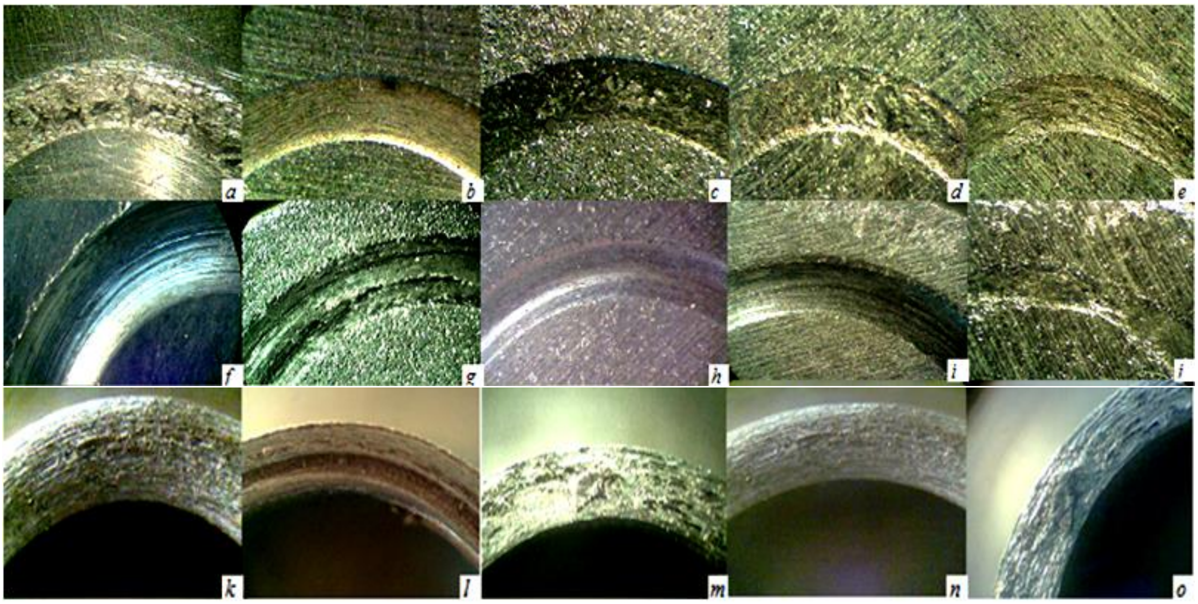
The covering BKHA takes the mid position by the wear resistance between molybdenum coverings and ПГ10Н01.

It's interesting to mark, that during the comparison of wear resistance histograms of tested materials we see the full compliance between them. So the wear resistance histograms of materials save their consequence as at the cyclical friction and one-sided. It may indicate the high probability of the results of experiment, and the designed installation can be used for determination the most wear resistance materials among the existing.

The high wear at the one-sided friction sliding can be explained by the fact that at the cyclical friction sliding appears the intensive oxidation of the surface and the created oxides work like a hard lubricant between two surfaces. At one-directed friction sliding oxides, which appear as the result of friction, precipitate and the new surfaces of friction make contact.

3.2 Topography of the friction surface of the coatings

During making the analyses of examples of the friction surface topography (Figure 3.3 f-i) we can say that all friction ways are smooth, without plucks and visible uncles, which appear as the result of testing on fritting-corrosion. The friction ways of all tested materials have the cup form as the result of crumbling of the surfaces. More hard parts of the surfaces at the one-sided friction sliding, which are between friction surfaces, perform the function of abrasive parts, that is one of the reason of so high wear of materials atone-sided friction sliding.



a, f - ВТ-22; *b, g* – ВКНА; *c, h* – Mo; *d, i* – ПГ10Н01, *e, j* – ПС12НВК01*; k* – 95Х18 with ВТ-22, *l* –95Х18 with ВКНА; *m* – 95Х18 with Mo; *n* – 95Х18 with ПГ10НВК01; *o* – 95Х18 with ПС12НВК01.

Figure 3.3 - Friction topography of specimens at fretting (*a,b,c,d,e*), friction sliding (*f, g, h, i, j*) and friction sliding contespecimens (*k,l,m,n,o*)

3.3 Comparative analysis of wear resistance of coatings applied by different methods

In Figure 3.4 you can see a comparative analysis of the wear resistance of the Molybdenum coating applied in different ways.

The graph shows that the most wear-resistant coatings are applied by methods in a high concentration of temperature (detonation, plasma, laser). This is explained by the fact that the porosity of the coating when applied by these methods is relatively small and, accordingly, the wear resistance of the coatings increases when tested without lubricant. However, when testing coatings with lubricants, the porosity of the coating will very well reduce wear due to the accumulation of lubricant in the pores.

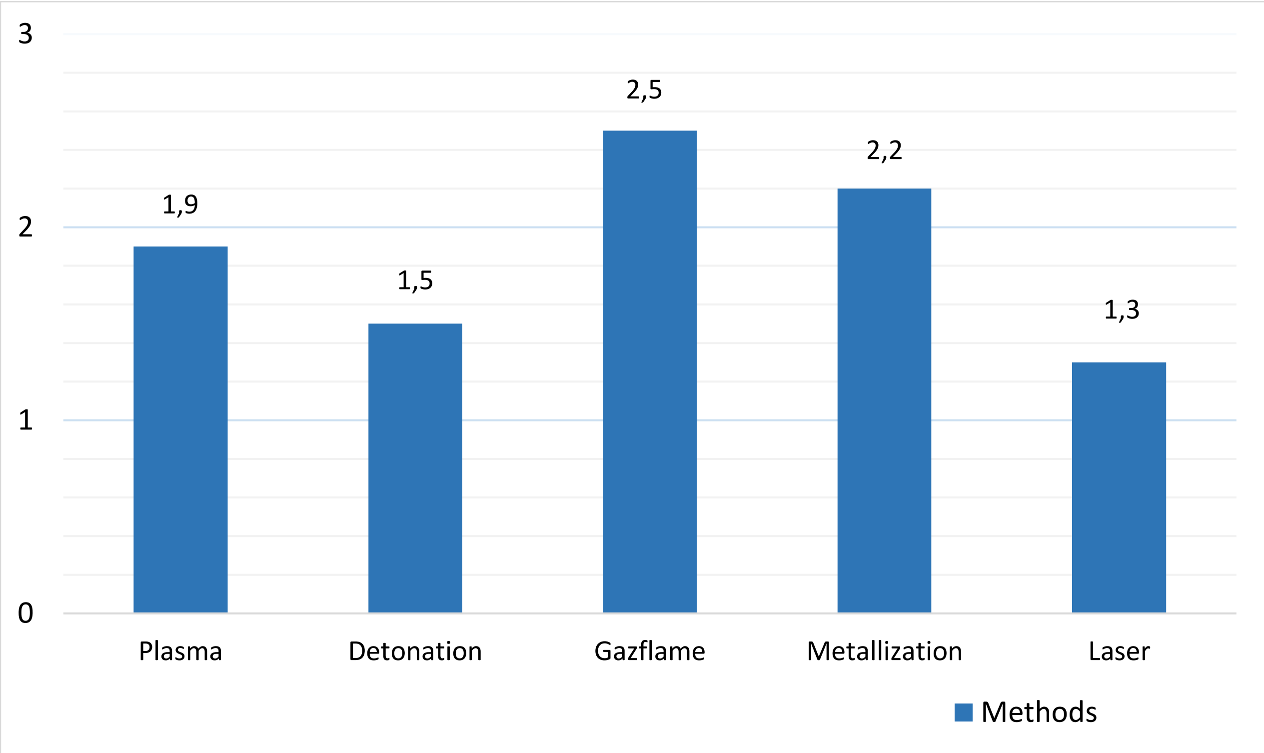


Figure 3.4 - Linear wear resistance of Mo coating applied by various methods of restoring

The laser recovery method showed the highest wear resistance. Due to the high temperature, this method welds molybdenum into the surface of the base and adheres as a whole.

Conclusion to part 3

On the base of the provided investigations the following conclusions can be made:

1. The comparative investigations of the materials at one-sided and alternating friction sliding were made.

2. It was determined that wear of materials at one-directed friction sliding is in ten times greater than at the cyclical friction sliding in the conditions of fretting-corrosion. It's explained by the formation of the oxides which work like a hard lubricant.

3.The most stable and wear resistant is the plasma coating of molybdenum.

4. It's determined that the consequence of the wear resistance of histograms at the one-sided and cyclical friction sliding (in condition of fretting-corrosion) is similar.

PART 4

LABOR PRECAUTION

4.1 Legislative and normative acts of Ukraine on labour precaution

Ukrainian legislation on labour protection is based on the constitutional right of all citizens of Ukraine for the proper, safe and healthy working conditions. In Article 43 of the Constitution of Ukraine mentioned that everyone has the right to work, which includes the opportunity to earn for living by work, which he chooses freely or freely agrees. Everyone has the right to proper, safe and healthy working conditions, wages, not less than stipulated by law. Citizens are guaranteed the protection from unlawful dismissal. The right to timely payment for work is protected by law.

Article 45 of the Constitution of Ukraine states that everyone who works has the right to rest. This right is ensured by providing weekly rest days and paid annual vacation, by establishing a shorter working day for certain professions and industries, and reduced working hours at night.

Article 46 of the Constitution of Ukraine states that citizens have the right to social protection which includes the right for provision in case of complete, partial or temporary disability, widowhood, unemployment due to circumstances beyond their control, in old age and in other cases provided by law.

The fundamental document in the field of labour precaution is the Law of Ukraine "On Labour Protection", which defines the basic position about the constitutional right of workers to protection of their life and health in the workplace, in the proper, safe and healthy working conditions, regulates with participation of corresponding state authority relations between employer and employee on security issues, occupational health and the working environment and establishes a uniform procedure for the organization of labour protection in Ukraine.

Law of Ukraine “On Labour Protection” identifies the position on the constitutional right of citizens to protection of life and health in the workplace, regulates the participation of relevant government bodies relationship between the owner of enterprises, institutions and organizations or authorized body (hereinafter - the owner) and employee safety, occupational health and the working environment and establishes a uniform procedure for the organization of labor in Ukraine.

There are a few normative legal acts concerning our specialty which it is necessary to mention: ДСН 3.3.6.037-099 Санітарні норми виробничого шуму, ультразвука та інфразвуку [30]; НАОП 5.1.30-4.09-86 Типовое положение о порядке допуска к работам повышенной опасности [31]; СП 5059-89 Санитарные правила для авиационно-технических баз эксплуатационных предприятий гражданской авиации [32].

4.2 Analysis of harmful and dangerous factors for subject of labour precaution

Let's consider that the subject is the technician and the object is the worktable in the factory. The choice and the implementation of specific measures for preventing workplace injury and ill health in the workforce of the iron and steel industry depend on the recognition of the principal hazards, and the anticipated injuries and diseases, ill health and incidents. The Dangerous and harmful production factors are laid out into State standard [33]. By the nature of origin, they are divided into the following groups: physical, chemical, psychophysiological, biological.

Below are the most common causes of physical injury and illness in the iron and steel industry[33]:

- noise and vibration;
- falls from height;
- contact with hot metal;
- fire and explosion;
- extreme temperatures;
- manual handling and repetitive work;

Psychophysiological hazards include the following:

- nervous - emotional overload;
- mental overload;
- overload of visual analyzer.

The ДСН 3.3.6.037-99 is the Ukrainian Public health standard which regulates noise effect. Exposure to noise levels exceeding those set by the competent authorities may result in noise-induced hearing loss. Exposure to high noise levels may also interfere with communication and may result in nervous fatigue with an increased risk of occupational injury.

Based on the assessment of the exposure to noise in the working environment, the technician should establish a noise-prevention programme with the aim of eliminating the hazard or risk, or reducing it to the lowest practicable level by all appropriate means.

Employers should ensure that technicians who may be exposed to significant levels of noise are trained in:

- the effective use of hearing-protection devices;
- identifying and reporting on new or unusual sources of noise that they become aware of; and
- the role of audiometric examination.

In the case of existing processes and equipment, technicians should first consider whether the noisy process is necessary at all, or whether it could be carried out in another way without generating noise. If the elimination of the noisy process as a whole is not practicable, technicians should consider replacing its noisy parts with quieter alternatives.

The ДСН 3.3.6.039-99 is the Ukrainian Public health standard which regulates the vibration effect. Exposure of technicians to hazardous vibration is mainly known as:

- whole-body vibration, when the body is supported on a surface that is vibrating, which occurs in all forms of transport and when working near vibrating industrial machinery; or
- hand-transmitted vibration, which enters the body through the hands and is caused by various processes in which vibrating tools or work pieces are grasped or pushed by the hands or fingers.

Where old machinery is still in use, sources of vibration that present a risk to safety and health should be identified and suitable modifications made by employing current knowledge of vibration-damping techniques.

Where technicians are directly or indirectly exposed to vibration transmitted via the floor or other structures, the vibrating machines should be mounted on vibration isolators (anti-vibration mounts), installed according to the manufacturer’s instructions or designed and manufactured according to internationally recognized plant and equipment standards.

Possible thermal risks arise in special conditions:

- temperature and/or humidity are unusually high;
- technicians are exposed to high radiant heat;
- high temperatures and/or humidity occur in combination with heavy protective clothing or a high work rate;
- temperature is unusually low;

If technicians are exposed in all or some of their tasks to any conditions, and the hazard cannot be eliminated, employers should assess the hazards and risks to safety and health from extreme temperatures, and determine the controls necessary to remove the hazards or risks or to reduce them to the lowest practicable level.

Technicians should be allowed sufficient time to acclimatize to a hot environment, including major changes in climatic conditions.

The assessment for the thermal environment should take into account the risks arising from working with hazardous substances in work situations such as:

- the use of protective clothing against hazardous substances, thereby increasing the risk of heat stress;
- a hot environment that makes respiratory protectors uncomfortable and less likely to be used, and necessitates restructuring of jobs in order to reduce the risks.

4.3 Methods of decreasing influence of harmful and dangerous factors for subject of labour precaution

In order to prevent adverse effects of noise on technician, employers should:

- identify the sources of noise and the tasks that give rise to exposure;
- seek the advice of the competent authority and/or the occupational health service about exposure limits and other standards to be applied;

- seek the advice of the supplier of processes and equipment about expected noise emission.

If reducing the noise at source or intercepting it does not sufficiently reduce workers' exposure, then the final options for reducing exposure should be to:

- install an acoustical booth or shelter for those job activities where technicians movement is confined to a relatively small area;
- minimize by appropriate organizational measures the time workers spend in the noisy environment;
- provide hearing protection;

If the elimination of noisy processes and equipment as a whole is impracticable, their individual sources should be separated out and their relative contribution to the overall sound pressure level identified. Once the causes or sources of noise are identified, the first step in the noise-control process should be to attempt to control it at source. Such measures may also be effective in reducing vibration.

For the prevention of adverse effects of vibration on technicians, employers should:

- identify the sources of vibration and the tasks that give rise to exposure;
- seek the advice of the competent authority about exposure limits and other standards to be applied;
- seek the advice of the supplier of vehicles and equipment about their vibration emissions; or
- if this advice is incomplete or otherwise of doubtful value, arrange for measurements by a technically capable person, to be carried out in accordance with recognized standards and regulations and currently available knowledge.

If technicians or others are frequently exposed to hand-transmitted or whole-body vibration, and obvious steps do not eliminate the exposure, employers should assess the hazard and risk to safety and health resulting from the conditions, and the prevention and control measures to remove them or to reduce them to the lowest practicable level by all appropriate means.

Where the assessment shows that unhealthy or uncomfortable conditions arise from increased air temperature, the employer should implement means to reduce air temperature, which may include ventilation or air cooling.

Technicians should be protected against the severest forms of cold stress, hypothermia and cold injury.

The core body temperature should not be allowed to fall below 36°C (96.8°F). Suitable protection should be provided to prevent injury to bodily extremities.

Calculation of workplace lighting

In the working area depending on condition of exerted work the illumination standard for application of luminescent lamps with degree I is E_n=400 l_x. The line voltage is 220 V. It is supposed to establish lamp appliances such as ODOR-2 with light sources LBR2-40 Wt hanged at altitude H_p=3.3 m. The area of the room S=a·b=(6·12) m^2. Reflectance values of ceiling ρ_c=0.5, walls ρ_w=0.3, working surface ρ_s=0.1. The assurance factor K=1.8. Calculate the power of the lighting installation and the number of lamp appliance.

While solving the problem we use the specific power computation method. From the special table we discover specific power of a lighting installation for voltage 220 V and K_1=1.5: W=17.6 Wt/m^2.

We make allowance for the given assurance factor K=1.8:

$$W_s = W\frac{K}{K_1}[Wt/m^2], \tag{4.1}$$

$$W_s = 17.6\frac{1.8}{1.5} = 21.12\ (Wt/m^2).$$

Let us find the power of a lighting installation.

$$W_{li} = P_A S[Wt], \tag{4.2}$$

$$W_{li} = 21.12 \cdot 72 = 1520.64\ (Wt).$$

The number of required lamp appliances

$$n = \frac{W_{li}}{NP_1}\ , \tag{4.3}$$

$$n = \frac{1520.64}{2 \cdot 40} = 19.008 \approx 20,$$

where N – number of lamps in a lamp appliance ODOR 2, 2 pieces;

P_1 – power of a lamp LB, Wt.

Approximating to an integer we find the number of a lamp appliances *n=20* pieces. This number of lamp appliances is enough for providing of labor precaution in coating application laboratory, regarding sufficient illumination of working zone. In the disposition my decision is to allocate 4 rows with 5 lumps in each. Scheme of the installation is on the Figure 4.1.

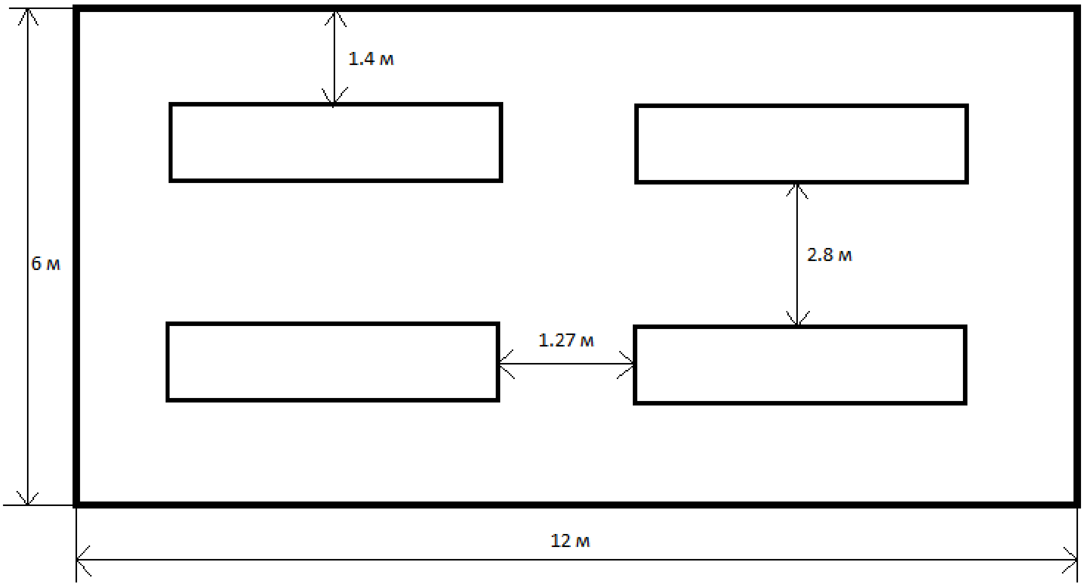


Figure 4.1 – Scheme of the fixtures disposition

All the calculations are made according to the State Standard [33]

4.4 Fire and explosive safety

Possible sources of fire are connecting and communication cables, electric systems elements, cutting and welding equipment, power supply cable lines for the electrical installations, arson and smoking.

When operating on the worktable there is a risk of various kinds of fires. In the factory, the electric systems elements are situated very densely. The connecting and communication cables are arranged close to each other. While the flow of the electric current a significant amount of heat is produced, that can raise the temperature of the separate nodes to 80-100 C. As a result, the wiring insulation may melt, stripping and short circuit may occur and, accompanied by arcing, it leads to the prohibitive overload of the electronic components. Because of the overheating, they burn with a spray of sparks.

There are ventilation and air conditioning systems that serve for the removal of excess heat in the working room. However, these systems also provide additional fire hazard. On the one hand, the air ducts provide oxygen supply, which is the oxidizing substance, to all premises. On the other hand, when the fire occurs, it spreads quickly along with the combustion products to all the connected premises and devices.

The power supply for the electrical installations is conducted by cable lines that are of special fire hazard. The presence of flammable insulation material, the possible source of ignition, in the form of electrical sparks and arcs, branching and inaccessibility make the cable lines the most probable places for fire development.

Fire Safety Regulations provides: fire safety requirements when the workers are at the station, place and the order to keep fire protection equipment, fire alarm, requirements for the content of areas, roads and entrances to buildings and structures, including evacuation routes; order of carrying out repairs, the storage requirements for flammable substances and materials, clothing; storage requirements of equipment and tools, the inspection tool and automatic, procedure for access and rules of traffic on the territory.

Once the technician have identified the risks of fire or explosion, he should take appropriate actions:

- carry out a fire safety risk assessment;
- keep sources of ignition and flammable substances apart;
- avoid accidental fires, make sure heaters cannot be knocked over;
- avoid build-up of rubbish that could burn;
- have the correct fire-fighting equipment for putting a fire out quickly.

To prevent fire development, all kinds of cables should be routed in metal gas-filled tubes. In data center premises, the fire hydrants should be installed in corridors, stairwells sites, at the entrances. Manual powder fire extinguisher should be installed indoors in an amount of 1-2 pc.

On escape routes both natural and artificial emergency lighting should be set. For the storage media there should be used the fireproof metal cabinets, doors to the storage should also be fireproof.

Due to the large amount of electrical devices, the room must be provided with grounding.

The range of organizational and technical measures of fire safety helps the prevention of fire. And in case it occurs, it helps to ensure the safety of technicians, to limit the spread of fire, as well as to create conditions for the effective fire extinguishing.

The fire extinguishers are the most appropriate of the fire-fighting appliances. While there’re electric installations in the room and due to its specificity, it is rational to use small manual fire extinguishers of the powder type (OP-1, OP-10, OP-25). They should be loaded with the dry chemical powder and injected with the noble (inert) gas (air, nitrogen, carbon dioxide) under pressure. They are designed to extinguish fires of classes A, B, C and the electric installations under voltage up to 1000 V. All of the above is taken from the State Standard [34].

Conclusion to part 4

During performing the investigation of given chapter the legislative and normative acts of Ukraine on labour precaution were analyzed. According to my topic of diploma work I choose the subject and object of the working process – the technician and the worktable in the factory. Among the most harmful factors for the subject on the working place it is possible to mention and describe noise, vibration and temperature effects. As the proper lighting of the work place is very important, the calculation of the workplace lighting was done. Each technician should know fire safety measures and have fire extinguishers on the working place.

If we will work in the compliance with all of the above requirements for the protection of labor, as well as strict compliance to prevent fire and emergencies – all the necessary requirements and standards for the protection of labor will be fully satisfied. Only after that we can be absolutely sure that our work is completely safe and the risks are reduced to minimum.

PART 5.
ENVIRONMENTAL PROTECTION

5.1 Introduction

Aircraft engines produce emissions that are similar to other emissions resulting from fossil fuel combustion. However, aircraft emissions are unusual in that a significant proportion is emitted at altitude. These emissions give rise to important environmental concerns regarding their global impact and their effect on local air quality at ground level.

A comprehensive assessment concerning aviation's contribution to global atmospheric problems is contained in the *Special Report on Aviation and the Global Atmosphere*, which was prepared at ICAO's request by the Intergovernmental Panel on Climate Change (IPCC) in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer and was published in 1999. This told us inter alia:

- that aircraft emit gases and particles which alter the atmospheric concentration of greenhouse gases, trigger the formation of condensation trails and may increase cirrus cloudiness, all of which contribute to climate change; and
- that aircraft are estimated to contribute about 3.5 per cent of the total radiative forcing (a measure of change in climate) by all human activities and that this percentage, which excludes the effects of possible changes in cirrus clouds, was projected to grow.

The Report recognized that the effects of some types of aircraft emissions are well understood, revealed that the effects of others are not, and identified a number of key areas of scientific uncertainty that limit the ability to project aviation impacts on climate and ozone.

5.2 Types of emissions

Harmful impact caused by the growth of air traffic originates from three types: aircraft noise, exhaust emissions and finally, the problems related to the air traffic management itself. Regarding worldwide the exhaust emissions generated by air traffic, it accounts for about 3.5 per cent of the global warming caused by people. The main air pollutants related to aircraft engine emissions are considered to be carbon dioxide, nitrogen oxides, water vapour and particles of soot and sulphur. These emissions are expected to grow- in the period from 1992 to 2015, at an annual rate of 3 per cent, since air traffic is growing faster than the technical development which contributes to the improvement of aircraft energy efficiency. In the entire world, 16,000 commercial jet aircraft generate annually more than 600 million tonnes of CO_2, the most significant greenhouse gas. In order to sustain the growth of aviation, 30 to 50 per cent of the busiest national airports have planned the expansion, and about 60 to 100 biggest airports have planned the construction of new runways, which has its environmental consequences. The fact that had not been considered until recently, is that the airports and the aircraft are the biggest individual polluters and that they cause enormous growing damage to the environment at the local level around the airports (dangerous exhaust gases and noise) and at the regional and the global level (greenhouse gases, and depletion of the ozone layer). Polluters which are emitted at the higher altitudes during cruising represent a greater problem, although the quantities of emitted pollutants are smaller since these layers are chemically more complex than the lower levels of atmosphere where the exhaust gases are emitted during the takeoff and landing cycles. The aim is, therefore, to provide an overview of the data on aircraft engine exhaust emissions and their impact at a global level as well as the possibilities of reducing the emissions i.e. carrying out the preventive measures.

The aircraft harmful emissions could participate in 2050 with 15 per cent in the global warming of the Earth, which can be blamed on the humans. There are two global environmental problems today that can be considered to have consequences due to the aircraft impact. These include: climatic changes, including changes in the weather models (e.g. for precipitation, temperature, etc.) and regarding supersonic aircraft, depletion of the stratospheric ozone and as consequence the increase in the UV-B radiation on the Earth surface. Large number of aircraft emissions can influence the climate. Carbon dioxide (CO_2) and water (H_2O) do this directly; other factors (e.g. ozone generation in the troposphere, different methane life-cycle, formation of contrails and the change in the cirrus clouds) act indirectly. Emissions which influence the atmospheric ozone (e.g. nitrogen oxides, particles and water vapour) act indirectly changing the chemical balance in the stratosphere. Besides, civil air traffic is constantly growing. Over the next 10 to 15 years, an increase in air traffic demand by 5 per cent annually is expected (Airbus 1997, Boeing; 1997, Brasseur, 1998) although regional deviations in demand are likely to be present. The EU Commission claim that the current fleet of subsonic aircraft consumes about 130 to 160 million tonnes of fuel annually. Although aviation consumes 13 per cent of fossil fuels that are used in traffic, it is the second largest form of transport regarding consumption, following road traffic which consumes 80 per cent of all fuels in transport (IPCC, 1996). Due to the increased growth of aviation there are numerous questions regarding the future influence of aviation emissions on the global environment: if the number of supersonic aircraft (flying mainly in Tropopause the stratosphere) increased significantly, what special effects would there be? The research studies indicate that the planned fleet of supersonic aircraft would spend 2-3 per cent of the remaining ozone in the stratosphere within 10 years, damaging most the ozone layer at the altitudes of 25 - 28 km above sea level.

Subsonic aircraft fly in the troposphere and lower stratosphere, whereas supersonic aircraft spend 80 - 85 per cent of their flying time in the stratosphere and cruise at an altitude of several kilometres above subsonic aircraft. The diversities in chemical and physical processes in these two areas have to be taken into consideration. Emissions can be divided into two groups, depending on their effect on the climate:

- direct effect: such as CO_2 (the emitted element is a substance which can change the climate);

- indirect effect: where the climatic type is not the same as the type of emission- e.g. the change in the coverage by cirrus clouds as consequence of particle influence.

Thus, harmful action of anthropogenic polluters which include also the advanced aircraft, is not reflected only regionally but to a great extent it influences the global ecological balance in three main indications:

- change in Earth radiation balance due to the anthropogenic greenhouse effect which is related to the change in the global climate i.e. by warming of the lower layers of troposphere;

- change in the ozone content of the atmosphere, which on the one hand influences the intensity of radiation on the Earth surface, and on the other hand, the ozone represents a significant greenhouse gas;

- change in the oxidation capacity of the atmosphere due to the increase in the tropospheric concentration of ozone.

One of the major sources of CO_2 is fuel combustion. The amount of CO_2 generated by aircraft fuel combustion is determined by the total volume of carbon in the fuel, since CO_2 is an inevitable by-product of the combustion process (just as water). CO_2 emitted from aircraft gets mixed with other CO_2 from fossil fuel origins and becomes a component which equally influences the climate. The growth rate of aircraft generated CO_2 emissions is faster than the global economic growth, so that the contribution of aviation, together with other transport modes, to the emission generated by human activities is showing the tendency of growth in the years to come.

Water vapour remains, however, in the troposphere for about 9 days. In the stratosphere, the time necessary for any aircraft generated water emission to disappear is longer (a month to a year) than in the troposphere and there is greater possibility that the aircraft emissions increase the concentration in space. The aircraft generated NOx emission is best seen as disturbance of the network of chemical reactions with the consequence of influencing the concentration of ozone, and it depends on the place, age, etc. In the upper troposphere and lower stratosphere, the aircraft generated NOx emissions have the tendency of increasing the volume of ozone, so that the increase in ozone and the greenhouse effect represent the main problem in NOx emissions generated by subsonic aircraft [35].

Technological achievements concretely reduce the majority of emissions per passenger km. However, there are possibilities for further improvements. Any technological change can cause change in the balance of the range of impacts on the environment. The subsonic aircraft manufactured today are about 70 per cent more fuel efficient per passenger km than forty years ago. The majority of improvements in efficiency have been achieved by improving the engine and the rest by improving the aircraft structure design. The forecast improvement in fuel efficiency or utilization by the year 2015 is 20 per cent, and by the year 2050 it amounts to 40 to 50 per cent compared to the present aircraft fuel efficiency. The improvements in engine efficiency have reduced the specific fuel consumption and the majority of various emissions. The development of engines and aircraft structure in the future encompasses the complex procedure of decision making and of requirements, uniform taking into consideration various factors, e. g. emission of carbon dioxide (CO_2), emissions of NOx at the Earth surface, emission of NOx at higher altitudes, emission of water vapour, generation of contrails or cirrus clouds (jet cirrus). At the international level, actual research programs for engines are developed with the aim of reducing NOx emission in LTO cycle by 70 per cent compared to the present regulation standards, as well as in order to improve, i.e. reduce the engine fuel consumption by 8 to 10 per cent compared to the latest engines by the year 2010. Reduction of NOx emission at cruising altitudes could also be achieved, although maybe not in the same proportion as for the LTO cycle. If it is assumed that these objectives are possible and feasible, the transition of the new technology to a certain and substantial number of more recently manufactured aircraft will take longer- the usual ten-year period. The research programs for supersonic aircraft generated NOx emissions are also being developed.

The research (DASA, MTV) in the area of preventing harmful exhaust generated by conventionally propelled aircraft (kerosene) is directed exclusively to technical improvement which includes two aspects of measures:

- improvement of the overall aircraft aerodynamics, primarily by applying the so-called variable wing curvature (bearing surfaces), which due to the reduced aerodynamic drag results in substantial reduction of fuel consumption and consequently also in the reduction of absolute value of pollution;

- designing of new generation of modern engines with the new concept of combustion chamber, where the specific fuel consumption has been substantially reduced as well as the relative share of pollutants, especially nitrogen oxides.

The policy of measures undertaken in order to reduce the emissions includes also much stricter regulations regarding aircraft engine emissions, abolishing extra taxes and incentives that have negative impact on the environment, measures on the market principle such as environmental contributions (fees and taxes), then emission trade, voluntary agreements, research programs and replacement of air carriage by railway or road carriage [36].

5.3 Calculation of the emissions of carbon monoxide and nitrogen oxides by aircraft engines

Mass of emissions of harmful substances in the airport zone is calculated for take-off – landing cycle (TOFF-LC) modes. Characteristics of modes and their duration are given in table 5.1.

Table 5.1 - Typical TOFF-LC for aviation engine working modes

Number of mode	Characteristics of modes	Relative thrust, $\bar{R}$	Mode duration t, min
1	Launching, idling	0,07	15,0
2	Take off	1,0	0,7
3	Ascending	0,85	2,2
4	Approach from 1000 m altitude	0,3	4,0
5	Taxiing after landing (idle mode)	0,07	7,0

Calculation of annual mass CO and NOx emissions is performed according to the formulas (5.1) and (5.2):

$$M_1 = M_{1G} + M_{1TL}, \quad (5.1)$$

$$M_2 = M_{2G} + M_{2TL}, \quad (5.2)$$

where M_{1G} , M_{2G}(formulas (5.3) and (5.4))–mass of harmful substances CO and NO_x accordingly,which are emitted during ground operations (launching, idling and taxiing before take-off and after landing– modes 1, 5); M_{1TL}, M_{2TL} - mass of harmful substances CO and NO_x accordingly, which are emitted during take-off – landing operations (take off, ascending 1000 m, approach from 1000 m altitude – modes 2, 3, 4).

$$M_{1G} = K_1 \cdot C_{spconsidle} \cdot R_{idle} \cdot T_{idle}, \quad (5.3)$$

$$M_{2G} = K_2 \cdot C_{spconsidle} \cdot R_{idle} \cdot T_{idle} \quad (5.4)$$

Here K_1, $K_2$are emission indexes (kilogram of harmful substance per kilogram of fuel) CO and NO_x accordingly during ground operations (Table 5.2);

$C_{spconsidle}$ – specific fuel consumption during idle working mode of engine, kg/N·hour (Table 5.2);

R_{idle} is the engine idle mode thrust, $R_{idle} = \bar{R} R_0$, where$R_0$is the maximum engine thrust N; T_{idle} – annual engine operating time on idle mode, hour/year (formula (5.5)):

$$T_{idle} = t_{idle} \cdot N \cdot n, \quad (5.5)$$

where t_{idle} is the operating engine time in hours on idle mode for one TOFF-LC (modes 1, 5 in Table 5.1); N is the annual quantity of take-off-landing procedures for all aircraft this type in the airport; n – quantity of engines for this type of aircraft.

Calculation of mass M_{1TL}andM_{2TL} emissions of CO and NO_x accordingly at take-off – landing procedures (modes 2, 3, 4) is performed according to the formulas (5.6) and (5.7):

$$M_{1TL} = n \cdot (W_{1TOFF} \cdot T_{TOFF} + W_{1A} \cdot T_A + W_{1n} \cdot T_n) \cdot N; \quad (5.6)$$

$$M_{2TL} = n \cdot (W_{2TOFF} \cdot T_{TOFF} + W_{2A} \cdot T_A + W_{2n} \cdot T_n) \cdot N, \quad (5.7)$$

where W_{1TOFF}, W_{2TOFF} are mass speeds of emission of CO i NO_x accordingly during aircraft take off, kg/hour (Table 5.3);

W_{1A},W_{2A} the same for ascending to 1000 m;

W_{1n} , W_{2n} the same for descending from 1000 m;

T_{TOFF}, T_A, T_n is the mode operating time in hours for engines during take-off, ascending to 1000 m and descending from 1000 m respectively (given in Table 5.1).

Table 5.2 - Emission indexes of CO and NO_2 during ground operations for different types of aviation engines (kilogram of harmful substance/kilogram of fuel)

Variant	AC type	Maximum engine thrust, kN	Aviation engine type	Engine number	$C_{spconsidle}$, kg/N·hour	CO	NO_2
1	Tu-134	68	Д-30-П	2	0,059	0,0276	0,0067
2	Yak-42	65	Д-36	3	0,037	0,0193	0,0084
3	Tu-154M	115	Д-30КУ	3	0,049	0,0546	0,0054
4	Il-62M	115	Д-30КУ	4	0,049	0,0546	0,0054
5	Il-76	115	Д-30КП	4	0,049	0,0546	0,0054
6	Tu-154A	105	НК-8-2У	3	0,061	0,0312	0,0049
7	Tu-154Б	105	НК-8-2У	3	0,061	0,0312	0,0049
8	Il-62	105	НК-8-4	4	0,046	0,0277	0,0055
9	Yak-40	15	AI-25	3	0,039	0,1457	0,0022
0	Yak-40	15	AI-25 with smokeless combustion chamber	3	0,039	0,0814	0,0146

$$M_{1TL} = n \cdot (W_{1TOFF} \cdot T_{TOFF} + W_{1A} \cdot T_A + W_{1n} \cdot T_n) \cdot N =$$

$$= 3 \cdot (12,2 \cdot 0,0117 + 10,2 \cdot 0,0367 + 19,1 \cdot 0,0667) \cdot 75 = 402,675 \ (\frac{\text{kg}}{\text{year}})$$

$$M_{2TL} = n \cdot (W_{2TOFF} \cdot T_{TOFF} + W_{2A} \cdot T_A + W_{2n} \cdot T_n) \cdot N =$$

$$= 3 \cdot (104 \cdot 0,0117 + 76 \cdot 0,0367 + 12 \cdot 0,0667) \cdot 75 = 1080 \ (\frac{\text{kg}}{\text{year}})$$

$$M_{1G} = K_1 C_{spconsidle} R_{idle} T_{idle} = 0,0312 \cdot 0,061 \cdot 7350 \cdot 82,5 = 1154 \ (\frac{\text{kg}}{\text{year}})$$

$$M_{2G} = K_2 C_{spconsidle} R_{idle} T_{idle} = 0,0049 \cdot 0,061 \cdot 7350 \cdot 82,5 = 181,245 \ (\frac{\text{kg}}{\text{year}})$$

And finally, annual mass CO and NO_x emissions are:

$$M_1 = M_{1G} + M_{1TL} = 1154 + 402,675 = 1556,728 \ (\frac{\text{kg}}{\text{year}})$$ - Total CO emissions

$$M_2 = M_{2G} + M_{2TL} = 181,245 + 1080 = 1261,245 \ (\frac{\text{kg}}{\text{year}})$$ - Total NOx emissions

For sources , the mouth of which is situated at a height h < 10 m, this zone is a circle of radius 50h centered at a location of the source; with h ≥ 10 m radius $r_{zone} = 20\varphi h$, where h – the height of the mouth of the source, m; φ – dimensionless error of the rise flare emissions in the atmosphere, which is given by the formula (5.9):

$$\varphi = 1 + \frac{\Delta T}{75°C}, \tag{5.9}$$

where ΔT – annual average temperature difference at the mouth of the source and the surrounding atmosphere at a mouth level, °C.

Initial data for calculation:

h = 2 m (for modes 1,5);

h = 50 m (for modes 2, 3, 4);

f = 10; ΔT = 500 °C.

The value of consolidated masses m_1 and m_2 annual emissions respectively CO i NO_x are calculated by the formulas (5.10) and (5.11):

$$m_1 = A_1 M_1, \tag{5.10}$$

$$m_1 = 1 \cdot 1556{,}728 = 1556{,}728 \text{ (kg)};$$

$$m_2 = A_2 M_2, \tag{5.11}$$

$$m_2 = 41.1 \cdot 1261{,}245 = 51837{,}19 \text{ (kg)},$$

where A_1, A_2 – signs of relative aggressiveness respectively CO (A_1=1) and NO_x (A_2=41,1).

Taking into account the values of γ andi *f* estimate the damage that is caused by different emissions of CO ($З_1$) and NO_x ($З_2$), will be determined by the formulas (5.12) and (5.13):

$$З_1 = 120 \cdot \sigma m_1, \tag{5.12}$$

$$З_1 = 120 \cdot 4 \cdot 1.557 = 747{,}2294 \text{ (UAH/year)};$$

$$З_2 = 120 \cdot \sigma m_2, \tag{5.13}$$

$$З_2 = 120 \cdot 4 \cdot 51.84 = 24881{,}85 \text{ (UAH/year)}.$$

At this point, the economic and ecological assessment of the damage that is caused by the annual emissions of the chosen engine is complete. The conclusions are drawn.

Conclusion to part 5

Aviation is different from other energy-using activities as the majority of emissions occur at altitude, and their influence on the atmosphere can be highly localized and short-lived. Emissions from aircraft are responsible for other atmospheric chemical processes that also have atmospheric warming consequences. Aviation emissions are therefore more significant contributors to climate change, than an equivalent amount of carbon dioxide emitted at ground level.

Combustion of fuel in airplane engines results in emissions of carbon dioxide (CO_2) and nitrogen oxides, (termed NO_x), as well as water vapour and particulates. It is the emission of NO_x, water vapour and particulates at altitude that account for the extra impacts of aviation emissions.

Carbon dioxide

Carbon dioxide is a greenhouse gas and alters the balance of incoming and outgoing radiation from the earth's surface and contributes to warming of the atmosphere. Aviation emissions of carbon dioxide have the same effect on climate as terrestrial emissions, from power stations, industry or transport sources. Carbon dioxide has an atmospheric lifetime of up to 200 years, so ends up well mixed in the lower atmosphere over this timeframe no matter where it is emitted.

Nitrogen oxides

Emissions of nitrogen oxides initiate a series of chemical reactions in the atmosphere. Nitrogen oxides form ozone (O_3) in the presence of light, and light intensity is higher at altitude, so more ozone is formed at altitude than from terrestrial sources of NO_x. Emissions of nitrogen oxides from sub-sonic aircraft accelerate local generation of ozone in the lower atmosphere where aircraft typically fly. The increase in ozone concentration will generally be proportional to the amount of nitrogen oxides emitted from aircraft.

Ozone is a potent greenhouse gas whose concentration is highly variable and controlled by atmospheric chemistry and dynamics. The increase in radiative forcing from ozone is greater than carbon dioxide emissions.

As we can see from the completed experiments results that emissions of is much more groundbreaking.

Three-dimensional model calculations suggest that the world's fleet of subsonic aircraft has enhanced the abundance of nitrogen oxides in the upper troposphere by up to 20–35 % and has produced a significant increase in the ozone concentration in this region of the atmosphere (4 % in summer and 1 % in winter). In year 2050, on the basis of current scenarios for growth in aviation, the concentration of NO_x at 10 km could increase by 30–60 % at middle attitudes, and the concentration of ozone could be enhanced by 7 % and 2 % in summer and winter, respectively (relative to a situation without aircraft effects). The perturbation is not limited to the flight corridors but affects the entire northern hemisphere. The magnitude (and even the sign) of the ozone change depends on the level of background atmospheric NO_x and hence on NO_x sources (lightning, intrusion from the stratosphere, and convective transport from the polluted boundary layer) and sinks which are poorly quantified in this region of the atmosphere. On the basis of our model estimates, 20 % of the NO_x found at 10 km (middle attitudes) is produced by aircraft engines, 25 % originates from the surface (combustion and soils), and approximately 50 % is produced by lightning. For a lightning source enhanced in the model by a factor of 2, the increase in NO_x and ozone at 10 km due to aircraft emissions is reduced by a factor of 2. The magnitude of aircraft perturbations in NO_x is considerably smaller than the uncertainties in other NO_x sources.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

While performing the degree work the key issues were considered and important problems were solved in the project and special parts, namely:

1. The analytical part of the work had shown that friction is one of the most widespread problems, connected with the work of the machines and mechanisms. Friction can lead to the wear of the surface. Mainly all mechanisms are subjected to the wear of surfaces. Thus, this is the major factor defining the durability and the longevity of the elements. As a lot of materials like titanium alloys have low wear resistance, it is necessary to develop technologies for application of protective coatings, surface modification and design of the surface layers and their properties.

One of the most dangerous types of friction is fretting-corrosion. Fretting is one of the most widespread defects that appear in the aviation engineering assemblies. Damage from the fretting is met almost in any mobile or nominally immovable connection, the parts of which are under vibration or subjected to the influence of repeated and variable loadings, sufficient for the appearance of relative movements.

2. The unique unit for the wear resistance properties of materials based on the МФК-1 unit was developed. The sense of it is that the recurrent-forward motion of installation was changed into the direct rotation with the given speed, so instead of fretting-corrosion it can imitate unidirectional friction sliding. It allows to provide investigations of standard specimens wear under low speed sliding in different environment and at the different temperatures.

The wear of different coatings can be measured under cyclic friction sliding and under corrosion using the same parameters of the way of friction and the sliding speed. Investigations at the cyclical friction sliding were made under the loading of 20 MPa and amplitude of 50mcm. Oscillation frequency remained constant and was 30Hz. Tests bases was $5\cdot10^5$ cycles.

Under one-directed friction sliding as the confirmative criterions between researches at the cyclical and one-sided friction sliding were taken average speed of sliding, which was 3mm/s, and way of friction – 50m.

3. The comparative investigations of the materials at one-sided and alternating friction sliding were performed in such way, that work during all experiments was constant. The results of testing shows that the wear resistance properties of materials and coatings are higher at the cyclical friction sliding in the conditions of fretting-corrosion. It's explained by the formation of the oxides which work like a hard lubricant. The better wear resistant properties at both types of friction has the coating of molybdenum.

4. In the degree work the issues of labour precaution and environmental protection were described.

The major issues on labour precaution make it possible to obtain the necessary and sufficient information for correct and safe work and for the calculation of the proper lighting of the work place.

5. The influence of coating methods on their wear resistance is analyzed. It has been determined that the most wear-resistant is the method of laser and detonation coating.

The following recommendations were developed:

1. The wear resistant properties of materials and coatings are higher at fretting-corrosion because at the cyclical friction sliding appears the intensive oxidation of the surface and the created oxides work like a hard lubricant between two surfaces.

2. It is better to use the coating of molybdenum, because it has the higher wear resistant properties due to the specific of this covering.

Thus, the tasks that were posed for the degree work were fulfilled in a full size.

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