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
“____”_____________ 2022 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА

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

Тема: «Методика проведення досліджень на зносостійкість при високому контактному навантаженні»

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Київ 2022

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
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«____”______________ 2022

MASTER DEGREE THESIS

(EXPLANATORY NOTE)

APPLICANT FOR ACADEMIC DEGREE OF MASTER

FOR EDUCATIONAL PROFESSIONAL PROGRAM
"MAINTENANCE AND REPAIR OF AIRCRAFT AND AIRCRAFT ENGINES"

Topic: « Methods of testing on wear at high contact pressure »

Fulfilled by: ______________ Kyryk L.S.

Supervisor:
Candidate of science (Engineering), assoc. prof. ______________ Khimko A.M.

Advisers on separate parts of explanatory note

Labour precaution:
Candidate of science (Engineering), assoc. prof ______________ Kazhan K.I.

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Kyiv 2022

NATIONAL AVIATION UNIVERSITY

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

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«____”_______________ 2022

GRADUATE STUDENT’S DEGREE WORK ASSIGNMENT
Kyryk Liliia

1. The Work topic: «**Methods of testing on wear at high contact pressure**» approved by the Rector’s order of September 29, 2022 No. 1786/st.
2. The work fulfillment terms: since September 26, 2022 till November 30, 2022.
3. Initial data for the project: Analysis of methodologies of conducting wear resistance tests in the conditions of fretting at the high contact pressure. High-strength steels (30Х2НВФА and ШХ15 type) for high-loaded friction nodes.
4. The content of the explanatory note (the list of problems to be considered): analysis of aircraft assemblies and aviation engines in the ball-plane contact; analysis of research methods for wear resistance at high contact pressure; development of test methods for ferreting corrosion at high contact pressures.
5. The list of mandatory graphic materials: List of tasks; implementation of sphere-plane contact; fretting problem; analysis of methodologies on conducting tests; developed holder; МФК-1 installation; wear measurement; wear resistance results; friction surfaces fractography; surface topography; conclusions and recommendations.

6. Time and Work Schedule

Stages of Graduation Project Completion	Stages Completion Dates	Remarks
Search for and analysis of reference material	16.09.2022 – 28.09.2022	
Analysis of wear resistance methodologies and friction machines	29.09.2022 – 10.10.2022	
Preparation for conducting experiments	11.10.2022 – 16.10.2022	
Conducting necessary experiments	17.10.2022 – 25.10.2022	
Processing of experiments' results	26.10.2022 – 30.10.2022	
Fulfillment of individual sections of degree work	01.11.2022 – 13.11.2022	
Preparation of explanatory note	14.11.2022 – 25.11.2022	

7. Advisers on individual sections of the work (Thesis):

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labour precaution	Ph. D., Assoc. Prof. K.I. Kazhan		
Environmental protection	Ph. D., Assoc. Prof. Pavlyukh L.I.		

8. Assignment issue date 26.09.2022.

Graduate Work Supervisor Khimko A.M. ____________________
(supervisor signature)

Assignment is accepted for performing:

Graduate student Kyryk L.S. ____________________
(graduate student's signature) (Date)

ABSTRACT

The explanatory note to master's degree work «Methods of testing on wear at high contact pressure»:

90 pages, 31 figures, 6 tables, 40 literature sources.

Object of research is fretting at sphere-plane contact.

The purpose of degree work is to develop a methodology of conducting wear resistance tests in conditions of fretting at sphere-plane contact.

The following tasks are therefore set:

1) To analyze existing wear resistance test machines;
2) To modernize contacting element of friction pair. Develop a device for sphere-plane contact;
3) To develop a methodology of conducting tests on wear resistance in conditions of fretting at sphere-plane contact.

Method of research is experimental modelling of fretting on МФК-1 installation, processing results with the help of vertical type optimeter ИКВ, microscope and personal computer.

Subject of research is an installation for conducting wear resistance tests in conditions of fretting.

Analysis of the present fretting test machines was made. Generally, all of them use cylinder-plane, plane-plane, sphere-sphere, cylinder-sphere, cylinder-cylinder as a main contact. However, in many industrial applications sphere-plane contact is present. Developing a methodology which will ensure this contact is therefore of high interest and actuality.

In a recent study, it has been confirmed that sphere-plane contact is particularly important for researching fretting damage. Methodology was developed and fretting was modelled using modified fretting test machine МФК-1.

FRETTING, WEAR RESISTANCE, METHODOLOGY, SPHERE-PLANE CONTACT, TEST MACHINE.

LIST OF ABBREVIATIONS

PTWA - plasma transferred wire arc

HVOF - high velocity oxygen fuel

SPPS – solution precursor plasma spray

TBC – thermal barrier coatings

USZ – ultra-stabilized zirconia

CMC– ceramic-matrix composites

EBPVD – electron beam physical vapor deposition

APS – air plasma spray

ESAVD – electrostatic spray assisted vapour deposition

CAA – clean air act

RCRA – resources conservation and recovery act

NAAQS– national ambient air quality standards

MACT – maximum achievable control technology

HEPA – high-efficiency particle absorption

BACT – best available control technology

CONTENTS

INTRODUCTION

As our technological civilization expands, material and energy conservation is becoming increasingly important. Wear is a major cause of material wastage, so any reduction of wear can result considerable savings. Friction is a principal cause of energy dissipation and considerable savings are possible by improved friction control [1].

It is universally recognized that friction and wear are common phenomena, which occur at machinery components which run together. 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. The researchers investigate friction and wear behavior of materials because of adverse effect observed in the performance and life of machinery components.

Fretting, being a special kind of material wear, considered in this degree work, takes up to 50% of wear of aircraft parts. All materials in almost all kinds of environment and conditions are subjected to the influence of fretting. For example, according to [2], among the main operational defects in domestic and foreign aircraft gas turbine engines, fretting type of wear constitutes 60% of all types of wear. Flexible couplings and splines, particularly where they form a connection between two shafts and are designed to accommodate some slight misalignment, can suffer severe fretting wear. Jointed structures are another source of fretting problems. Eventually, there is no such thing as a static joint on an aircraft. In turbines, where the turbine disk is either shrink-fitted onto the driving shaft or attached to the shaft by means of a bolted flange and where the blades are fixed into the disk by either a dovetail or fir-tree type fixture – here and not only fretting can take place.

In order to ensure, improve and conduct the laboratory tests on wear resistance of mechanical components, it is necessary to develop an accurate and adequate methodology. To achieve this, it is important to consider the size and cost of friction test machine at its development. Samples for friction must have a smaller size, but also be sufficient in dimensions for the required type of friction, which installation realizes. When beginning a research, the development of methodology should be conducted in accordance with two requirements. On the one hand, the simulation of sliding friction in the laboratory should maximally correspond to conditions in real structures. On the other hand, methodology should enable comparison of obtained results with data from other researches [3].

Tribological situations encountered in different machines may present certain features in common insofar as they all embody surfaces in relative motion. However, it will be apparent that the nature and configuration of surfaces may vary widely as between one machine and another as will the modes of force and motion. Conventional specimen contact configurations include cylinder-plane, plane-plane, sphere-sphere, cylinder-sphere, cylinder-cylinder and finally sphere-plane contact pairs. Different types of contact have their advantages and disadvantages. The disadvantages of the plane-plane contact are unequal wear conditions of samples working areas, since their amplitude displacements in such case are proportional to distance from the axis of rotation. In other types of contact is the uneven pressure distribution in contact zone, leading to the different wear conditions. Sphere-plane contact makes possible to generate high pressures in the contact for relatively small normal applied load.

Most of the current friction test machines use plane or cylinder on a flat surface as a main contact pair. In such case, these machines ensure plane or line contact. However, in many industrial applications, considered later in this degree work, where high-loaded friction units are used, sphere-plane contact is present. There are very few methodologies describing and dealing with such contact. And they do have their advantages and disadvantages. Taking all the above-mentioned into consideration, it is actual to develop a methodology that will allow conducting wear resistance tests in a wide range of loading conditions. Furthermore, this methodology shall provide sphere-plane contact.

PART 1

WEARING PROCESSES IN AVIATION

1.1 Friction and wear as a phenomenon in mechanical engineering

When two surfaces, round or flat, are in contact and one is moving, we recognize that friction is preventing smooth and easy movement, that we may wish to squirt a bit of lubricant onto one surface to reduce the friction, and that one or both surfaces may show wear tracks after some time has passed. When engineers change the design of a shaft and bearing, the friction may be reduced and the bearing may show less wear. For existing machines, we make decisions about lubricants that will change friction and wear, hopefully in the direction of a longer useful life.

Friction creates heat, promotes wear, and wastes power, so the reduction of friction, by any means, is vital. It is estimated, that from 1/3 to 1/2 of the total energy produced in the world is consumed by friction.

Reduction of friction and wear leads to increases in service life, less downtime and lower operating costs, which can add up to tremendous savings.

But friction is not entirely bad. Without friction we could not drive a car, walk, write or play violin, or even light a match. Without friction, nails and screws would not hold parts together. Sometimes frictional force must be increased to improve safety conditions, such as in automobile brakes, friction clutches, and tires on icy roadways.

Friction is the resistance to relative motion of two adjacent bodies, whether they are solids, liquid or gas molecules [4]. When the sliding velocity is zero, the friction force required to start sliding is generally called the “static friction”. The friction force between two bodies that are moving relative to each other is “kinetic friction”.

For a given system, the static friction is usually greater than kinetic friction. No wonder, it takes more force to start moving a chair across a wooden floor and less force to keep it moving across the floor.

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact, occurring when two solid surfaces are in sliding or rolling motion. The rate of removal is generally slow, but steady and continuous [5]

Wear may take many forms depending upon surface topography, contact conditions and environment but, generally, there are two main types, mechanical and chemical.

The surface shape or topology depends upon the process used for forming, be it molding, casting, or cutting and abrading. As shown in figure 1.1, this is often seen microscopically as a series of asperities rather than the flat surface seen macroscopically.

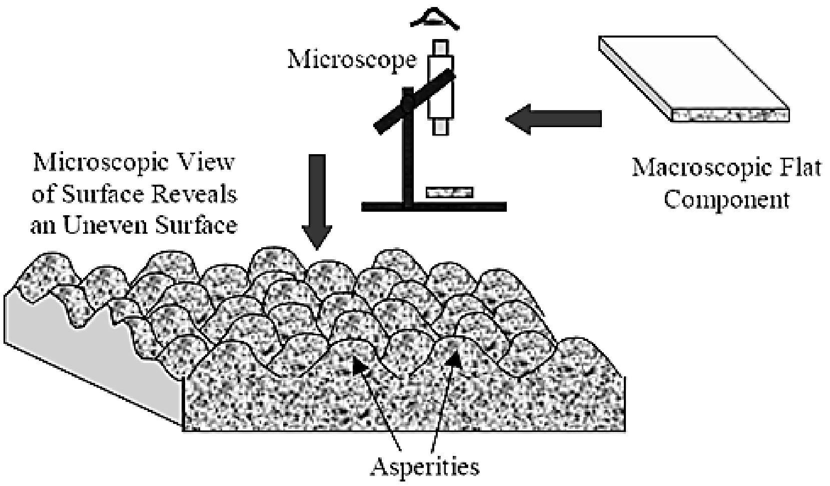


Figure 1.1 - Surface asperities of a nominal smooth surface

Mechanical wear involves processes, which may be associated with friction, abrasion, erosion and fatigue. Chemical wear arises from surface attack by reactive compounds and the subsequent rubbing or breaking away of the reaction products by mechanical action. The different types of wear may occur singly, sequentially or simultaneously, but all wear phenomena centre on a common characteristic, an overstressing of the surface.

The most common harmful forms of wear are abrasion, erosion, adhesion and fretting.

Abrasive wear (Figure 1.2) entails cutting or gouging of the surface of a solid metal when in contact with partially constrained but slowly moving, hard non-metallic or metallic particles from an adjacent, moving surface. The particles are confined between two surfaces being pressed together. Generally, no lubricants are used. Heat due to friction is always created. Wear debris from the solid, softer metal are destroyed in the process. Abrasion often occurs in ore or earth moving equipment.

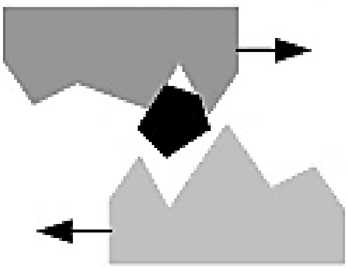


Figure 1.2 - Representation of abrasive wear

Erosion is similar to abrasive wear but the shearing force that degrades the metal surface is provided by free-moving solid particles that impact the wearing surface as they are conveyed by a flowing fluid – either liquid or gas. Larger, harder particles cause more damage than smaller, softer particles. If the fluid is corrosive to the wear surface then another mechanism – erosion-corrosion – occurs that combines both wear and corrosion so that the result is worse than either acting alone. Erosion and/or erosion-corrosion often occur on pump impellers, marine vessel propellers and in certain pressure valves.

Abrasion, erosion and erosion-corrosion are typically controlled by selection of a sufficiently resistant material for the given application. This material's key parameter is its high overall hardness or its surface hardness. Options include high hardness steels, steels with tungsten carbide particles added, high manganese steels, certain austenitic stainless steels and cobalt-based alloys. A case hardened surface layer can also be effective. In the case of erosion-corrosion, the corrosion resistance of the selected material for the given service conditions is usually more important than its abrasion resistance although both affect results.

Cavitation is a special form of erosion in which vapor bubbles in the fluid form in low-pressure regions and are then collapsed (imploded) in the higher-pressure regions (Figure 1.3). The implosion can be powerful enough to create holes or pits, even in hardened metal if the implosion occurs at the metal surface. This type of wear is most common in hydraulic pumps, especially those which have restricted suction inlets or are operating at high elevations.

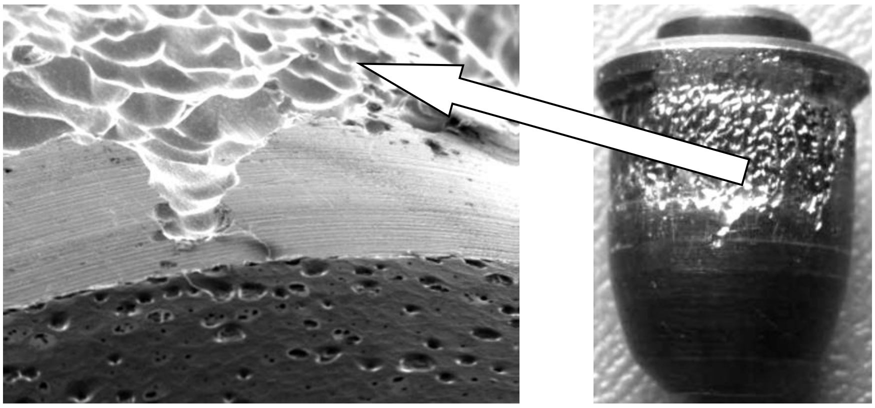
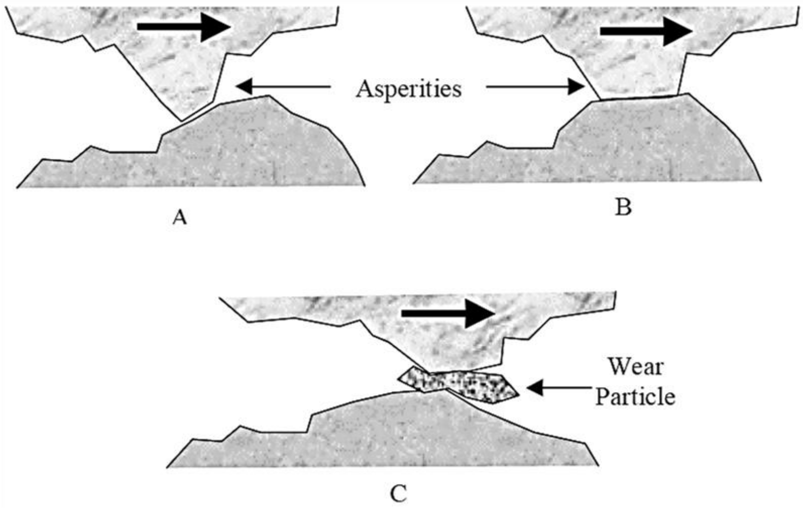


Figure 1.3 - Steam control valve cavitation damage

Restricting the oil from entering the pump suction reduces the pressure on the oil and, thus, tends to create more vapor bubbles. Cavitation can also occur in journal bearings where the fluid pressure increases in the load zone of the bearing. No metal-to-metal contact is needed to create cavitation.

Adhesive wear (Figure 1.4) is the result of micro-welding of the microscopic high points, called asperities, on two metal surfaces sliding on one another without a sufficient lubricant. As this continues, asperities break off and are transferred to the softer metal, while frictional heat causes interfacial temperature to increase. Failure is relatively common due to the many dynamic machine applications where a proper lubrication system is essential.



a) - contact of two surfaces, b) - gripping of two surfaces, c) - the appearance of the wear result.

Figure 1.4 - Schematic of generation of a wear particle as a result of adhesive wear process

Corrosion is often caused by the contamination or degradation of lubricants in service. Most lubricants contain corrosion inhibitors that protect against this type of attack. When the lubricant additives become depleted due to extended service or excessive contamination by moisture, combustion or other gases or process fluids, the corrosion inhibitors are no longer capable of protecting against the acidic (or caustic) corrosive fluid and corrosion-induced pitting can occur. The pits will appear on the metal surface that was exposed to the corrosive environment.

This may be the entire metal surface or just the lower portion of the metal that may have been submerged in water not drained from the oil sump or at the roller/race contact points. Generally, an even and uniform pattern of pits will result from this form of attack. Mild forms of moisture corrosion result in surface staining or etching. More severe forms are referred to as corrosive pitting, electro-corrosion, corrosive spalling or rust.

Moisture corrosion involves material removal or loss by oxidative chemical reaction of the metal surface in the presence of moisture (water). It is the dissolution of a metal in an electrically conductive liquid by low amperage and may involve hydrogen embrittlement. It is accelerated, like all chemical reactions, by increased temperatures. No metal-to-metal contact is needed. It will occur with a full oil fluid film.

Frictional corrosion is a general form of wear caused by loaded micromovements or vibration between contacting parts without any water contaminant being present, although humidity may be necessary. It may also be referred to as fretting wear. It includes both fretting corrosion and false brinelling, which in the past were often considered to be the same mechanism.

False brinelling occurs due to micromovements under cyclic vibrations in either static or rotating boundary lubrication contacts. Mild adhesion of the metal asperities is occurring. Shallow depressions or dents are created in which the original machining marks are worn off and no longer visible due to the wearing damage of the metal. False brinelling occurs on the rolling elements and raceway, similar to small-scale plastic deformation or brinelling and hence the name “false brinelling”.

False brinelling is usually associated with static nonrotating equipment and, thus, the wear appears at the roller contacts with the exact same spacing as the rollers. The depressions in the metal can appear shiny with black wear debris around the edges. If the equipment is rotating, the wear appears as a gray, wavy washboard pattern on the raceway. Reduced bearing life or failure ultimately occurs, sometimes in a catastrophic fashion, through surface fatigue initiating in these damaged surface layers.

An example of false brinelling occurs in standby electric motors and pumps (and others) which sit idle for periods of time, but are subjected to vibration from the plant floor up through the load-bearing rolling elements of the bearings. Antiwear additives may be beneficial in reducing the wear damage.

1.2 Fretting as a specific form of wear

Fretting wear (Figure 1.5) is defined as a special kind of wear, caused by small repetitive motion in an apparently stationary situation. The term “fretting corrosion” refers to the combination of fretting wear and corrosion, e.g. such as oxidation. Fretting wear will occur with almost any combination of materials under conditions of cyclic slip under load.

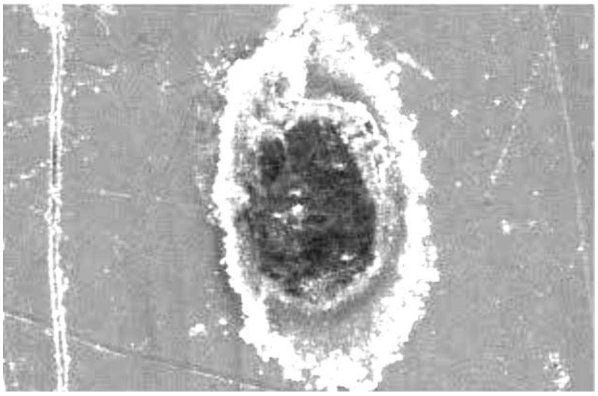


Figure 1.5 - Fretting wear example

It is generally agreed that when fretting wear is taking place between two flat surfaces or two conforming cylindrical surfaces (that is, conditions in which escape of debris is not as easy), the progress with time (or number of cycles) can be recognized as occurring in three stages [6, 7]:

1) Initial stage of a few thousand cycles when metal-to-metal contact is prevalent, resulting in local welding, roughening of the surface, high friction, and low contact resistance. Fatigue cracks are initiated in this stage if the movement is a result of cyclic stressing.

2) Formation of beds of compacted oxide with a fall in coefficient of friction and erratic behavior of contact resistance as it oscillates between high and low values.

3) Onset of a steady state in which the friction is more or less constant and the contact resistance is generally high with occasional momentary falls to a low value.

The length of the initial stage depends on the amplitude of slip and the normal load. Observation of the debris on steel shows that it is platelike. One of the early theories of fretting wear maintained that the debris arose by continual scraping and regrowth of oxide film [8]. A modification of this idea suggests, from evidence of sections through a fretted surface on a carbon steel, that there are three well-defined zones [9]:

1) Zone 1: outer layer of compacted oxide.

2) Zone 2: severe deformation in which grains are comminuted and oriented in the fretting direction.

3) Zone 3: plastic deformation (from which it is concluded that in the steady-wear state, flake like debris are formed by stripping oxide layers from the metal surface).

The opposite point of view is that metal particles, which become progressively ground up and oxidized between the fretting surfaces, are removed. The evidence for this is that with reactive metals, such as aluminum and titanium, the debris are flake like but contain metal [10]. In experiments in which steel filings were introduced between two hard inert surfaces and subjected to fretting, the metal was soon converted to oxide. How the metal particles are generated is still subject of controversy. However, in certain instances there is evidence that the particles are generated in the later stages of a delamination process (Figure 1.6).

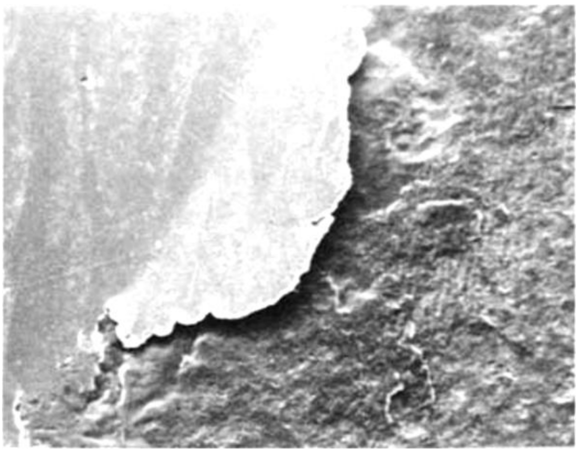


Figure 1.6 - Typical delamination in the fretted region produced by metal-to-metal contact

1.2.1 Fretting occurrence examples in machinery

Fretting movement, it follows that the most likely area for it to occur is in mechanical components. Typical, well known examples are the fretting wear of ball bearings in cars during railway transportation, and fretting wear of gold plated rack and panel connectors, when transported in assembled condition. In these cases the motion consists of internal vibrations that are caused by external excitation. However, micro-motion and fretting wear associated with it does not necessarily have to be in response to external, mechanical excitation. A well known, non-mechanical phenomenon that can cause it is the relative, small amplitude motion of surfaces in contact with each other due to different thermal expansion of the bodies carrying these surfaces. A specific example of such fretting wear is that of contacts in long edge connectors on printed circuit hoards that heat and cool in cycles.

The contacts between hubs, shrink- and press-fits, and bearing housings on loaded rotating shafts or axles are particularly prone to fretting damage, but because the movement arises from alternating stresses in the shaft surface, the problem is more one of fatigue than wear [11]. However, wear rather than fatigue can be a problem in bearing housings. Thin-shell bearings are universally used in diesel engines, and such bearings involve an interference fit between the bearing and the housing. If the contact pressure is not high enough, movement can occur, giving rise to the fretting damage.

Flexible couplings and splines, particularly where they form a connection between two shafts and are designed to accommodate some slight misalignment, can suffer severe fretting wear.

Jointed structures are another source of fretting problems. According to Mitchell [12], there is no such thing as a static joint on an aircraft. An aircraft structure is largely an assemblage of aluminum and steel components riveted together or joined by fasteners.

Even in a simple riveted joint, there are at least three possible sites where fretting can occur (Figure 1.7):

1) Between the riveted panels.
2) Between the underside of the rivet head and the panel.
3) Between the shank of the rivet and the rivet holes.

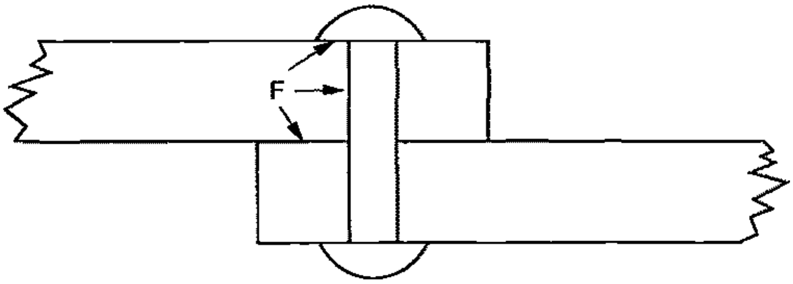


Figure 1.7 – Locations (indicated by F) prone to fretting in aluminum-steel riveted joint

Turbines, both steam and gas, operate under conditions that subject these components to fretting damage. There are three main sites:

1) Where the turbine disk is either shrink-fitted onto the driving shaft or attached to the shaft by means of a bolted flange.

2) Where the blades are fixed into the disk by either a dovetail or fir-tree type fixture.

3) Where snubbers at the outer ends of the blades contact those on adjacent blades.

The first two sites are more likely to be areas for fatigue crack initiation, but loss of material by wear of the snubbers will give rise to increased vibration of the blades and the onset of impact fretting. In some turbines, a wire is threaded through holes in the outer ends of the blades to dampen down vibration. In this case, the frictional energy dissipated in the fretting process is the effective agent and may be said to be one of the few cases where fretting is beneficial.

1.2.2 Fretting affecting parameters

Experimental investigations have concentrated on the effect of specific physical variables (such as amplitude of slip, normal load, frequency of vibration, and the circumstances of the fretting situation, type of contact, mode of vibration, and the condition of the surfaces) to indicate how the problem can be overcomed in the future design of contacting components. These results are discussed below.

Amplitude of slip. Tomlinson [13] established that relative movement was essential for fretting to occur and showed that extremely small movements of the order of a few nanometers were capable of causing damage. The small-amplitude characteristic of fretting is the basis of many of the important features of the process. It means that the relative velocities of the two surfaces are much lower, even at high frequencies, compared with conditions in unidirectional sliding. At a frequency of 25 Hz and an amplitude of 25 μm, the average velocity is 1.25 mm/s, whereas sliding speeds in bearings arc of the order of 1 m/s. Debris tend to stay where they generated, so that high spots (for example, machining marks) become imprinted on the other surface if it has a higher degree of finish. Debris may never become exposed to the atmosphere and can become compacted under the compressive load, often changing its appearance.

Normal load. When two surfaces are placed in contact and loaded, plastic deformation of contacting high spots (asperities) occurs, as established by Bowden and Tabor [14].

Frequency. It was found an increase in wear volume at low frequencies for a given number of cycles. This was related to the formation and disruption of oxide films and was considered by Waterhouse [15]. In the total-slip situation, there is little effect over the frequency range 100 to $20 \cdot 10^4$ Hz, and these high frequencies could be used in accelerated tests. Not all movements that can lead to fretting damage take place at anything like the frequencies mentioned above. Relative movement can be due to differential thermal expansion, which, if arising from diurnal changes in temperature, can have a frequency of only a few cycles a day. The pressurizing of airplane cabins is in a similar frequency range. The movement of mooring cables due to water flow is of considerably higher frequency but is assumed to be ~ 0,1 Hz. In such circumstances, the environmental and corrosion effects have much greater importance.

Surface finish. Early observations of practical examples of fretting damage suggested that the more highly polished the contacting surfaces, especially if flat, the worse the damage. On polished aluminum where the debris are largely $A1_2O_3$ (corundum) with a high hardness, it could spread the damage, whereas on a rough surface the debris can escape into the hollows between the real contact areas. There is also the possibility that on a rough surface, if the exciting force is of small amplitude, some of the relative movement will be taken up by elastic deformation of the asperities. Some work by Calhoun shows that a rougher surface suffers less damage [16].

Type of contact. When the role of fretting debris in the process is discussed, the ease with which debris can escape from the contact region is an important factor in the fretting process itself. It also gives rise to further problems by contamination of other surfaces (in a machine, for example). With flat contact surfaces, however, the initiation and development of areas of wear damage are sporadic no matter how carefully the surfaces are prepared and the alignment controlled. Contacts consisting of geometrical surfaces such as sphere on flat, cylinder on flat, and crossed cylinders allow some initial calculations based on elastic theory of the area of contact and stress distribution therein. However, these quantities are rapidly changed as the wear process proceeds. Also, such contacts increase the possibility for debris to escape. It has recently been shown that the escape of debris in the crossed-cylinder arrangement is greatly influenced by the direction of motion. Debris are being pushed out by the axial movement of the upper cylinder, leading to more frequent metal-to-metal contact and a higher wear rate. However, in experimental investigations, the ease and cost of preparing specimens are significant factors, and the crossed-cylinder arrangement is one of the most convenient.

1.2.3 Fretting damage prevention methods

The steps that can be taken to reduce or to eliminate the damage due to fretting are extremely diverse, and each case or prospective case needs to be analyzed individually in order to select the most promising method to be applied. Here are some general indications of how the problem can be tackled.

Improved design. Because fretting only arises where there is relative movement between two surfaces, the elimination of this movement is a prime objective. Fretting often arises as a result of a stress concentration. In any case, reducing the stress via improved design (for example, raised wheel seats or stress-relieving grooves in hub/axle assemblies) is demanded by fatigue considerations. Increasing the normal pressure by reducing the area of contact (when the normal load is to be kept constant) or increasing the normal load will reduce the area of slip, but such action may introduce fatigue problems. The ultimate goal is to make the component in one piece and to get rid of the junction, but this is not always possible.

Surface finish. Rougher surfaces are less prone to fretting damage than highly polished surfaces.

Coatings. Surface treatments that radically change the chemical composition of the surface can be divided into three categories:

1) Methods where foreign atoms or ions are introduced into the existing surface by diffusion (for example, carburizing, nitriding, chromizing, and aluminizing) or by bombardment (for example, ion implantation).

2) Methods where the surface reacts with a chosen environment to form a compound (for example, oxidation, anodizing, and phosphating).

3) Methods where an entirely foreign material is applied to the surface (for example, electro deposition, plasma spray, ion plating, physical vapor deposition, and chemical vapor deposition).

Most of these coatings are harder and consequently more brittle than the substrate, which, if it is not strong enough, will plastically deform in the fretting contact, where local stresses can be high. This plastic deformation will crack and break up the coating. If the coating is particularly hard (for example, titanium nitride, with a hardness of 300 HV), further damage can occur by abrasion [17].

The Carbon content in the steel determines whether it can be directly hardened. If the Carbon content is low (less than 0.25% for example) then an alternate means exists to increase the Carbon content of the surface. The part then can be heat-treated by either quenching in liquid or cooling in still air depending on the properties desired. This method will only allow hardening on the surface, but not in the core, because the high carbon content is only on the surface. This is sometimes very desirable because it allows for a hard surface with good wear properties (as on gear teeth), but has a tough core that will perform well under impact loading.

Carburizing is a process of adding Carbon to the surface. This is done by exposing the part to a Carbon rich atmosphere at an elevated temperature and allows diffusion to transfer the Carbon atoms into steel. This diffusion will work only if the steel has low carbon content, because diffusion works on the differential of concentration principle. If, for example the steel had high carbon content to begin with, and is heated in a carbon free furnace, such as air, the carbon will tend to diffuse out of the steel resulting in Decarburization.

Pack Carburizing. Parts are packed in a high carbon medium such as carbon powder or cast iron shavings and heated in a furnace for 12 to 72 hours at 900 ºC (1652 ºF). At this temperature CO gas is produced which is a strong reducing agent. The reduction reaction occurs on the surface of the steel releasing Carbon, which is then diffused into the surface due to the high temperature. When enough Carbon is absorbed inside the part (based on experience and theoretical calculations based on diffusion theory), the parts are removed and can be subject to the normal hardening methods.

The Carbon on the surface is 0,7 % to 1,2 % depending on process conditions. The hardness achieved is 60 - 65 RC. Depth of the case ranges from about 0,1 mm up to 1,5 mm. Some of the problems with pack carburizing is that the process is difficult to control as far as temperature uniformity is concerned, and the heating is inefficient.

Gas Carburizing. Gas Carburizing is conceptually the same as pack carburizing, except that Carbon Monoxide (CO) gas is supplied to a heated furnace and the reduction reaction of deposition of carbon takes place on the surface of the part. This process overcomes most of the problems of pack carburizing. The temperature diffusion is as good as it can be with a furnace. The only concern is to safely contain the CO gas. A variation of gas carburizing is when alcohol is dripped into the furnace and it volatilizes readily to provide the reducing reaction for the deposition of the carbon.

Liquid Carburizing. The steel parts are immersed in a molten carbon rich bath. In the past, such baths have cyanide (CN) as the main component. However, safety concerns have led to non-toxic baths that achieve the same result.

Nitriding is a process of diffusing Nitrogen into the surface of steel. The Nitrogen forms Nitrides with elements such as Aluminum, Chromium, Molybdenum, and Vanadium. The parts are heat-treated and tempered before nitriding. The parts are then cleaned and heated in a furnace in an atmosphere of dissociated Ammonia (containing N and H) for 10 to 40 hours at 500-625 ºC. Nitrogen diffuses into the steel and forms nitride alloys, and goes to a depth of up to 0,65 mm. The case is very hard and distortion is low. No further heat treatment is required; in fact, further heat treatment can crack the hard case. Since the case is thin, surface grinding is not recommended. This can restrict the use of nitriding to surfaces that require a very smooth finish.

Carbonitriding process is most suitable for low carbon and low carbon alloy steels. In this process, both Carbon and Nitrogen are diffused into the surface. The parts are heated in an atmosphere of hydrocarbon (such as methane or propane) mixed with Ammonia (NH_3). The process is a mix of Carburizing and Nitriding.

Carburizing involves high temperatures (around 900 ºC) and Nitriding involves much lower temperatures (around 600 ºC). Carbonitriding is done at temperatures of 760 - 870 ºC, which is higher than the transformation temperatures of steel that is the region of the face-centered Austenite.

It is then quenched in a natural gas (Oxygen free) atmosphere. This quench is less drastic than water or oil-thus less distortion. However, this process is not suitable for high precision parts due to the distortions that are inherent. The hardness achieved is similar to carburizing (60 - 65 RC) but not as high as Nitriding (70 RC). The case depth is from 0,1 to 0,75 mm. The case is rich in Nitrides as well as Martensite. Tempering is necessary to reduce the brittleness.

Carburizing and nitriding of steels is a well-established treatment for reducing wear in gears and is also effective against fretting [18]. Electrodeposited coatings are extensively used in electrical contacts; gold alloys are the preferred coating because they are not subject to oxide formation, which is disastrous in its effect on conductivity.

The growth of oxide films at high temperatures has been specified above to provide wear-resistant **self-repairing** coatings. These have been improved by ion implantation, particularly in titanium alloys, to give coatings that have low friction and low wear [19].

Anodizing is applied to aluminum alloys and the hard coating provides protection against fretting, but it may cause wear of the opposing surface.

Inserts. Separation of the two surfaces by an insert, either a shim of a soft metal or a shim of a polymer with a low elastic modulus, will sometimes be effective. The intention is to take up the movement by either plastic deformation or elastic deformation of the material. A combination of metal and polymer can be more effective because it combines the advantages of both materials the low elasticity of the polymer and the good conductivity of the metal. Bronze-filled polytetrafluorethylene when fretted against steel has a very low friction coefficient and undetectable wear [20].

Lubricants. Lubricants are usually difficult to apply in fretting contacts because of the difficulty of maintaining the lubricant in the contact, but lubricants are included in the construction of steel ropes. Solid lubricants applied to the surfaces reduce the coefficient of friction initially, but eventually tend to wear away [21].

1.3 Semi-fluid greases for friction mechanisms lubrication

Depending on the application, grease can present several benefits over fluid lubrication. Greases provide a physical seal preventing contamination ingress, resist the washing action of water, and can stay in place in an application even in vertically mounted positions. Greases are uniquely suited for use in applications where relubrication is infrequent or economically unjustifiable, due to the physical configuration of the mechanism, type of motion, type of sealing or the need for the lubricant to perform all or part of any sealing function in the prevention of lubricant loss or ingress of contaminants. Due to their semisolid nature, greases do not provide application cooling and cleaning functions associated with the use of a fluid lubricant. With these exceptions, greases perform all other functions of a fluid lubricant. While fluid lubricants are typically preferred by design, the aforementioned mechanical circumstances will always exist and thus the need for grease remains. As a result, greases are used in approximately 80% of rolling elements bearings.

Grease components. Greases are manufactured by combining three essential components: base oil, thickener, and additives.

Base Oils. Base oil comprises the largest component of a grease, representing 80 – 97 % by weight. The choice of base fluid may be mineral oil, synthetic oil, or any fluid that provides lubricating properties. It must be noted that the base oil portion of a grease performs the actual lubrication except in very slow or oscillating applications. The same rules applied to determine proper viscosity grade in a fluid lubricant apply to the selection of the base oil portion of lubricating grease.

Thickeners. The thickener may be any material that, in combination with the base oil, will produce the solid to semi-fluid structure. Simply put, a grease thickener in combination with the base oil acts much the same way as a sponge holding water. Principal thickeners used in greases include lithium, aluminum, calcium soaps; clay; polyurea; either alone or in combination. Lithium soap is the most common thickener in use today.

Additives. As in lubricating oil additives, grease additives and modifiers impart special properties or modify existing ones. Additives and modifiers commonly used in lubricating greases are oxidation or rust inhibitors, polymers, extreme pressure additives, anti-wear agents, lubricity or friction-reducing agents (soluble or finely dispersed particles such as molybdenum disulfide and graphite) and dyes or pigments. Dyes or pigments impart color only having no effect on grease's lubricating capability.

Grease consistency. Consistency is defined as the degree to which a plastic material resists deformation under the application of force. In the case of lubricating greases, this is a measure of the relative hardness or softness and has some relation to flow and dispensing properties. Consistency is measured by cone penetration of lubricating grease.

Cone Penetration. Grease consistency is measured at 25 °C after the sample has been subjected to 60 double strokes in the grease worker. After the sample has been prepared, a penetrometer cone is released and allowed to sink into the grease under its own weight for 5 seconds (Figure 1.8). The depth the cone has penetrated is then read, in tenths of a millimeter. The further the cone penetrates the grease, the higher the penetration result and the softer the grease.

Figure 1.8 - Penetrometer cone released in grease

The most common grease grade represents a smooth, buttery consistency.

It must be noted that grease consistency is related to thickener content and has no relationship to base oil viscosity.

Grease Structural Stability. Mechanical stability. This is an essential performance characteristic of lubricating grease as it is a measure of how the grease consistency will change in service when it is subjected to mechanical stress (shear) resulting from the churning action caused by moving elements or vibrations generated by, or external to, the application. Grease softening in a bearing may eventually cause grease to leak out from the housing, requiring more maintenance and frequent grease replenishment to avoid premature failure resulting from lack of lubricant on the rolling elements. In order to have good mechanical stability, greases are developed through careful selection of the thickener composition and optimization of the manufacturing process. Mechanical stability abroad is often measured using the ASTM (American Society for Testing and Materials) 9D217 prolonged worker test (e.g., 100,000 double strokes), or the ASTM D1831 Roll Stability test [22]. ASTM D1831 subjects the grease to shearing by rotating a cylinder containing a 5 kg roller at 165 rpm for 2 hours. The change in penetration at the end of the tests is a measure of the mechanical stability. Figure 1.9 illustrates extreme mechanical softening of one grease on the left compared to little softening of another grease on the right. This test produces low shearing forces approximately equal to those found in the grease worker used for ASTM D217.

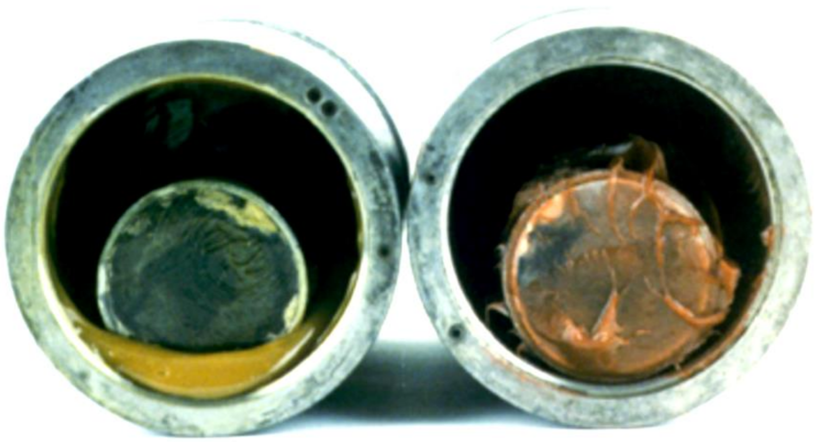


Figure 1.9 - Grease at end of ASTM D1831 Roller Test

In application and use, ingress of environmental contaminants is unfortunately a common reality that often adversely affects the mechanical stability of the grease. It is important that greases not only be developed to provide excellent structural stability in a pristine state, but also in the presence of environmental contaminants such as water, process fluids, or other contaminants. This can be assessed by means of laboratory bench tests operating in a variety of conditions with presence of water.

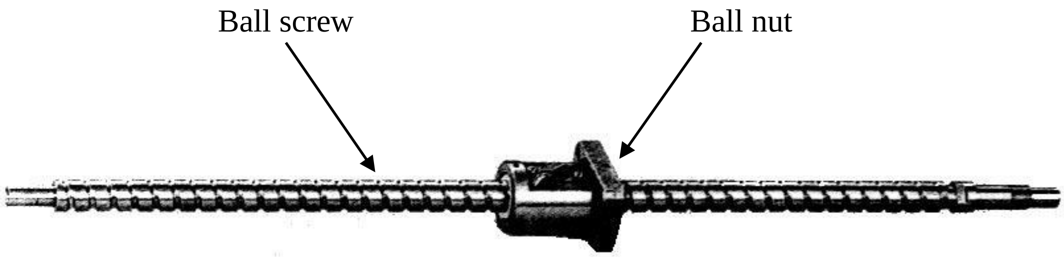
Dropping point. The dropping point of grease is the temperature at which the thickener loses its ability to maintain the base oil within the thickener matrix. This may be due to the thickener melting or the oil becoming so thin that the surface tension and capillary action become insufficient to hold the oil within the thickener matrix. A small grease sample is placed in a cup and heated in a controlled manner in an oven-like device. When the first drop of oil falls from the lower opening of the cup, the temperature is recorded to determine the dropping point. Dropping point is a function of the thickener type. High drop points, typically above 240 °C, are commonly observed for lithium complex, calcium complex, aluminum complex, polyurea and clay greases while much lower dropping points are typical of conventional lithium (180 °C), calcium (180 °C) and sodium (120 °C) soaps. The dropping point is one of the determinations that characterize the grease’s thermal stability. However, it is not an accurate prediction of the grease’s upper operating temperature limit which is a function of many variables such as base oil oxidation stability, additive degradation, thickener shearing, oil separation and so forth. A high dropping point, while not a predictor of upper operating temperature, is an indicator of the maximum peak temperature that the grease may be subjected to for a short duration while not releasing oil excessively and therefore drastically reducing the life of the grease and potentially damaging the application in the long run.

1.4 Industrial application of sphere-plane contact

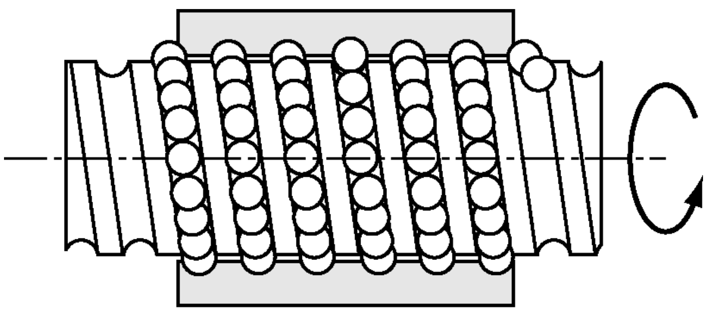
Sphere-plane contact is widely used in machinery. Let me just give some well-known examples of this contact usage: ball screws, constant velocity joints, overrunning clutches, ball bearings, ball type check valves etc. Below is the brief discussion of presented friction units that use sphere-plane contact in their design.

Ball screws (Figure 1.10). When you rotate a ball nut around its axis, the ball nut moves in its axial direction since screw grooves are continuously provided in a helical form. Namely, the screw is a mechanical element that converts a rotational motion into a linear motion. These screws that move things or transmit forces are the means to convert small rotational force into large thrust (a force to push).

Yet, the technology of their manufacture is complex and for its realization special equipment is needed.



a)



b)

a) - ball-screw general view, b) - mechanism

Figure 1.10 - Representation of ball-screw general view a) and mechanism b)

“CV joint” is short for **constant-velocity joint**, an example of a type of mechanisms that connects two intersecting rotating shafts making an angle with one another, especially when this angle varies in service. In other words, it is a mechanical coupling in which the rotational speed of the output shaft is the same as that of the input shaft whatever the operating angle of the joint.

These joints are now very widely used in front-wheel drive cars at the connection of a half-axle with a wheel. They transmit torque evenly when the wheel moves in steering or suspension.

In most applications, the inboard constant velocity joint is a plunge joint that allows the effective length of the side shaft to change due to suspension travel. In front (or steer) axle applications, the outboard joint must transfer torque effectively through a wide angle (up to 52 degrees). In rear axle applications, joint operating angles are much lower.

Perhaps, the most well-known is the **Rzeppa constant velocity** joint (Figure 1.11). This joint is a ball-bearing type in which the balls furnish the only of driving contact between the two halves of the coupling. A Rzeppa constant velocity joint consists of a star-shaped inner race, several ball bearings, bearing cage, outer race or housing, and a rubber boot.

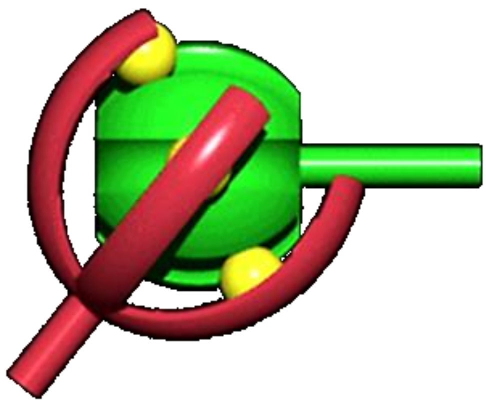


Figure 1.11 - Schematic representation of Rzeppa joint.

Overrunning clutch (Figure 1.12) is used to connect two coaxial shafts or a shaft to a freely moving part that is seated on the shaft. An overrunning clutch transmits rotary motion and torque from a driving member to a driven member in one direction only.

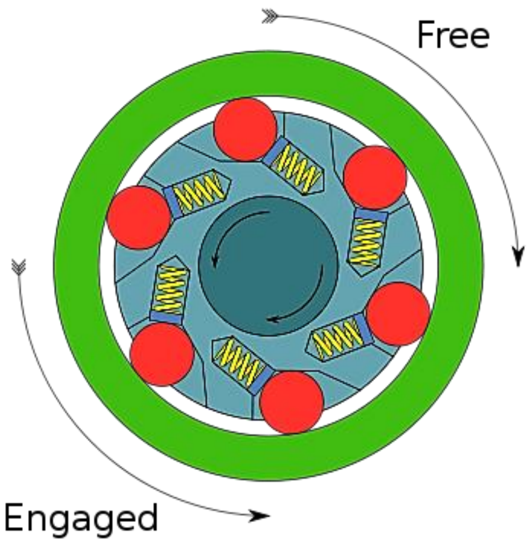


Figure 1.12 - Overrunnig clutch

Ball check valves are simple in operation and commonly used on small pumps and in low head systems. This valve is depicted on figure 1.13.

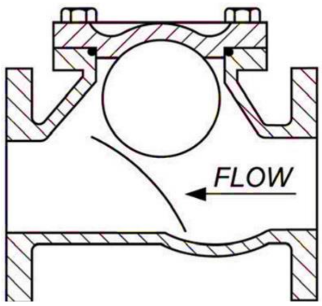


Figure 1.13 - Ball check valve

Ball bearings (Figure 1.14) are used primarily to support rotating shafts in mechanical equipment. They can be found in everything from personal computers to passenger cars and aviation engines. A ball bearing consists of an inner ring, an outer ring, a complement of balls, and a separator to contain the balls. The balls fill the space between the two races and allow the bearing to rotate smoothly within the grooves.

Figure 1.14 - Rotary ball bearing

Linear ball bearings (Figure 1.15) are ball bearings designed to support loads that move along a straight line, rather than rotating about an axis. Linear ball bearings usually consist of an outer ring, a ball retainer, balls and two end rings. The linear bearing is designed so that balls roll directly on the surface along which the bearing moves. These bearings provide increased precision and greater longevity than do simple sliding bearings. They are easy to install or replace and usually require minimum maintenance. Linear ball bearings are occasionally referred to as linear guides and are widely used in precision machinery, medical instrument s, agricultural equipment and automated production equipment.

Figure 1.15 - Linear bearings (ball-type)

Conclusions to part 1

Friction is always present in mechanical contacts; it is inevitable phenomenon. Because of friction, wear is obtained, adverse effect of which is one of the main reasons of machine elements' failure. In its turn, fretting wear damage is one of the most widespread damages of aerospace and mechanical engineering, which, according to statistics, constitutes nearly 50 % of all kinds of wear. Therefore, it is necessary to investigate tribological contacts for wear resistance in conditions of fretting to ensure their durability and reliability.

Nitriding, as a treatment that fights against fretting phenomenon, highly increases wear resistance of friction surface of high-loaded steels. Wear resistance increase constitutes minimum 10 %, which positively affects friction unit and, consequently, detail life.

The usage of semi-fluid lubricants in friction nodes considerably decreases surface wear and prolongs detail life. There are lots of semi-fluid consistent lubricants, which are utilized in friction units, where the usage of fluid lubricants is impossible.

PART 2
RESEARCH METHODOLOGY

2.1 Analysis of present methodologies of conducting wear resistance tests

It is well demonstrated earlier, that there could be countless applications, where it is important to quantify the friction characteristics or generally investigate and conduct experiments using the contact of a particular spherical shape on a particular surface.

There are many methodologies on carrying out fretting tests. But most of them deal with plane-planem cylinder-plane, cylinder-cylinder or sphere-sphere contact, although plane-sphere contact can still be met. Below are the examples of fretting test methodologies.

In a scientific research of [23] fretting tests have been carried out using sphere-plane configuration, where the radius of sphere was 50 mm. Specific fretting device has been rigidly mounted on the universal fatigue machine. Schematic diagram of fretting test equipment is presented in the figure 2.1.

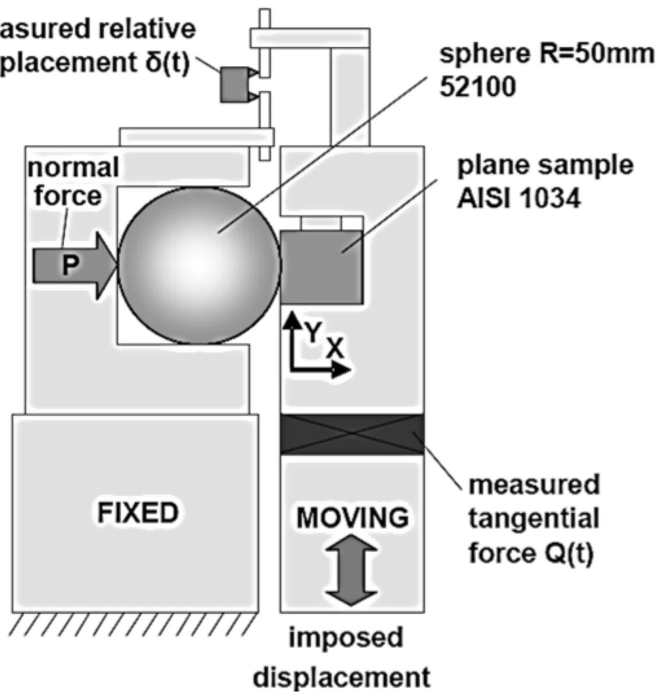


Figure 2.1 - Schematic diagram of fretting test device in sphere-plane configuration.

During the test, applied normal force *P* has been kept constant, sinusoidal displacement has been successively increased. The normal force *P*, tangential force *Q* and relative displacement δ have been recorded. All experiments have been performed at displacement frequency of 20 Hz. Before the tests, all specimens have been cleaned in acetone and ethanol. Tests have been performed in ambient labolatory conditions at the temperature ~ 23 ºC, and the relative humidity between 40 % and 45 %.

In the paper of [24] it is stated that tribometer as an experimental device was used for friction and wear. The schematic representation of the alternative sphere on plane tribometer is presented in figure 2.2. Depending on the tribometer, the contact geometry can be sphere-plane, cylinder-plane, cylinder-cylinder or plane-plane. The author points out that in the case of the sphere-plane contact geometry adjustment of the contact is easy and high pressures are generated in the contact (1 GPa) for relatively small normal applied load (12 N). Ball diameter is 9,5 mm. It is made of 52100 AISI steel as well as the plane.

Depending of the system, the normal load can be applied by a mass deposited onto the arm of the tribometer or by an elastic device (spring). The normal and friction forces are measured either by piezo electric transducers or strain gauges devices. Control of the tribometer, data acquisition and treatments are done using computer.

The authors [25] propose the next fretting test methodology.

The schematic view of the present sphere-on-plane friction tester is shown in figure 2.3. Sphere specimen is fixed to the end of an arm. The counter weight is put on the other end of the arm to keep balance of the arm. The arm is supported by two ball bearings which are fixed on the slide guide with two leaf springs. The horizontal dotted line means that the contact point of two specimens and the center of ball bearings are on the horizontal line. Normal force is applied by putting weights directly on the weight table. The friction force is measured by strain gauges which are set on the leaf springs.

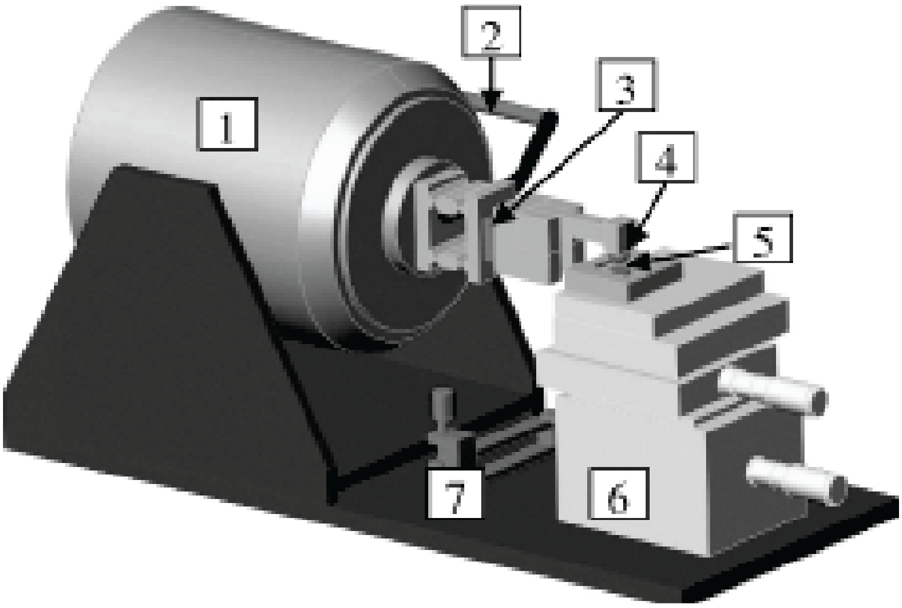


Figure 2.2 - Schematic representation of an alternative sphere-plane tribometer:

a) – motor; b) - displacement transducer; c) - triaxial force transducer; d) – sphere; e) – plane; f) - x,y,z adjustable sample holder; g) - elastic device for normal load application.

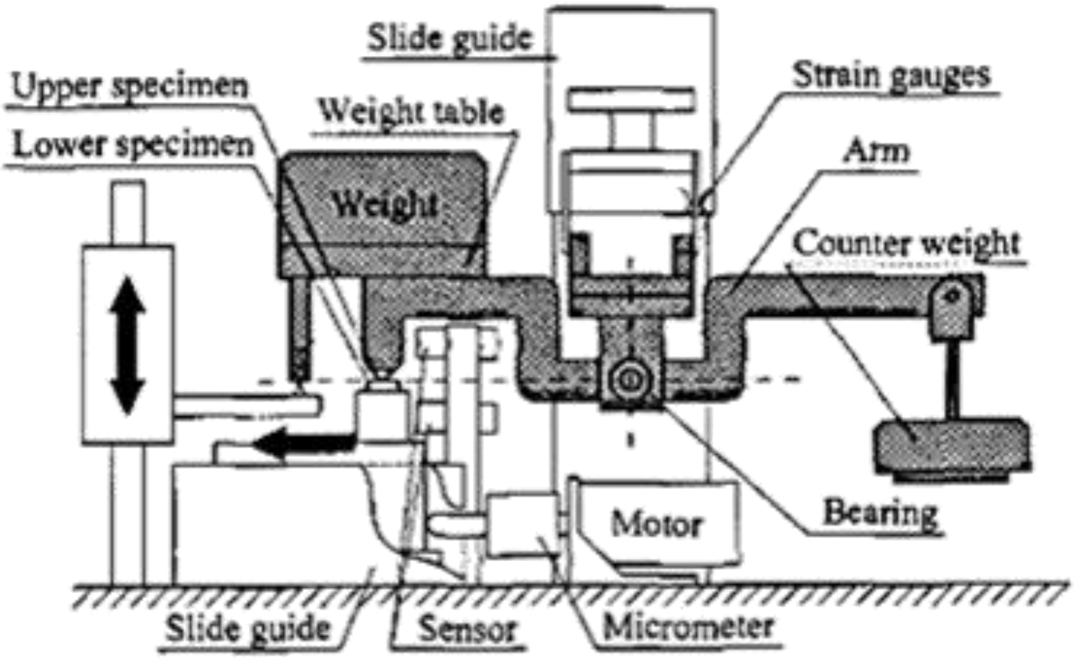


Figure 2.3 – Experimental apparatus

Two displacement sensors are used to measure the relative displacement between the lower and the upper specimens.

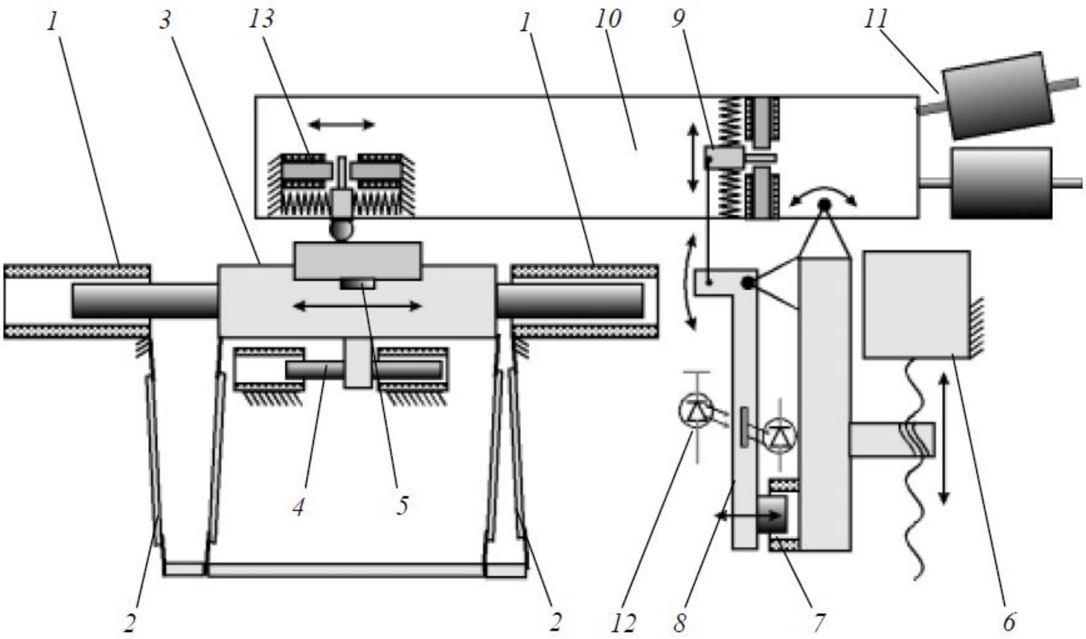
The sliding friction tests between sphere (SUJ2) and plane (0.45 % carbon steel) were carried out under a dry condition.

The combinations of two specimens are five kinds. Upper and lower specimens are a sphere of SUJ2 in a diameter of 9,52 mm and a column (contact surface is flat) of S45C in a diameter of 15 mm respectively. The normal force was set from elastic contact force of l N, 2 N to elastic-plastic contact force of 30N with intervals of approximately 1,5 times in the contact pressure. The normal force was applied for a 20 seconds before the start of the sliding friction test. The lower specimen was moved in the speed of 50 vm/s. The contact time and the moving speed of lower specimen were constant in all tests.

Another methodology is proposed by [26]. The instrument parameters were adopted in accordance with the loading conditions: controlled normal load of 10 mN - 1 N, sliding speed 0,1-10 mm/ s. sphere-plane scheme was chosen to carry out tribological tests, that is the most accurate method to calculate the area of the contact points and the contact pressure values, as well as eliminate the inevitable influence of inclination of the indenter and the plate on the geometry of the contact. Ball diameter is selected in the range of 1-5 mm, depending on the desired contact pressure. The coatings are applied on the plate, typically silicon. The test coating may also be applied to the ball to broaden the range of investigated pairs of friction. For qualitative assessment of processes of changing the structure of of the surface layers of the sample prior to the start of their irreversible damage during testing, the device is equipped with a recording unit of acoustic emission . Transmission, reception and processing of data is carried out using a personal computer. Software allows to set the speed of movement of the sample, the magnitude of the normal load and the length of the track to record the amount of force and the friction coefficient, as well as the counting rate and amplitude of AE signals during testing. These data may be stored in a file for further analysis. Besides, it is possible to visualize and save the results in a unit testing cycle file, which is important in the study of friction and the transition to sliding friction. Testing with high frequency and small amplitude motion of the sample makes it possible to study the dynamics of fretting wear. The process of testing is fully automated.

Loading system. Normal load on the indenter and the sample set is kept constant during the test using electromagnetic feedback system. Tractive force of the electromagnet 7 (Figure 2.5), is transmitted by a lever 8 through the load sensor 9 for swinging head 10. Initial balancing of the head is carried out by means of loads 11. The angular position of the head is monitored via the optocoupler 12 a signal of which depends on the angle of inclination of the lever 8. Electromagnet 7 and a load sensor 9 are electrically connected in a circuit with feedback, which ensures maintaining a normal load constant regardless of vertical displacement of head caused by the error of manufacture and installation of the sample. Stepper drive 6 serves to supply indenter to the sample surface before testing, as well as removal from the surface at the end of testing.

Analyzing all mentioned above methodologies, one can make a conclusion that without any doubt each of the given installations has its own advantages and disadvantages. As the result of one conducted experiment, we obtain one contact point. All of them provide relatively small loading (from 10 mN to 30 N), which may not comply with some real load conditions. It is actual to develop a methodology that will satisfy all other conditions and be able to conduct tests in conditions of fretting at sphere-plane contact.



a) - drive electromagnets; b) – guides of bending; c) – table-holder of the sample; d) – position sensor; e) – sensor of tribo-acoustic emission; f) – stepper drive; g) – loading system electromagnet; h) – lever; i) – loading sensor; j) – head; k) – balancing loads; l) - optocoupler; m) – friction force sensor

Figure 2.5 – Scheme of microtribometer

2.2 The prototype test machine

The performance of investigations in conditions of fretting and fretting corrosion is characterized by diversity of methodologies that are used, i.e. schemes of loading and type of contact as well as estimation of surface damage. The choice of methodology needs to be in correspondence with two requirements:

1) Fretting imitation in laboratory conditions should be as close as possible to the conditions of appearance of this kind of surface damage in real structures.

2) The chosen methodology should give the possibility to make comparison of obtained results with the data from other sources.

Test machines, should meet the following requirements taking into account the specifics of fretting appearance:

1) Backlash-free mounting of samples in the clamping devices.

2) Torsion rigidity and low deformability of device.

3) Presence of vibro-sliding motion of regulated frequency and amplitude.

4) The presence of a controlled normal force to create the necessary contact pressure.

5) Possibility of supplying lubricant or other medium.

Wear resistance tests were conducted on a modified installation imitating vibration МФК-1 (Figure 2.6). Test machine allows conducting experiments at the next parameters:

1) Loading of samples in axial direction by forces from 200 to 1000 N.

2) Reciprocating rotary movement of counter sample relative to immovable sample with frequency from 10 to 30 Hz and amplitude from 10 to 1000 mcm.

3) Installation measuring system provides a continuous recording in the process of testing number of cycles of reciprocating rotary motion of counter sample with error no more than 50 cycles.

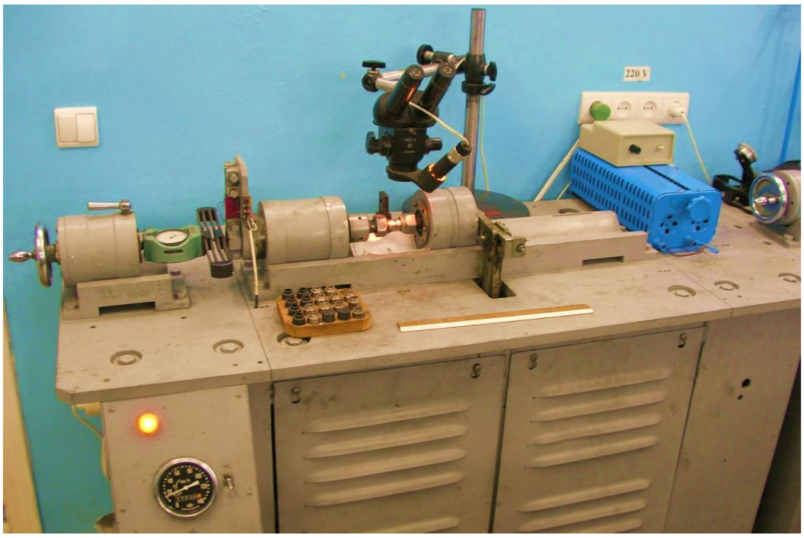
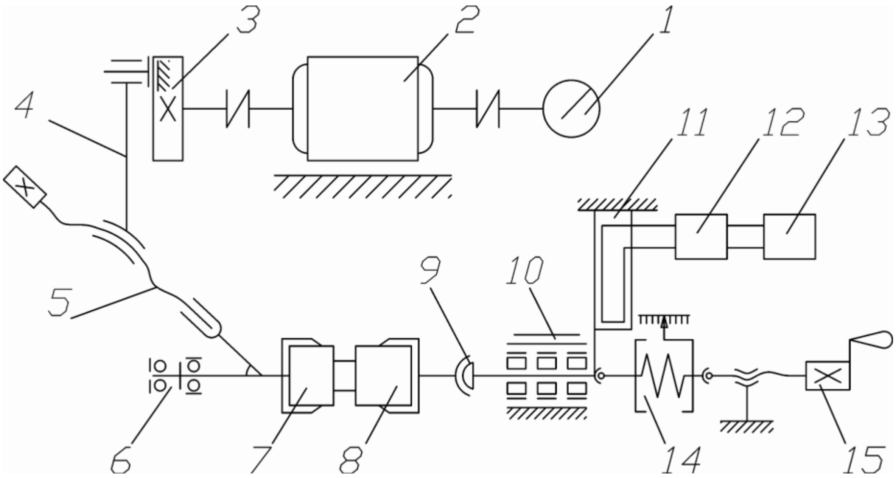


Figure 2.6 – General view of the МФК – 1 installation for the testing on fretting

2.3 Kinematical scheme and installation description

Layout of the installation is shown on figure 2.7.



1 – revolution counter; 2 – electromotor; 3 – eccentric; 4 – vertical rod;
5 – adjusting device; 6 – horizontal rod; 7 – moving sample; 8 – fixed sample;
9 – self orienting collet; 10 – movable head; 11 – tenzo beam; 12 – amplifier;
13 – registering apparatus; 14 – dynamometer; 15 – loading device

Figure 2.7 – МФК-1 installation layout

Installation works as follows: electromotor *2* transmits the rotational motion to the eccentric *3* of adjustable eccentricity. Rotational frequency and the quantity of revolutions are recorded by the device *1*. Eccentric *3* through the rod *4* is related to the crank *6* of the drive *7* axis *6* of control sample *8* swing-rotation motion. Amplitude of the displacements of the control sample *8* is regulated by the eccentric device *5*. Fixed sample *8* is fixed in the centered collet *9* installed on the shaft of the movable head *10*. Samples are loaded by the dynamometer *14* and loading device *15*. Value of the axial loads on the specimens is recorded by the dynamometer ЗІП 02-79 type ДОСМ-3-0,2 (ГОСТ 2283-79) with the boundary measurements from 0.2 to 2 kN. Registration of friction force is done by the device НО71.5М *13* through the amplifier 8-АНЧ-7М *12* with the help of tenzo beam *11*.

The number of test cycles has to be controlled by the counter, located on the front panel of the aggregate.

Oscillation amplitude is governed by the change of eccentric eccentricity (roughly) and by changing of the length of the horizontal rod length (exactly). The rough amplitude regulation allows changing of its size from 10 to 1000 microns, the exact one – from 5 to 15 microns. The amplitude of relative displacement is defined as the oscillation difference of movable and fixed samples. Measuring of the amplitude is held directly on the samples using the optical binocular microscope МБС-2 (with an increasing from 8 to 56 times), using the strobe effect (stroboscope ТСТ-100).

The essence of the method is that the movable counter sample which touches the immovable cylindrical sample by its end face at a given load is driven by reciprocating rotary motion at specified amplitude and frequency. Immovable sample wear is measured for a given quantity of cycles, by the value of which is wear resistance of researched material is determined.

2.4 Modifiied installation

The peculiarity of the installation is the developed holder (Figure 2.8), which allows conducting tests with real balls. Holder *3* is a cup-like sleeve, which by means of screws *2* rigidly fixes three balls *1*. Thus, sphere-to-plane contact is formed, in which the tests on fretting-corrosion simultaneously involve three balls.

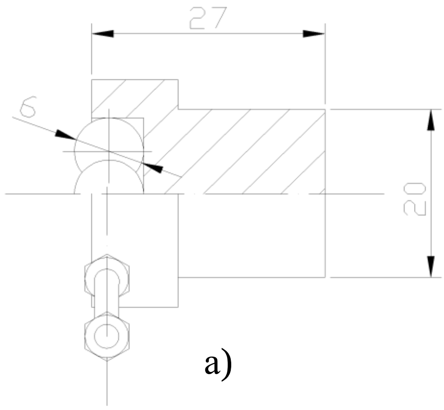
Samples for conducting experiments were chosen as follows:

1st case: Sample was made of the same material as the screw in a screw-nut pair of flaps mechanization unit of Antonov An-124 aircraft - steel 30Х2НВФА using further nitriding in accordance with the requirements for the product and the same grade of high-strength steel but without surface treatment. Counter sample in figure 2.8 is represented by three balls 6 mm in diameter, made of steel ШХ-15. Investigation was done at axial load of 100 kg and amplitude, equal to 200 microns. Frequency was equal to 30 Hz. The base of test was 3·105 cycles.

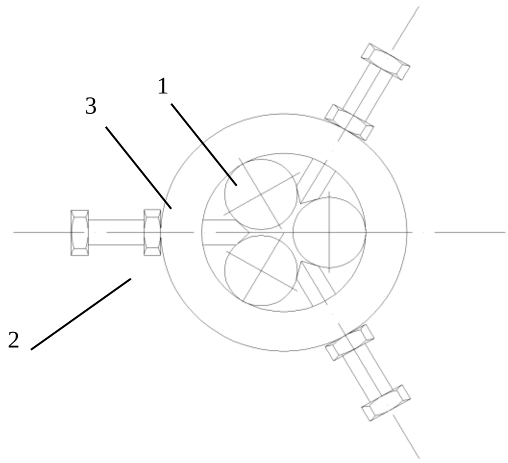
Temperature of conducting tests – 293 K. The tests were carried out in the air and with the usage of semi-fluid grease ЭРА.

2nd case: Samples made from ШХ-15 at dry friction and with ЭРА grease.

Below, is the overall view of tested samples (Figure 2.9).



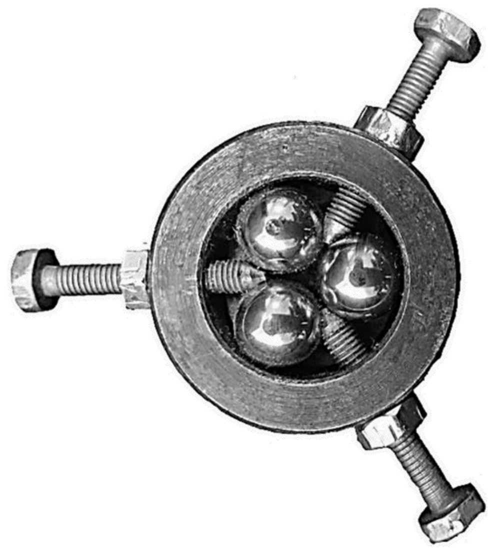
a)



b)

a) – Side view, b) – Front view: 1 – Ball; 2 – Screw; 3 – Holder

Figure 2.8 - Counter sample scheme for testing



a)

b)

a) – Counter sample, b) - Sample

Figure 2.9 – General view of tested samples

2.5 Measurement of wear

2.5.1 Typical methods of wear measurement

Wear measurement is carried out to determine the amount of materials removed (or worn away) after a wear test. The material worn away can be expressed either as weight (mass) loss, volume loss, or linear dimension change depending on the purpose of the test, the type of wear, the geometry and size of the test specimens, and sometimes on the availability of a measurement facility.

Common techniques of wear measurement include using a precision balance to measure the weight (mass) loss, profiling surfaces, or using a microscope to measure the wear depth or cross-sectional area of a wear track so as to determine the wear volume loss or linear dimensional change.

Mass loss measurement by a precision balance is a convenient method for wear measurement, especially when the worn surface is irregular and unsymmetrical in shape. Sample to be measured is carefully cleaned, and the weight is measured before and after a wear test. The difference in weight before and after test represents the weight loss caused by wear. The unit can be gram (g) or milligram (μg).

Volume loss. Wear volume is normally calculated from the wear track (scar) depth, length, width and/or scar profile according to the geometry of the wear track/scar. A surface profilometer, or sometimes a microscope with scale is used for the measurement. The reporting unit of wear volume loss is mm3 or μm3. Wear volume loss enables a better comparison of wear among materials having different densities. However, it is not easy to measure volume loss when a wear track is irregular. In this case, mass loss may be measured first, and the volume loss is calculated if the materials is uniform and its density is known.

Linear dimension loss. Measuring wear by linear dimension change is very useful in many engineering situations, where certain dimension such as length, thickness or diameter is more critical to the normal function of the system. A surface profilometer, a micrometer or a microscope can be used. The unit for linear dimension loss can be μm or mm.

2.5.2 Linear wear measurement for conducted experiments

In this degree work, linear wear of immovable specimen was measured with the help of vertical type optimeter ИКВ. The criterion of wear resistance was the maximum averaged depth of point contact. Thus, 3 experiments were conducted for each type of material pairs (30Х2НВФА (both nitride and without surface treatment) on ШХ15; ШХ15 on ШХ15) in dry condition as well as using semi-fluid grease ЭРА. Mathematical interpretation of wear measurement principle is given below (formula (2.1)):

$$h_{mean\Sigma} = \frac{h_{mean1}+h_{mean2}+h_{mean3}}{3} \quad (2.1)$$

is the averaged maximal depth of point contact taken for three experiments, where

$$h_{mean} = \frac{h_{max1}+h_{max2}+h_{max3}}{3} \quad (2.2)$$

(averaged maximal depth for one experiment (Figure 2.10)).

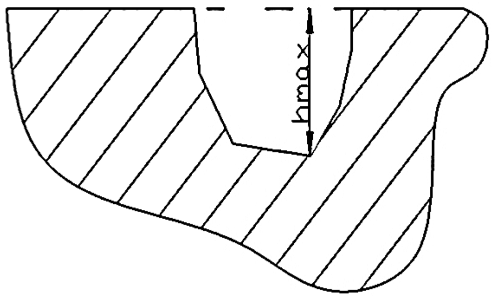


Figure 2.10 - Schematic representation of determination of maximal depth of point contact

2.6 Metallographic and fractographic investigations.

2.6.1 Fractography

Fractography is description of fractured metal surfaces in order to analyze the causes and process of fracture. Fractographic examination may be performed by the unaided eye or with the use of a magnifier, optical microscope, or electron microscope. The fracture surface itself can be studied with a scanning electron microscope. The type of fracture encountered depends on the conditions of experiment carrying out.

Fractography is study of fracture surfaces of materials to determine nature and origin of product failure. One of the aims of fractographic examination is to determine the cause of failure by studying the characteristics of a fracture surface

[27, 28]. Under the fractography of fractures of the contacting surfaces, in the given case, we consider the finding of kinds, tracks of contact interaction, analysis of which will allow revealing the peculiarities of surface destruction, and also the classification of the traces creation (damages) with the goal to determine the leading mechanism of surface wearing out.

The first stage of the laboratory analysis is the researching of the surfaces by visual inspection. In most cases the oxides are observed on the surfaces. Despite of the fact the products of fretting are varied by its external developing, nature and structure it is possible to determine with the great probability the breaking processes at the fretting according to the colour of oxides on the damaged surfaces.

Removal of wear products from the analysing surfaces (second stage). Practically in all cases you can do it with the help of the next compositions [29]:

1) Composition №1:
   a) fluohydric acid – 5 mL;
   b) nitric acid – 5 mL;
   c) water – 90 mL.
2) Composition №2:
   a) hydrochinone – 4 grs;
   b) ortho-phosphoric acid (concentrated) – 22 mL;
   c) spirit – 20 mL;
   d) water – 100mL.

Processed, according to the given technology, surface is ready for the further analysis (third stage of the investigation of the damaged surfaces) with the help of double binocular microscope МБС-9. Using the methods of optical metallographic the investigation of the typical changes was performed, taking place on the surface and in the surface layers of the samples. The plastic deformations, developing of micro-scratches, surfaces oxidising and others were studied. All investigated surfaces were observed at the different scales from 5 up to 500 times. The great attention is necessary to pay to the position of the light sources.

2.6.2 Metallography

Metallography is the characterization of the structure and substructure of metals, usually with a focus on examining the grains, phases, inclusions, defects, and other details. Traditionally, metallography is performed with optical microscopy, electron microscopy, and X-ray diffraction to identify and characterize different crystalline phases and other critical materials properties that are invisible to the naked eye. The first step is cutting a specimen and mounting it, typically in plastic or epoxy. The mounted specimen is ground with successively finer grits of sandpaper until the surface is quite smooth, at which point silica, alumina, or diamond polishes are normally used to achieve a mirror-like finish. Chemical or electrochemical etching of the surface is then performed; depending on the method chosen, a variety of details can be identified and characterized.

Surface treatment techniques in metallography are performed as follows:

Cutting. This is done using metal cutting saw. The metal is cut out from the longer one and flat surface is to be maintained. Maintenance of flat surface is to enhance grinding. The long mild steel is held firmly in the vice during the cutting. The mild steel or material is positioned well and less pressure is to be applied during the cutting process to avoid alteration in the final result. Engineer that cut should first be prepared in terms of safety. He must do everything possible to avoid accident in the workshop by wearing safety boots, overall, face shield, hand groves and other necessary equipment.

Grinding. This process comes after cutting out of the metal sample. This stage takes more time than other stages during metallography. This is because smooth surface must be obtained at the end of the stage. Grinding is rubbing the flat surface of the mild steel sample against various sizes of emery papers. The emery paper can also be called abrasive or silicon carbide paper. The stating is from the rough to the fine size. In grinding, little or no pressure is applied to avoid generation of heat which may alter the final result in the process. Note that after grinding on each paper, the surface is cleaned with cotton wool before using it on another emery paper. The reason for is to avoid transfer of mesh (particles from emery paper during grinding) from one silicon carbide paper size to the other which can affect grinding result.

Polishing. It is smoothening the ground surface of the mild steel until a smoother surface is obtained. Polishing is conducted by rubbing the ground surface against gamma-alumina powder with the molecular formula of Al_2O_3. The gamma-alumina powder has one of large particles and other of fine particle. That of large particle is first used for polishing before that of fine particles. Polishing is continued until a mirror-like image is obtained. All stripes on the ground surface must be polished out in this stage before etching. No mark is to be seen on the polished surface of the sample. This is done to make the image at the end of the process to be clear and sharp.

Etching. This comes after polishing. It is treating the polished surface with reagent called etchant. The etching period can be between 10 to 50 seconds. The period depends on the metal to be etched. Etching is carried out in fume chamber. Metal sample is held with forceps during etching to avoid etchant from being in contact with the hand. Another reason is because many etchants are concentrated. Etchant can harm the person carry out the etching if proper precautions are not taken into consideration.

Viewing. It is the last stage in metallography. After the sample had been etched, the surface needs to be dried.

By examining and quantifying a material’s microstructure, its performance can be better understood. Thus, metallography is used in almost all stages during the lifetime of a component: from the initial materials development to inspection, production, manufacturing process control, and even failure analysis if needed. The principles of metallography help to ensure product reliability.

Conclusions to part 2

1) The developed methodology allows to conduct experiments in conditions of fretting using sphere-plane contact.

2) 2 high strength steels were chosen for tests: 30Х2НВФА (nitrided and without surface treatment) and ШХ-15.

3) Tests were conducted in dry condition and with the usage of plastic lubricant ЭРА.

4) Linear wear was determined with the help of vertical type optimeter ИКВ.

PART 3
SCIENTIFIC - RESEARCH

3.1 Experiment results

Figure 3.1 and figure 3.2 represent the results on wear resistance of high-strength steels in ЭРА grease and without it in the conditions of fretting.

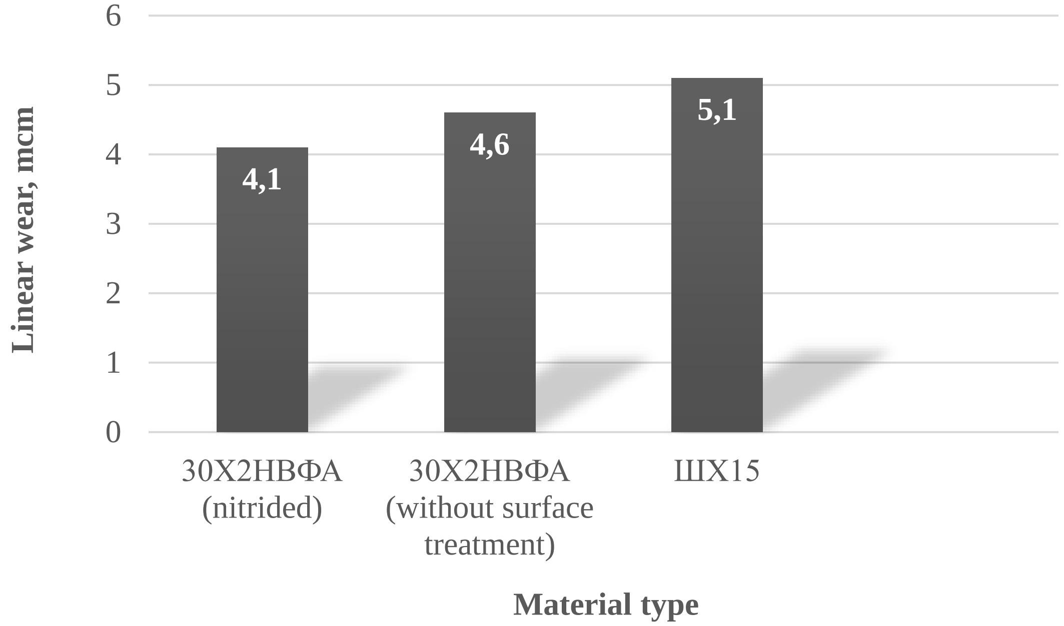


Figure 3.1 - Wear resistance of high-strength steels in ЭРА grease

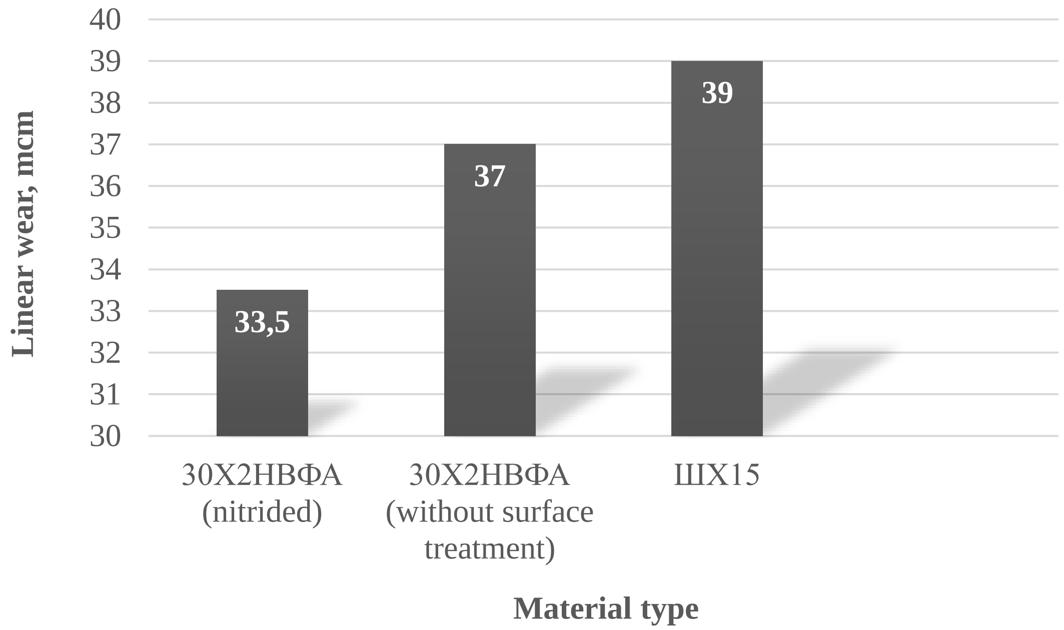


Figure 3.2 - Wear resistance of high-strength steels in dry friction

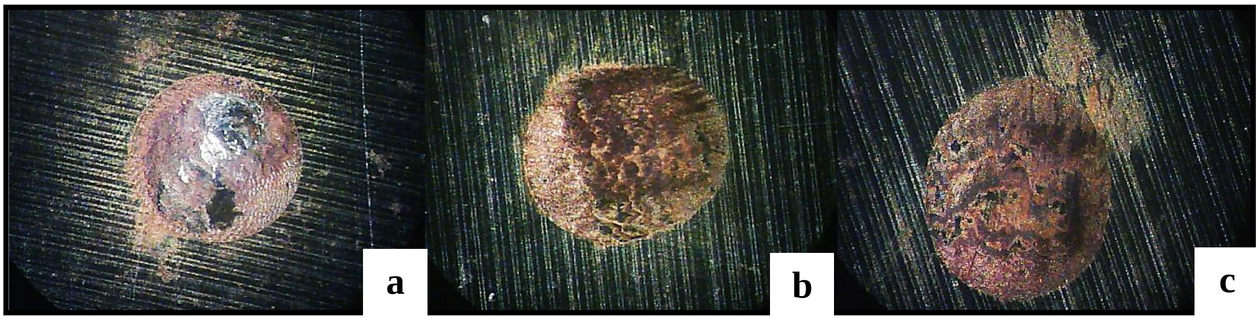
Analyzing the results of conducted experiments one can make a conclusion that the most wear resistant is high-strength 30Х2НВФА steel with surface treatment – nitriding. The surface has minimal wear at friction with and without semi-fluid lubricant ЭРА. Lubrication allows to reduce friction in 8 times and consequently wear of nitrided surface of high-strength steel.

Besides, the experiments on wear resistance were conducted for 30Х2НВФА material without surface treatment and the most widespread high-strength steel ШХ15. It follows that material 30Х2НВФА is more wear resistant than ШХ15. This is true while conducting experiments using ЭРА grease and without it as well. Nevertheless, increase in wear resistance of high-strength steel 30Х2НВФА can be compared with the experiment error. Wear resistance of high-strength steel in ЭРА grease is on 0,5 mcm higher while in dry friction wear resistance is higher on 2 mcm. The results require additional investigations in order to reveal the relation of wear resistance between these materials.

Performing the analysis of obtained results on wear resistance increase because of thermo-chemical treatment of 30Х2НВФА material, one can make recommendation to perform nitriding of high-strength steels, which are used in high-loaded friction units. The result of thermo-chemical treatment usage is the increase of wear resistance of materials on 10%.

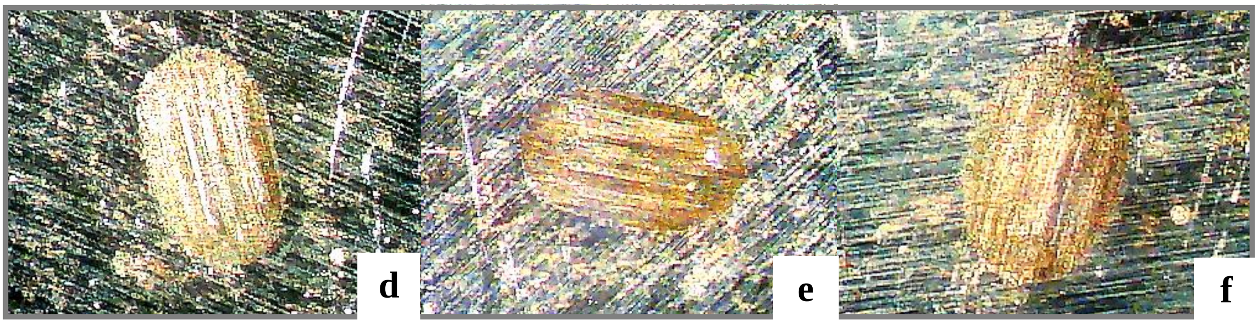
3.2 Analysis of results

The figures represent friction surface topographies of high-strength steels with and without surface treatment. The experiment was conducted in the conditions of fretting with (Figure 3.4) and without semi-fluid lubricant ЭРА (Figure 3.3). Besides, the counter sample surfaces are represented (ШХ15 balls) at conducting tests on dry friction with high-strength steels (Figure 3.5).



a) - 30Х2НВФА with nitrided layer; b) - 30Х2НВФА without surface treatment; c) - ШХ15

Figure 3.3 - Fractography of friction surfaces of high-strength steels at testing on wear resistance in conditions of fretting without usage of grease



a) - 30Х2НВФА with nitrided layer; b) - 30Х2НВФА without surface treatment; c) - ШХ15

Figure 3.4 - Fractography of friction surfaces of high-strength steels at testing on wear resistance in conditions of fretting using ЭРА grease

a) – 30Х2НВФА with nitrided layer; b) – 30Х2НВФА without surface treatment; c) – ШХ15

Figure 3.5 - Fractography of friction surfaces of high-strength steel ШХ15 (counter sample) at testing without usage of grease with the following materials (samples)

Performing the analysis of friction surfaces of high-strength steels, one can make conclusion that in the process of conducting experiments on fretting imitation in dry friction there were many places of cold welding of counter sample with tested material. Cold welded places are located on nitrided surface as well as on surface without treatment, which is seen on figure 3.3. The whole surface is covered with rubbing and pits, which is the result of abrasive fatigue mechanism of surface wear.

The results of tests given with the usage of ЭРА grease show surface wear decrease and almost absence of welded places. Surfaces are covered with scratches from linear displacement of samples caused by the fact that ЭРА grease forms secondary structures on friction surface.

Topographies of damaged surfaces (30Х2НВФА with nitrided layer) at tests without and with ЭРА grease are represented on figures 3.6 and 3.7 [30]. As it can be seen, at dry friction entire surface of steel is covered with microcracks that are formed due to cold welding of balls with 30Х2НВФА surface.

Topography of surface at testing with lubricant ЭРА looks smoother without crack formations. There are several specific areas on the surface where elemental composition was determined.

Elemental composition was determined by scanning the surface of friction paths on bitmap scanning electron microscope CamScan 4D with the help of microspectral x-ray analyzer INCA 200 Energy. Secondary and reflected back electrons were used in the analysis.

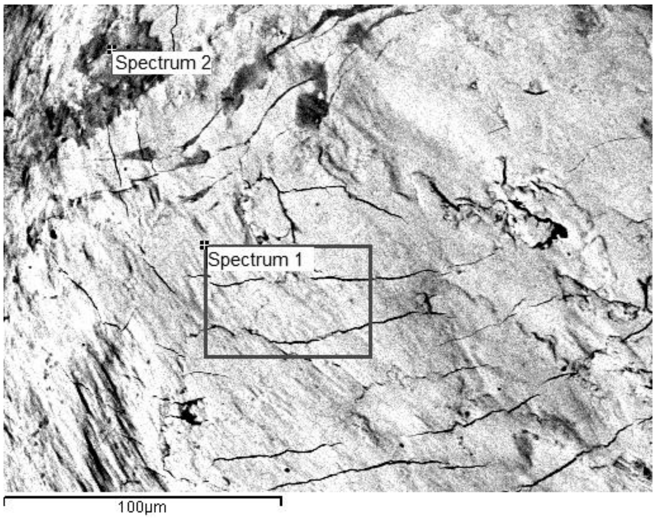


Figure 3.6 - Topography of damaged surface of nitrided steel 30Х2НВФА at testing without lubricant

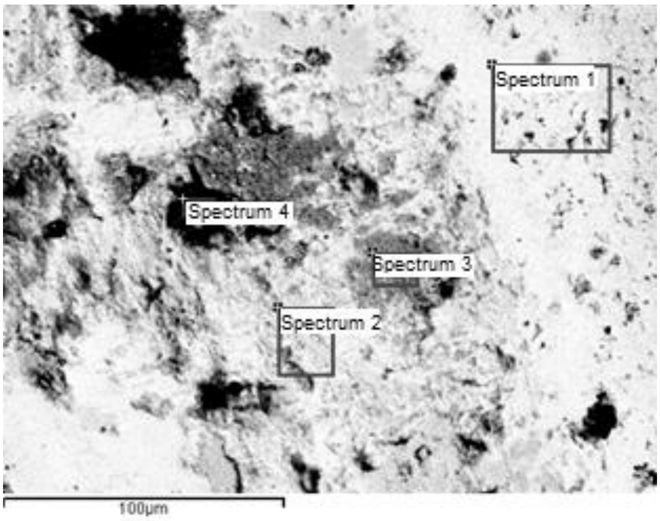


Figure 3.7 - Topography of damaged surface of nitrided steel 30Х2НВФА at testing with lubricant ЭРА

Tables 3.1 and 3.2 show that dark spots on the friction surface are probably products of oxidation of steels 30Х2НВФА and ШХ-15. However, in these areas there is an increased amount of carbon about 50 %, which indicates possible formation of compounds with lubricant or insufficient cleaning of friction surface. Lightest areas in figure 3.7 correspond to material that is most close to the primary steel before testing on friction. Intermediate gray spots Spectrum 2 and Spectrum 3 correspond to an intermediate material between the primary and oxidation, which has undergone. In these areas there is change of chemical elements (such as Cr, Fe, Ni, W) toward oxidation.

Table 3.1 - Chemical composition of friction surface when testing without lubricant, %

Spectrum	N	O	Si	Cr	Fe	Ni	W	Total
Spectrum 1	9,1	0	0,39	1,85	85,47	1,5	1,67	100
Spectrum 2	3,54	23,1	0	1,42	69,73	1,24	0,96	100
Max.	9,1	23,1	0,39	1,85	85,47	1,5	1,67	-
Min.	3,54	0	0	1,42	69,73	1,24	0,96	-

Table 3.2 - Chemical composition of friction surface when testing with lubricant ЭРА, %

Spectrum	C	N	O	Si	P	Ca	Cr	Mn	Fe	Ni	W	Total
Spectrum 1	15	5,8	6,62	0,44	0,61	0	1,55	0	68,87	1,12	0	100
Spectrum 2	22,13	2,33	5,36	0	0	0	1,42	0	66,98	1,03	0,75	100
Spectrum 3	21,09	1,32	12,22	0	0,38	0	1,1	0,36	62,7	0	0,81	100
Spectrum 4	53,42	1,02	16,7	0	0,42	0,17	0,72	0	27,55	0	0	100
Max.	53,42	5,8	16,7	0,44	0,61	0,17	1,55	0,36	68,87	1,12	0,81	-
Min.	15	1,02	5,36	0	0	0	0,72	0	27,55	0	0	-

Conclusions to part 3

Analyzing the obtained results, one can make the following conclusions:

The most wear resistant is 30Х2НВФА material with surface treatment in the form of nitriding. Its wear resistance is on 10 % higher than resistance of the same material without surface treatment and on 20 % higher than ШХ15 material resistance.

Material ШХ-15, which is used as a main material for all high-loaded friction units showed the worse results on wear resistance among tested materials.

The usage of semi-fluid lubricants considerably decreases surface wear and prolongs detail and friction units' life.

The analysis of topography of surface shows that at dry friction abrasive fatigue mechanism of wear at sphere-plane contact is prevailing, which is proved by conducted tests on electronic microscope.

PART 4
LABOUR PRECAUTION

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

Ensuring safe human activity largely depends on the correct assessment of dangerous, harmful factors. However, the complexity of the changes in the body can be caused by various reasons. This can be any factors of production environment, excessive physical and mental stress, neuro-emotional stress, and various combinations of these reasons.

The theme of my diploma work is connected with developing methodology of conducting wear resistance tests and, in particular, assessing the results of the conducted experiments on the basis of developed methodology. That is why, as a labour precaution subject I have chosen the researcher and an object is laboratory with computers which the researcher will use during his work.

Tribology Laboratory, in which the research and processing of data was carried out, is located at the department of renovation and repair of aircraft engineering.

The Dangerous and harmful production factors are laid out into State standard [35]. In the laboratory for computer operator following physical factors can act negatively on the researcher:

1) lack of lighting in the workplace;
2) high and low temperature;
3) high and low humidity;
4) exceeding the permissible noise standards.

Among nervous-psychological harmful factors are:

1) nervous-emotional overload;
2) mental overload;
3) overload of visual analyzer.

4.2 Measures to reduce the impact of harmful and dangerous production factors

4.2.1 Calculation of lighting of working environment

Due to the fact that natural light is dim, at the workplace should be used also artificial lighting. Further calculation will be made of artificial lighting.

Placement of lamps is determined by the following dimensions:

H = 3 meters is room height.

h_f = 2,75 meters is height of lamps from the floor.

Besides, lamps of LB-40 type (4x40 Watt) are used.

L is distance between neighboring lamps (rows of lamps), L_l (on the room length) is 1,76 meters, L_w (on the room width) is 3 meters.

Fluorescent lamps for the rooms intended for working are recommended to be placed in rows. The method of utilization of light flux is intended for calculating the overall uniform illumination of horizontal surfaces in the absence of large objects that obscure. The required flux of each lamp:

$F_{bulb} = E \cdot S \cdot K \cdot Z / (n \cdot \eta)$,

where E is given minimal luminance equal to 300 lux, because of class of visual work equal to 3;

K is assurance factor equal to 1,3 (for rooms connected with personal computer work);

S is lighting surface equal to 30 m^2;

Z is characterizes non uniform lighting, equal to1,1 (for luminescent).

n is number of lamps (equal to 16).

η is usage of luminous flux ratio. To find it we choose room conforming index φ and the room surface reflection values:

ρ_c. (ceiling) = 70 %;

ρ_w. (wall) = 50 %,;

ρ_s. (working surface) = 30%.

$\varphi = a \cdot b/(H \cdot p \cdot (a+b))$ = 5 · 6/(2.75 · (5+6) = 0.992. Then η = 0,45.

$F_{bulb} = E \cdot S \cdot K \cdot Z / (n \cdot \eta) = 300 \cdot 30 \cdot 1.3 \cdot 1.1/(16 \cdot 0.45) = 1788$ (lm)

Let's choose LB-40 lamps and ODOR-4 as a lamp appliance with calculated power $W = 21{,}5 \cdot 30 \cdot 0{,}92 = 594$ Watt and 220 Volts voltage.

Number of lamp appliances is equal to:

$N = W/(N \cdot P) = 594/(4 \cdot 40) = 4$

The scheme of lamps placement is given below (Figure 4.1).

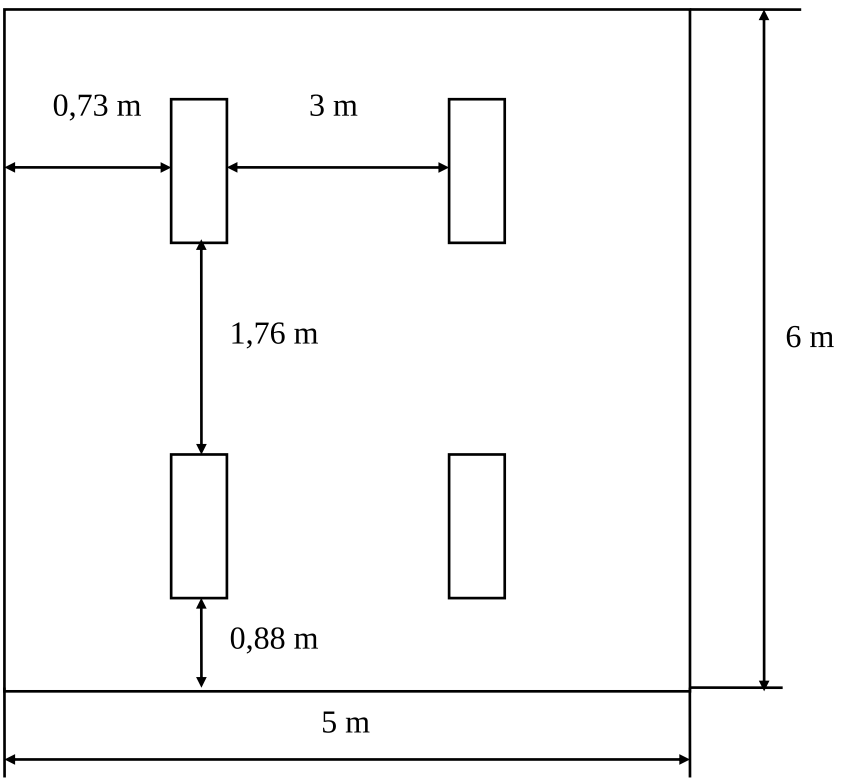


Figure 4.1 - Scheme of lamps placement**.**

4.2.2 The workplace microclimate

Microclimate of production facilities is a climate of internal environment of buildings, defined by acting on the human body combinations of temperature, humidity and air velocity

The laboratory room belongs to I b category (performed easy physical work with energy consumption equal to 121-150 kilocalorie/hour, work applied by experts in any industry), so it must comply with the requirements given in [36]. Below is the summarized table for all microclimate parameters (Table 4.1).

Table 4.1 - Optimal and Acceptable Norms for Air Temperature, Air Humidity and Air Circulation in the Work Zone

Year period	Work category	Temperature, °C					Humidity, %		Movement rate, m/s	
		Opti-mal	Acceptable limits				Opti-mal	Upper accep-table limit	Opti-mal	Upper accep-table limit
			Upper		Lower					
			Workplace							
			fixed	unfixed	fixed	unfixed				
Cold	Easy Ia	22…24	25	26	21	18	40…60	75	0.1	0.1
	Easy Ib	21…23	24	25	20	17	40…60	75	0.1	0.2
	Normal IIa	18…20	23	24	17	15	40…60	75	0.2	0.3
	Normal IIb	17…19	21	23	15	13	40…60	75	0.2	0.4
	Hard III	16…19	19	20	13	12	40…60	75	0.3	0,5
Warm	Easy Ia	23…25	28	30	22	20	40…60	55 – at 28°C	0.1	0.1…0.2
	Easy Ib	22…24	28	30	21	19	40…60	60 – at 27°C	0.2	0.1…0.3
	Normal IIa	21…23	27	29	18	17	40…60	65 – at 26°C	0.3	0.2…0.4
	Normal IIb	20…22	27	29	16	15	40…60	70 – at 25°C	0.3	0.2…0.5
	Hard III	18…20	26	28	15	13	40…60	75 – at 24°C	0.4	0.2…0.6

So, taking into account work category the optimal values for the cold period are: 21…23 °C temperature, 40…60 % humidity and air circulation equal to 0.1 m/s; while during warm period the values are: 22…24 °C temperature, 40…60 %

humidity and air circulation equal to 0.2 m/s. To create and automatically maintain in the laboratory regardless of external conditions, the optimal values of temperature, humidity, cleanliness and air velocity in a cold time of the year water heating is used and for the summer time I recommend to use conditioner.

4.2.3 Noise impact on personal computer operator

In rooms with low overall noise, which is the laboratory, where researcher works, sources of noise interference may become ventilation systems, air conditioning and computer peripheral equipment (plotters, printers, etc.). Prolonged exposure to this noise has adverse impact on the emotional state of worker.

According to [37] Annex 1 operators in the information processing rooms on computer, equivalent sound level should not exceed 65 dBA. In order to achieve this it is recommended to use noise-absorbing wall coverings. As a measure to reduce the noise I can offer the following:

1) facing the ceiling and walls by sound absorbing material (reduces noise by 6-8 dB);
2) screening of workplace (staging partitions diaphragms);
3) setting in computer areas equipment that makes minimal noise;
4) rational planning of room.

Therefore, I suggest to reduce the noise in the laboratory of matrix printer that makes a lot of noise, by quieter one – laser printer.

4.2.4 Psychophysiological unloading

When leadthrough of sessions of psychophysiological unloading, it is recommended to use some elements of autogenic training method, which is based on the conscious use of complex interrelated mental techniques and self-fulfilling simple physical exercises with verbal self-hypnosis.

The main attention is paid to the acquisition and consolidation of skills of muscle relaxation. If necessary, on the background of music programs may be pronounced certain phrases of recreation suggestion, wellbeing and at the final stage is vigor.

In the recommended session, which should be conducted in a room of psychophysiological unloading with appropriate color and interior design, three periods are separated corresponding to phases of the recovery processes. Detailed description of these periods can be found in Annex 8 of [37].

After the session of psychophysiological unloading decreases fatigue, appears vigor, good humor. Overall condition is improved significantly.

4.3 Fire and explosive safety

According to [38] buildings and parts of buildings - rooms or groups of rooms that are functionally related to each other by functional fire hazard are divided into classes depending on how they are used and on the extent to which the safety of people in them in case of fire is under threat, according to their age, physical condition, the possibility of staying in the sleep state, the form of the basic functional contingent and its quantity.

By a functional fire danger the laboratory belongs to a class Ф 4.2 - universities, training institutions.

Fire in the laboratory, can lead to very negative consequences (loss of valuable information, property damage, loss of life, etc.), so it is necessary to: identify and eliminate all the causes of fires, to develop an action plan for the elimination of fire in the building, evacuation plan.

Causes of fire may be:

1) malfunctioning of wiring, sockets and switches that could cause a short circuit or breakdown of insulation;
2) use of damaged (defective) electric appliances;
3) indoor use of electric heaters with open heating elements;
4) failure to comply with fire safety measures.

Fire prevention is a complex of organizational and technical measures to ensure the safety of people on the prevention of fire, restriction of its spreading, as well as creating conditions for successful fire fighting. For the prevention of fire it is extremely important to accurately make fire risk assessment of the building, identify hazards and study ways and means of fire prevention and protection.

One of the conditions for ensuring fire safety - elimination of possible sources of ignition.

In the laboratory, ignition sources can be:

1) faulty electrical equipment, fault in the wiring, electrical sockets and switches. To eliminate the risk of fire of these reasons it is necessary to timely identify and troubleshoot, conduct routine inspection and timely eliminate all the faults;

2) faulty electrical appliances. Necessary measures to exclude fire include timely repair of appliances, good fixing of damage non- usage of faulty electrical appliances;

3) room heating by electric heaters with open heating elements. Opened heating surfaces can cause a firebecause the room has paper documents and reference literature in the form of books, manuals, and paper - flammable object. To prevent fire, I suggest not to use open heaters in the laboratory;

4) -short circuit in the wiring. In order to reduce the likelihood of fire due to short circuit it is necessary that the wiring was hidden.

5) failure to comply with fire safety measures and smoking in the room can also cause fire. To eliminate fire as a result of smoking in the laboratory I suggest strongly to prohibit smoking, and to allow doing it in only strictly designated place.

To prevent fire I suggest to conduct with engineers and students working in the lab, fire protection acquisition, which informs employees with the rules of fire safety and teaches using primary means of fire fighting.

In the event of a fire one must disconnect the power, call the fire department by telephone, evacuate people from the room until elimination of fire by extinguishers. In the presence of little flames, you can use the materials at hand to stop airflow to the object of fire.

The room, which accommodates personal computers should be equipped with portable carbon dioxide fire extinguishers at the rate of one fire extinguisher BKK-2 (former designation YC-3) on three portable computers, but at least one fire extinguisher of this type for 1 room. Personal computers after completing the work must be switched off from the mains.

4.4 Labor protection instructions for aircraft technician

1.1. Individuals who are at least 18 years of age, have special training, have passed a medical examination and have no contraindications for health reasons, who have undergone introductory and primary labor safety briefings at the workplace, trained in safe methods and techniques of work, have been trained in workplace and testing knowledge of labor protection requirements, as well as training in fire safety rules and testing knowledge of fire safety rules in the scope of job duties; training in electrical safety rules and testing of knowledge of electrical safety rules in the scope of job duties with the assignment of an appropriate group.

1.2. An aircraft technician must:

- know and comply with the requirements of this manual, the rules and norms of labor protection and industrial sanitation, rules and norms for environmental protection, the rules of the internal labor schedule;
- follow the rules of conduct on the territory of the enterprise, in production, auxiliary and household premises;
- take care of personal safety and personal health;
- comply with fire and explosion safety requirements, know fire warning signals, the procedure for dealing with it, the location of fire extinguishing means and be able to use them;
- know the location of the first aid kit and be able to provide first aid to the victim;
- know the order of actions in case of emergencies.

1.3. An aircraft technician must pass:

- Repeated instruction on labor protection at the workplace at least once every 3 months;
- periodic medical examination in accordance with the current legislation of the Russian Federation;
- regular testing of knowledge of labor protection requirements at least once a year.

1.4. An aircraft technician is obliged to perform only the work entrusted to the immediate supervisor of the work. It is not allowed to entrust your work to other employees and to admit unauthorized persons to the workplace.

1.5. In the process of work, the following hazardous and harmful production factors can negatively affect aircraft equipment:

- moving special vehicles, self-propelled and manually moved machines and mechanisms, as well as their moving and unprotected parts;
- movable, protruding and unprotected parts and structural elements of the aircraft;
- falling products, parts, spare parts, tools, materials and other various devices when performing both ground-based and parallel maintenance work on aircraft;
- sharp edges and protruding parts of special devices, equipment, inventory;
- location of the workplace or work area at a considerable height relative to the ground;
- outflowing jets of gases or liquids from vessels and units of aircraft systems operating under pressure;
- air streams or objects caught in the jet of exhaust gases during operation of aircraft engines;
- harmful chemicals that are part of fuels and lubricants, special fluids, greases, sealants and paints and varnishes;
- increased temperature on the surfaces of units or parts (structural elements of the chassis after landing, engines);

 increased or decreased temperature of the glider skin surface in conditions of low or high outside air temperature;

 increased sliding due to icing, wetting or oily coating of the glider surfaces, ladders, ladders and stepladders;

 cluttering of workplaces with tools, spare parts, units, materials, etc.

 the risk of fire or smoke associated with the use of fuels and lubricants during ground handling of aircraft;

 increased noise and vibration level during taxiing, takeoff and landing of aircraft, from running engines;

 increased gas pollution in the compartments of aircraft from the operation of special equipment, evaporation from used fuels and lubricants and aviation fuel, etc.

 insufficient illumination in the compartments of aircraft;

 insufficient illumination of the workplace when servicing aircraft systems.

1.6. An aircraft technician must be provided with personal protective equipment in accordance with the current Norms for the issuance of special clothing, special footwear and other personal protective equipment (PPE), developed on the basis of cross-industry and industry rules for providing workers with special clothing, special footwear and other personal protective equipment.

1.7. The issued special clothing, special footwear and other PPE must correspond to the nature and conditions of work, ensure occupational safety, have a certificate of conformity or a declaration.

1.8. Personal protective equipment for which there is no technical documentation, as well as with an expired shelf life, are not allowed for use.

1.9. It is prohibited to use overalls and other PPE for purposes other than the main work.

1.10. The aircraft technician must know and follow the rules of personal hygiene. Eat, smoke and rest only in specially designated areas. Drink water only from installations specially designed for this.

1.11. It is prohibited to drink alcoholic beverages and appear at work in a drunk state, in a state of narcotic or toxic intoxication.

1.12. An aircraft technician is obliged to immediately notify his manager about any situation that threatens the life and health of people, about every accident that occurs at work, or about the deterioration of his health, including the appearance of an acute occupational disease (poisoning), as well as about all equipment malfunctions noticed , devices.

1.13. The requirements of this instruction on labor protection are mandatory for aircraft technicians. Failure to comply with these requirements is considered a violation of labor discipline and entails liability in accordance with the current legislation of the Russian Federation.

Conclusions to part 4

During investigation of the labour precaution part of my diploma, I developed necessary measures to ensure that my labour is protected in accordance with labour protection legislation of Ukraine.

In particular, as a result of assessing harmful factors at the researcher workplace (in front of a personal computer) I came to the conclusion that microclimate parameters must be properly ensured in order to keep the worker in a good mood and health.

Besides, the calculation of lamps placement was made in accordance with existing norms. The scheme was given. As a result, the obtained data shows that chosen lamp appliance satisfies the norms for high accuracy work.

As a result, careful compliance with the above-developed recommendations will satisfy all the requirements on labour precaution in Ukraine and guarantee safe and pleasant work of a researcher in front of his personal computer.

PART 5

ENVIRONMENTAL PROTECTION

5.1 Introduction

Like any other form of public mass transport that relies on finite planetary resources, aviation cannot (in its present form) be considered sustainable in the very long term. Because of the finite nature of the resources upon which aviation relies, it is more realistic in the medium term to think how best to improve the sustainability of air transport rather than it achieving sustainable development [39].

Demand for air transport is continually growing and, if this demand is to be met with all the attendant benefits, society must accept the costs (noise, pollution, climate change, risk, resource use etc). Whilst it is not possible to make aviation sustainable (in its present form) in the very long term, much can be and is being done to improve aviation's sustainability.

Aviation air quality concerns are principally related to the areas on and around airports. Further, for most airports the most significant air quality related emissions presently come from ground transport (cars, buses, trains etc). However, because of factors such as growth in demand, more public transport access to airports, and the long service life of aircraft, it is widely expected that aircraft will eventually become the dominant air quality related pollution source for many airports.

Global aircraft fuel burn for scheduled flights was at 187 million tonnes (Mt) in 2006 excluding certain aviation-related operations on the ground and non-scheduled flights, which combined could increase the figure by 10 % to 12 %. Fuel consumption is expected to rise by 3 % to 3.5 % and reach between 461Mt and 541 Mt in 2036. Aircraft engines produce emissions that are similar to other emissions resulting from any oil based fuel combustion. These, like any exhaust emissions, can effect local air quality at ground level. It is emissions from aircraft below 1,000 ft above the ground (typically around 3 kilometres from departure or, for arrivals, around 6 kilometres from touchdown) that are chiefly involved in influencing local air quality [40]. These emissions disperse with the wind and blend with emissions from other sources such as domestic heating emissions, factory emissions and transport pollution.

The chief local air quality relevant emissions attributed to aircraft operations at airports are as follows :

1) Oxides of Nitrogen (NO_x);
2) Carbon Monoxide (CO);
3) Unburnt hydrocarbons (CH4 and VOC_s);
4) Sulphur Dioxide (SO_2);
5) Fine Particulate Matter (PM 10 and PM 2.5);
6) Odour.

These are produced by aircraft engines, auxiliary power units, apron vehicles, de-icing, and apron spillages of fuel and chemicals. Often NO_x is by far the most abundant and is often considered the most significant pollutant from an air quality standpoint.

On the other hand, 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 localised 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 aeroplane 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 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. However, the ozone is responsible for the destruction of atmospheric methane (CH_4). Methane is also a potent greenhouse gas, with an atmospheric lifetime of 14 years. The destruction of methane as a direct result of aviation therefore reduces the extent of warming caused by aviation emissions.

Water vapour is also an important greenhouse gas, but emissions of water vapour from aviation only have a minor direct warming effect. Water vapour has a short lifetime in the atmosphere and is controlled by the hydrological cycle. Emission of water vapour at high altitudes will produce contrails – the cloud-like trails behind aircraft that are visible from the ground. These contrails also trap heat in the atmosphere and their warming effect is believed to be equivalent to that of carbon dioxide alone. Contrails do not form at lower altitudes, so could be avoided by flying lower. In practice this is not done as the fuel burn, and therefore running cost, is greater when flying at lower altitudes where the atmosphere is denser. The contrails themselves are implicated in the formation of high altitude cirrus clouds, which are believed to have a strong warming effect on the atmosphere, although quantification remains poorly understood.

Soot and aerosols. Sulphate aerosols and soot from combustion also have small temperature effects on the atmosphere. Traces of sulphur are present in fuel oil, and form aerosols of sulphate compounds. These reflect incoming solar radiation back into space and so have a small cooling effect. Conversely, small particulates produced from combustion (soot) trap outgoing infrared radiation within the atmosphere and so have a small warming effect. These are both poorly quantified but are believed to be small effects that roughly cancel each other out.

5.2 Calculation of the emissions of carbon monoxide and nitrogen oxides by aircraft engines and their ecological and economic assessment of the damage that is caused by the annual emissions

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, $\overline{R}$	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 $N0_x$ 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} and M_{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	Maximu engine thrust, kN	Aviation engine type	Engi-ne 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

Table 5.3 - Mass emission speed of CO and NO_x for different types of aircraft aviation engines

Variant	AC type	Quantity of flights per year	Realtive thrust $\overline{R}$ of respective mode (2, 3, 4)	Mass emission speeds, kg/hour	
				CO	NO_x
1	Tu-134	40	1 0,85 0,3	5,5 5,5 6,0	80 50 10
2	Yak-42	80	1 0,85 0,3	0,2 0,2 0,3	96 59 10
3	Tu-154	100	1 0,85 0,3	6,0 7,5 18,0	89 61 11
4	Il-62M	85	1 0,85 0,3	6,0 7,5 18,0	89 61 11
5	Il-76	85	1 0,85 0,3	6,5 7,5 18,0	95 61 11
6	Tu-154A	90	1 0,85 0,3	12,2 10,2 19,1	104 76 12
7	Tu-154Б	75	1 0,85 0,3	12,2 10,2 19,1	104 76 12
8	Il-62	120	1 0,85 0,3	12,5 11,0 20,5	110 65 10
9	Yak-40	140	1 0,85 0,3	7,9 10,4 17,0	9,2 4,5 1,6
0	Yak-40 (with smokeless combustion chamber)	60	1 0,85 0,3	3,1 4,5 6,5	9,5 6,0 1,5

Solution for Variant #7 according to the above-mentioned formulas:

$$R_{idle} = \bar{R} \cdot R_0 = 105000 \cdot 0,07 = 7350 \text{ (N)}$$

$$T_{idle} = t_{idle} \cdot N \cdot n = 0,3667 \cdot 75 \cdot 3 = 82,5 \text{ (hour)}$$

$$W_{1TOFF} = 12,2 \ (\frac{\text{kg}}{\text{hour}})$$

$$W_{1A} = 10,2 \ (\frac{\text{kg}}{\text{hour}})$$

$$W_{1n} = 19,1 \ (\frac{\text{kg}}{\text{hour}})$$

$$W_{2TOFF} = 104 \ (\frac{\text{kg}}{\text{hour}})$$

$$W_{2A} = 76 \ (\frac{\text{kg}}{\text{hour}})$$

$$W_{2n} = 12 \ (\frac{\text{kg}}{\text{hour}})$$

Let’s calculate the emissions for take-off, landing and ground operations:

$$M_{1TL} = n \cdot (W_{1TOFF} \cdot T_{TOFF} + W_{1A} \cdot T_A + W_{1n} \cdot T_n) \cdot N =$$
$$= 3 \cdot (12,2 \cdot 0,0117 + 10,2 \cdot 0,0367 + 19,1 \cdot 0,0667) \cdot 75 = 402,675 \ (\frac{\text{kg}}{\text{year}})$$

$$M_{2TL} = n \cdot (W_{2TOFF} \cdot T_{TOFF} + W_{2A} \cdot T_A + W_{2n} \cdot T_n) \cdot N =$$
$$= 3 \cdot (104 \cdot 0,0117 + 76 \cdot 0,0367 + 12 \cdot 0,0667) \cdot 75 = 1080 \ (\frac{\text{kg}}{\text{year}})$$

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

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

And finally, annual mass CO and $N0_x$ emissions are:

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

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

Losses estimates 3 (UAH/p.y) for any source is calculated by the below given formula (5.8).

$$З = \gamma\sigma f m, \quad (5.8)$$

where γ – constant, numerical value of which is equal 12 UAH/p.m т;

σ – sign of relative risk of air polution;

f – error which takes into account the nature of the scattering of mixture in the atmosphere (dimensionless);

m – reduced weight of the annual emissions of pollutants from the source.

The value of σ is determined by special table determining the active zone of contamination.

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} = 20φh, 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):

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

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):

$$m_1 = A_1 M_1, \quad (5.10)$$

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

$$m_2 = A_2 M_2, \quad (5.11)$$

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

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):

$$З_1 = 120 \cdot \sigma m_1, \qquad (5.12)$$

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

$$З_2 = 120 \cdot \sigma m_2, \qquad (5.13)$$

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

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.

Conclusions to part 5

Compared to other sources, aviation emissions are a relatively small contributor to air quality concerns both with regard to local air quality and greenhouse gas emissions. While small, however, aviation emissions cannot be ignored. In my case, for Tupolev-154Б aircraft annual mass CO and $N0_x$ emissions are 1556,728 kg/year for CO and 1261.245 for NOx emissions.

But it should be kept in my mind that emissions are not only concerned with local air quality and greenhouse gas effect but also cause significant economical damage – 747,23 UAH/year and 24881,85 UAH/year for CO and NOx emission respectively for Tupolev-154Б aircraft.

Nevertheless, aviation has progressively improved its environmental performance. Fuel economy, which is one strong indicator of environmental performance, has consistently improved. Aircraft engines have gotten more efficient and been designed with environmental performance in mind. Regulatory frameworks have developed to constrain emissions growth from many aviation sources. And improvements to the efficient operation of the complex aviation network have had a positive effect on the environment.

GENERAL CONCLUSIONS

1) Fretting can be considered as a form of wear, which occurs when wear mechanisms act together under conditions of small oscillatory displacements. It may arise in any assembly of engineering components if a source of vibration is present and either cause localized wear or initiate fatigue cracks, which may drastically lower the fatigue strength of some materials. Fretting wear is different from that of any other wear condition in that it enjoys retention of the majority of the debris by the wear action itself.

2) The methodology of conducting fretting tests of high-loaded friction pairs in conditions of Hertzian contact is developed. Developed methodology allows conducting experiments in a wide range of loads and simultaneously testing of three friction pairs.

3) Analyzing the obtained results, the following conclusions can be made:

a. The most wear resistant material is 30Х2НВФА with surface treatment in a form of nitriding. Its wear resistance is on 10 % higher than of the same material without surface treatment and on 20 % higher than of ШХ15 material.

b. ШХ15 material, which is widely used on all highly loaded friction units, showed the worse results on wear resistance among tested materials.

c. Usage of semi-fluid lubricants considerably decreases surface wear and prolongs detail and friction units' life.

4) Analysis of surface topography indicates that at dry friction fretting fatigue mechanism of wear is prevailing at sphere-plane contact, which is evidenced by conducted experiments on electronic microscope.

5) Besides, this degree work contains labour precaution and environmental protection chapters, in which the calculation of lighting and analysis of harmful factors are presented.

RECOMMENDATIONS

1. Higher educational institutions and enterprises may be recommended to use the developed methodology of conducting wear resistance tests of materials and coatings in the fretting conditions at the sphere-plane contact. The alike methodology may be used as a laboratory work for introduction of the basics of materials wear resistance and investigations in this area.

2. It is recommended to replace material ШХ15 onto material 30Х2НВФА in high-loaded friction nodes, where plastic greases are used, which results in wear resistance increase up to 10-20 %.

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