**МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ**
**НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ**
**АЕРОКОСМІЧНИЙ ФАКУЛЬТЕТ**
**КАФЕДРА ПІДТРИМАННЯ ЛЬОТНОЇ ПРИДАТНОСТІ ПОВІТРЯНИХ СУДЕН**

**ДОПУСТИТИ ДО ЗАХИСТУ**
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«_____»_____________2022 р

# КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА )

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ
**«МАГІСТР»**

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

**Тема: “Підвищення ресурсу деталей механізації крила літаків із високоміцних сталей”**

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**Нормоконтролер:** _____________

**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
_____________ O. V. Popov
«____”_______________ 2022

# MASTER’S DEGREE THESIS

(EXPLANATORY NOTE)

GRADUATE OF EDUCATIONAL DEGREE

**«MASTER»**

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

**Topic:** **“Increase resource of wing high lift devices of aircrafts of high-strength steels”**

**Created by:** _____________ **I.I. Kostianets**

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**Labour precaution:** _____________ **K.I. Kazhan**
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**Environmental protection: Assoc. Prof.** _____________ **L.I. Pavlyukh**
Candidate of science (Engineering), assoc. prof.

**Standards Inspector:** _____________

**Kyiv 2022**

**NATIONAL AVIATION UNIVERSITY**

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

PPERMISSION TO DEFEND
Head of the department
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«____”_______________ 2022

**Graduate Student's Degree Work Assignment**
**KOSTIANETS ILLIA**

1. The topic of the work: **«Increase resource of wing high lift devices of aircrafts of high-strength steels»** 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 (thesis): structural material ВКС-170 with mechanic-pulse hardening and without surface processing; structural material 30Х2НВФА with the hardening of the surface layer by nitriding and without surface processing.
4. The content of the explanatory note: analysis of coatings and methods for improving of wear resistance of steel alloy details in fretting conditions, the study of nitriding and mechanic-pulse coatings deposited on steel alloy parts wear in fretting conditions, analysis of damage of friction pair (screw – nut) of wing devices nodes of aircraft AN type, development of measures for labor precaution and environmental protection.
5. The list of mandatory graphic materials: pictures of wing lift devices of aircraft AN type; general view of screw and nut of the wing flaps elevator of the aircraft AN-124 and its damages; fractographic and metallographic researches of the surfaces of screw and nut of flat elevator of aircraft AN-124; installation for fretting testing; samples for fretting testing; the wearability of high-strength steels at the fretting tests; fractography of friction tracks of high-strength steels at the testing on wearability in the fretting conditions.

Graphic materials is represented in the view of presentation Microsoft Power Point

6. Calendar schedule

| Task | Fulfillment term | Completion mark |
|---|---|---|
| Literature review of materials for degree work | 26.09.22 – 28.09.22 | |
| Analysis of technological process of work fulfillment | 29.09.22 – 10.10.22 | |
| Preparation of necessary equipment for research carrying out | 11.10.22 – 16.10.22 | |
| Work on a special part of degree work | 16.10.22 – 25.10.22 | |
| Processing of research results | 25.10.22 – 30.10.22 | |
| Fulfillment of individual sections of degree work | 02.11.22 – 13.11.22 | |
| Processing of master's degree work | 13.11.22 – 22.11.22 | |

7. Advisers on individual sections

| Section | Adviser | Date, Signature | |
|---|---|---|---|
| | | Assignment Delivered | Assignment Accepted |
| Labour precaution | candidate of engineering sciences, assoc. professor Kazhan K.I. | | |
| Environmental protection | candidate of engineering sciences, assoc. professor Pavlyukh L.I. | | |

8. Assignment issue date "_____"____________ 2022.

Degree work supervisor: _________________________________A.M. Khimko

(signature)

Assignment accepted for fulfillment ______________________I.I. Kostianets

(signature)

## ABSTRACT

The explanatory note to master's degree work «Increase resource of wing high lift devices of aircrafts of high-strength steels»

101 pages, 19 figures, 4 tables, 51 literature sources.

Object of study – different types of coatings and structural materials 30Х2НВФА and ВКС-170 that are damaged by contact interaction in friction units.

The purpose of degree work – is the failure analysis of wing devices nodes of aircraft (elevators of leading-edge flap) and development of measures for the reduction and prevention of damaging of friction pair screw–nut.

Research method – laboratory studies of the wear mechanisms of coatings on the parts made of steel 30Х2НВФА and ВКС-170 in fretting conditions.

A complex analysis of wearability of high-strength steels, which are used at the production of details of aircraft wing lift devices, at the fretting condition was concluded. We considered damages of aircraft wing lift devices under the influence of the special kind of wear (fretting) and under the atmospheric influence. Metallographic and fractographic researches of damaged details were carried out. The recommendations according to diminishing of damages of wing flaps elevator in the process of operation were developed.

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

This degree work contains described measures in strengthening and further restoration of steel aircraft details, it contains recommendations concerning the replacement in the production of wing lift devices of aircraft AN type, made of material 30Х2НВФА with nitriding, from which the screw and nut are manufactured, by the material ВКС-170 without surface hardening in order to enhance aircraft reliability and reduce environmental impact. This work was directed for solving these problems.


FRETTING, FRETTING RESISTANCE, WEARABILITY, CORROSION, COATING

**CONTENT**

# INTRODUCTION

Ensuring of the high figures of wearability and durability of friction details is one of the major factors of reliability increasing and increasing of modern machines life cycle. Statistics shows that about 80 % of failures in the machines work occur as the result of wear and destruction of friction surfaces of machines details.

Wear leads to the decreasing of the products functional qualities and to the loss of their consumer value. Increasing of products wearability contribute both and applying of materials with the high wear resistance, and design decisions, ensuring the compensation of wear, redundancy of wearability, common improving of friction conditions (using of high quality lubricants, protection from the abrasive influence, for example: welding deposition, thermal spraying, metallization and others).

Wear can be considered as the mechanical process, complicated by the actions of physical and chemical factors, which cause the durability decreasing of surface layer microvolumes.

Due to the wear the shaped and sizes of the details are changed, it results in the increasing of gaps in the movable connections, disruption of fit density of immovable connections. At the detail wear limit occurrence, its further using is impossible, because of disruption of node or mechanism normal work that can result in accident.

One of the most responsible units of aircraft wing lift devices are elevators of leading-edge and trailing-edge flaps. The elevators serve for the moving of leading-edge and trailing-edge flaps after take-off and before landing. The elevator represents itself as the pair of screw-nut with the intermediate marbles, which serve for the effort transmission from the drive screw onto the nut, which is fastened on the carriage of the flap. The carriage moves on the rail of wing lift devices and pulls out the wing flap along the certain trajectory.

The elevators of leading-edge and trailing-edge flaps are especially responsible units on an aircraft. They work in the non-insulated from the external environment medium that is they work under the influence of complete operating range of temperatures ± 60 °C and in the conditions of all atmospheric influences. The break-down of any elevator during the flight results to the special situation.

In the given work we considered the affined friction pair (screw-nut), which works in the rigid connection with the carriage and rail of wing lift devices. Damages of wing lift devices screw during the operation were shown. Also the optimal solution for the wearability increasing of working surface was found – namely, it was proved the actuality of using of steel ВКС-170.

The purpose of degree work – is the conduction of researches on wearability of high-strength steel and steel with the surface hardening for the delivering of recommendations in relation to the increasing of wearability and resource of wing lift devices screws of aircraft AN type.

To achieve this goal we had to solve the following problems:

1) analyze the operational damageability of friction pair (screw-nut) and methods of their restoration;

2) carrying out a set of comparative researches in selection the optimal high-strength steels and steels with the surface hardening;

3) learning of wearing mechanism of steel ВКС-170 with mechanic-pulse hardening and without surface processing and steel 30Х2НВФА with the hardening of the surface layer by nitriding and without surface processing during the friction at the fretting conditions;

4) analyze of the performed work in order to define the most suitable material for the given working conditions;

5) recommendations development for the introduction of steel with the best performance (technical, economical, etc.) for the screws of wing lift devices of aircraft AN type.

Object of research – wearability of high-strength steels (30Х2НВФА and ВКС-170) with the different coatings and without surface hardening at fretting conditions.

Subject of research – is establishment of the wearability interaction of high-strength steels with the different coatings at the fretting conditions.

It should be noted the possibilities of wearability increasing has its own limitations and it is impossible to avoid the wear completely. Thus, it is important to develop the technology for the restoration of such objects.

On the basis of these studies the practical recommendations for the introduction of steel ВКС-170 for the screws of aircraft wing lift devices in Antonov Company were developed.

All main results were obtained by the author in person or by her direct participation. The author was directly involved in the experiments preparing and conducting, in the wear determining of the samples, conducting of the surface factography and analyzing the results.

# PART 1

# FRICTION ANALYSIS OF AVIATION EQUIPMENT

## 1.1 Friction and wear

### 1.1.1 Friction

Friction – is the process of interaction between the solid bodies at their relative motion (displacement) or at the movement of the solid body in a gaseous or liquid medium [1].

Two main factors affect the friction: loading (application force) and materials' properties. But, we must take into account that metal surfaces on the air are quickly covered with a thin oxide film, in fact, the contact takes place not between the clean metal surfaces, but between the oxide films, which have the lower shear resistance. Penetration of any liquid or paste-like liquid generally changes the pattern of contact [2].

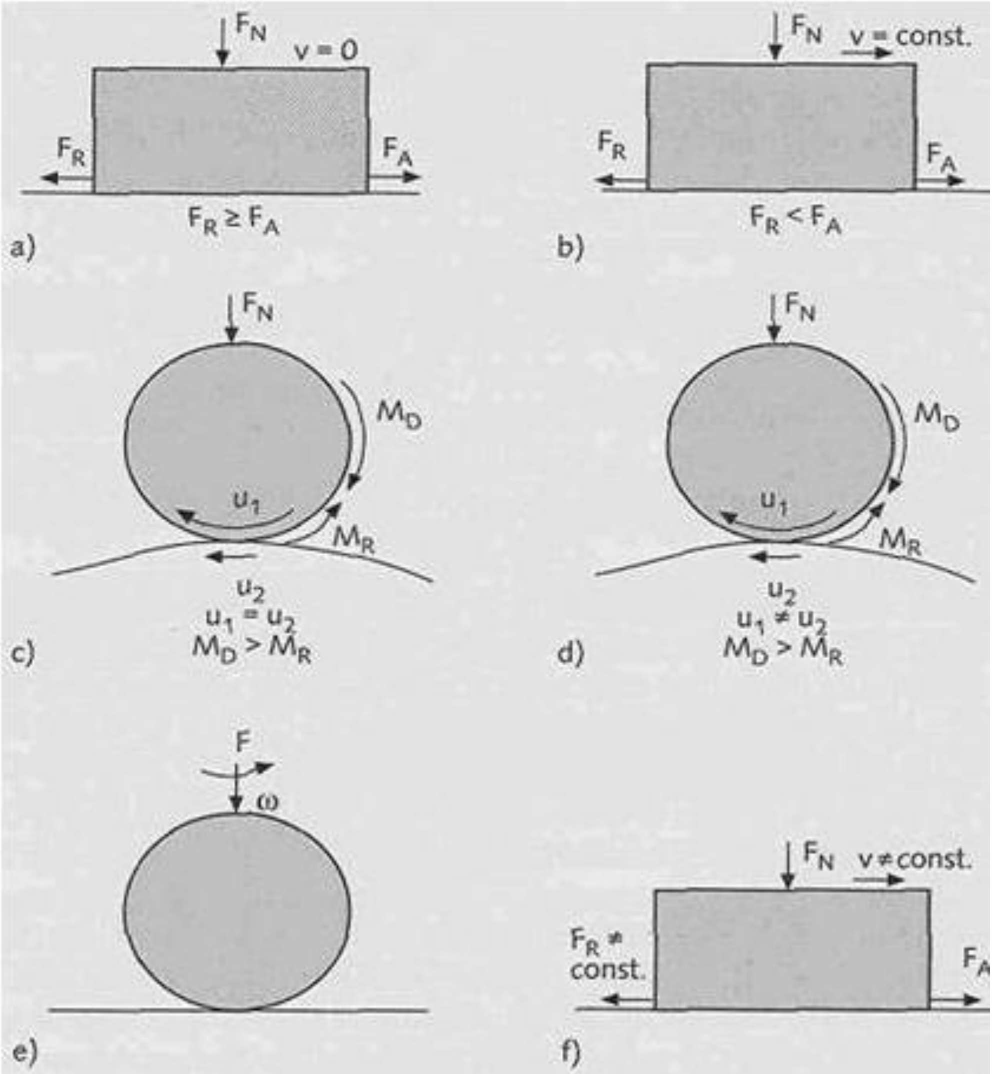
### 1.1.2 Types of the friction

There are two main classifications of friction types: first – depending on the presence and character of motion; second – depending on the presence of lubrication [3].

Friction types according to the presence and character of motion (figure 1.1) is divided into the friction at rest and friction at motion (kinematic friction).

Kinematic friction (sliding friction) acts between the contacting and moving relative to each other bodies. It develops on the macroscopic level. There is a uniform, irregular and intermittent kinematic friction *[4]*.

Uniform kinematic friction appears when the surfaces move relative to each other. Depending on the relative motion there are the next types of friction.




| | |
|---|---|
| $F_N$ – normal force; | $u_1$ – rotary velocity, body 1; |
| $F_R$ – friction force; | $u_2$ – rotary velocity, body 2; |
| $F_A$ – moving force; | **w** – angular speed; |
| v – velocity; | $M_D$ – angular momentum; |
| u – rotary velocity; | $M_R$ – friction force momentum |

a) – static friction; b) – f) – kinematic friction;

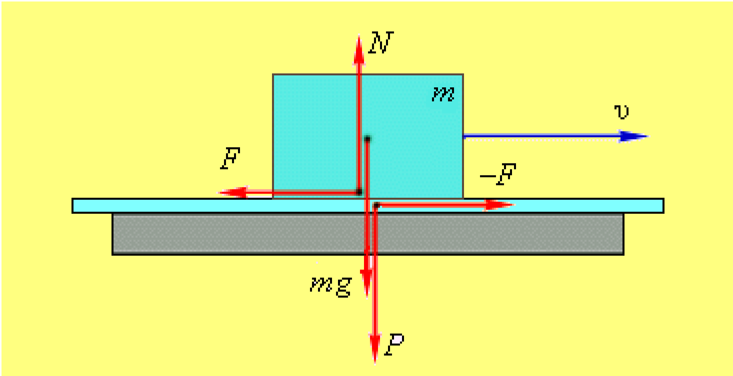
b) – e) – uniform kinematic friction; b) – sliding friction;

c) – rolling friction; d) – combined friction;

a) – torsion friction; f) – intermittent kinematic friction

Figure 1.1 – Types of kinematic friction, presented in the form of diagram:

Sliding friction (figure 1.2) – the force, occurs at the forward movement of the one of the contacting/interacting bodies relative to another and acts on this body in the direction opposite to sliding (translational motion at the point or at the linear contact of the surface).




| |
|---|
| N – force of the support reaction; |
| P = -N – weight of the body; |
| F – friction force; |
| v - velocity |

Figure 1.2 – Friction forces when sliding (υ ≠ 0)

Rolling friction – the moment of forces, appears by the rolling one of two contacting/interacting bodies relative to another (rotating motion at the point or at the linear contact of the surface) [5]. Usually rolling friction force is much smaller than the sliding one, which causes the less friction losses in the rolling bearings in comparison with the sliding bearings [4].

Combined friction – is the combination of the sliding and rolling friction.

Torsion friction – the rotational motion about an axis perpendicular to the plane of the surfaces contact.

Intermittent kinematic friction – the kind of friction, which has no the constant value, but has the periodical highs and lows. So called “stick-slip behavior” – is a form of intermittent dynamic friction.

Non-uniform kinematic friction occurs during deceleration, i.e. towards the end of the movement.

Friction types according to the presence of lubrication are divided into:

1) dry, when the contacting solid bodies are not separated by any additional layers/lubricants (including solid lubricant) – met a very rarely case in practice. The characteristic feature of dry friction – the presence of a considerable force of static friction;

2) boundary friction, when the layers and parts of the various nature (oxide films, liquid, etc.) are in the contact area – the most widespread case at the sliding friction;

3) mixed, when the contact area contains the part with the dry and liquid friction;

4) liquid (viscous), the interaction between the bodies separated by a layer of a solid (graphite powder), liquid or gas (lubricant) with the different thicknesses – as a rule, it meets at the rolling friction, when solids are plunged into the liquid, the magnitude of the viscous friction is characterized by the viscosity of the medium;

5) elastohydrodynamic, when the inner friction in the lubricant has the critical importance. It occurs at the increasing of the relative velocities of the displacements [6].

### 1.1.3 Wear, wear resistance, wearing out

Several classifications of the wear types and factors affecting its magnitude are described in the technical literature. It is easy to find the special wear results on the details surfaces in each case: hardly visible scratches on some, peeling of the thin metal films at others, torn out parts of the surfaces at third one, etc. Variety of reasons types of the surface damage, causing them, complicates the classification of the wear types.

To classify the wear types, first of all it is necessary to consider the concepts of "wear", "wear resistance", "wearing out" and "intensity of wearing out", which are accepted and used in the daily practice.

Wear – changing of the sizes, shapes, masses of the solid bodies or conditions of their surfaces as the result of residual deformation from the constant acting loadings or destruction of the surfaces layer during friction.

Wearing out is classified as a process of separation the material from a surface of solid body and increasing its residual deformation. Friction in mechanism nodes leads to wearing out of the rubbing surfaces, which is manifested in the form of mass loosing, size changing and distortion of the geometric shapes.

Wear resistance – strength of the details' materials of the machines and other rubbing parts to wear. Wear resistance is estimated, for example, by mass reducing of the molded detail during operation, its linear dimensions or changing of the detail volume. It should be noticed that wearing – is, first of all, a process of interaction between surfaces, which is accompanied not only by their micro-cutting, deformation and heating, but also changing of the mechanical properties, structure, phase composition and chemical activity of surfaces layers.

During the long influence of micro- and macroscopic abrasive parts on the detail surface the wear takes place, estimated by decreasing of the sizes, volumes, masses of details in absolute and relative units. Wear, referred to the way of friction, volume of the performed work, friction work etc., is an indication of the intensity of wearing out.

Wear and intensity of wearing out is determined and due to another oblique features. More often under the wear is understood the constant activation of the detail surfaces as the result of friction. Wear, regarded to the time interval of friction process, is determined by the velocity of wearing out [7].

Velocity of wearing *out* – is wear per units of time.

### 1.1.4 Wear types

Type of wear depends on loading and its nature, speed of the relative movement of the rubbing surfaces and temperatures between them, medium, where the details work, materials, from which they are made, their processing and a number of other factors.

So far there is no universally recognized classification of wear types. Most scientists identify three main groups of wear (figure 1.3).

**WEAR**

**MECHANICAL**

Abrasive
- gas-abrasive
- hydro-abrasive

Cavitational

Fatigue
- thermal
- contact
- heat

Erosion

**MOLECULAR-MECHANICAL**

During jamming

Adhesive wear

**CORROSION-MECHANICAL**

Oxidizing

Corrosion
- chemical
- electrochemical
- contact
- Fretting

Figure 1.3 – Types of wear

In order to reduce the mechanical wear (conjugate shaft – bearing, piston – cylinder, guide – bearing; shaft parts; axes; gears; springs, etc.) it is necessary to use the wear resistance materials in the design, regular lubrication, increasing of the surface cleanness of the conjugate surfaces, surface strengthening and correct operation of equipment.

The essence of the abrasive wear is the destruction of metal with the solid grains of abrasive at the plastic deformation and micro-cutting of the rubbing surfaces [4].

Abrasive wear is the simplest form of the destruction of the metals surfaces layers. It is characterized by micro-plastic deformations and clipping the metal thin surface layers using solid abrasive particles of the medium, where was the work of details. Solid abrasive particles, sliding under the pressure along the detail surfaces, are cut for the chips, deforming the micro volumes of the surfaces layers. Abrasive wear occurs under conditions of friction, when more solid rough surface sliding along more soft one, scratch or plough it, creating free particles. It also can appear when the solid particles fall between the surfaces of the friction connection and they wearing them out [6].

Intensity of the abrasive wearing out is determined first of all as the relation between micro-hardness of abrasive grains and metal, as well as the speed at friction.

Gas-abrasive wear. It is caused by mechanical actions of solid particles, which transported by the gas flow. In this case metal destruction takes place as the result of clipping, spalling, dislodging and multiple plastic deformations of its surface micro-volumes.

Hydro-abrasive wear – is similar to gas-abrasive wear, but the carrier of the abrasive particles is not gas, but liquid.

Cavitational wear. The essence of this type of wear is the metal surface destruction under the impact of gas bubbles, created in high-speed liquid flow at the pressure drop. Presence of corrosion mediums and abrasive particles accelerate the process of cavitational wearing out [4].

Fatigue wear. Wear at surface fatigue occurs as result of periodical action of shear stress at the near-contact volume of metal. At long-term cyclic action of stresses the fatigue cracks are formed on the surface layer of metal. Closely placed cracks are combined that lead to the separation of thin metal scales.

Thermal fatigue **–** appears as the result of many cycles “heating – cooling”. At this, as rule, just part of detail’ surface or tool is subjected to heating. The local heating causes the heat expansion of some metal volume, cabined surrounding cold metal. As the result the heated metal experiences compression and it under the following cooling changes to expansion. Cycles of thermal “compression–extension” lead to the appearance of the “thermal fatigue cracks” on the surface. Often they look like “net”, which is also called “net of high point cracks”.

Contact fatigue. At higher kinematic pairs, where details contact at a point or along the line, pressure, as rule, is high. It leaves a mark on the character of wearing out. High pressure is capable, even at the first working contact, to cause the plastic (irreversible) deformation of surfaces. But this case is not typical, as it can be easily prevented, we need only avoid exceeding of the material yield point by working stresses. However, even if this condition is met, the plastic deformation occurs under the influence of a great amount of loadings.

Heat fatigue is called the process of surfaces' destructions of machines' details as a result of heating of friction's zone up to the metal melting point. Destruction at this type of wear is the result of metallic bonds' creation: between the contacting surfaces, metal collapse, melting and sticking. Wear from high temperatures reveals in a view of oxidation and cracks of thermal fatigue. Oxidizing – process similar to corrosion, but in this case the accelerated oxidizing of surface is not caused by the aggressive environments, but it caused by high temperatures. Oxidizing speed as well as corrosion speed can be high.

Erosion – ablution of grooves on the details surfaces by the liquid or gas flows. Friction of gases and liquids about the details surfaces, by virtue of its physical peculiarities first, seems, cannot be large. However at high pressures and speeds outflows their force interaction rapidly increases, it becomes the reason of quick wearing out.

Molecular-mechanical wear (for example: in gear pair, screw pair, bearings) in order to decrease its influence it is necessary regular and in sufficient quantity lubrications. Representatives of this group are jamming (prehension) and adhesive wear.

Jamming (prehension) – phenomenon of firm metal connection as the result of mutual friction or mutual deformation at temperature below recrystallization temperature. At the same time the firm metal bonds are formed in zones of immediate surface contact. In the places of prehension the boundary between the contiguous bodies is disappeared, joining of one- and contralateral metals takes place. As the result the wide and deep grooves with the rough edges are created, sometimes they are joined; big incrustations are presented; it is possible the burning-off the surface. The complete jamming of details can happen [7, 8].

Due to the roughness of the surface their contact takes place not by all surface, but along the separate parts and even points. Point contact along micro-asperity can be accompanied by plastic deformation with the destruction of the surfaces films, revealing of pure atoms and creation of the welded point. Relative motion immediately destroys it with the appearance of "pock marks" on one surface and "incrustations" on the other. Incrustations add the abrasive character to the wearing out, leaving grooves (scratches) on the conjugate surface. When the prehension processes are a lot, then at first pasting of harder metal with softer one takes place, after it – "jamming" occurs that is stop of rubbing surfaces. Prehension during friction quickly put the mechanisms nodes out of action that is undesirable and needs measures for the eliminations.

Adhesive wear. Wear at friction of two metal surfaces under loading takes place at metal plastic deformation in contact points. Development of wear is accompanied by approaching of surfaces up to the energization of adhesion forces between the atoms of contacting metals and appearing of adhesion on the limited plots. Repeated repetition of adhesive connections with their following destruction and separation of metal particles is the essence of adhesive wearing out. This type of wearing out can be in sliding bearings (crankshafts, axes, running gears of different machines).

Corrosion-mechanical wear, occurring from simultaneous chemical and mechanical influence (axes and shafts journals, rolling bearings), it is reduced by using of regular lubrication for the rubbing and coloration for the no-working surfaces, applying of non-corrodible materials and coverings.

Oxidizing is called the wear, at which characteristics of friction depend on oxygen diffusion into metal, deformable at the friction of the surfaces layers, formation of oxygen solid solution in metal and its chemical compounds. This type of wear occurs both at the rolling friction and at the sliding one, in the last case the oxidizing wear is leading. Intensity of wearing out at the oxidizing wear is less than at other types of wear that is why it is related to the admissible wear types. This type of wearing out does not accompanied by the transfer of material from one surface to the other and it is passed very slow. The essential wear of the rubbing parts are absent. At start time of friction the micro-deformation (texturing) of surfaces with revealing of pure atoms, which oxidized by the lubricant or air with the formation of oxide films, takes place. Thus, the friction involves no main materials of details, but just their oxides. During friction the oxide films are destructed fragmentarily (disperse), but the new ones immediately appear on these places.

Corrosion wear occurs, when the contact of surfaces takes place in the corrosion mediums. During the sliding formed on the surface films are destroyed and corrosion influence spread deep into materials. Corrosion is called the destruction of the metal as the result of affecting of chemical or electrochemical mediums. Metal corrosion can take place independently of the friction presence; the mutual action of corrosion, loadings and mechanical wearing out magnify the intensity of details surfaces destructions. It happens that corrosion becomes active just because of friction in the conjugated details [7, 8].

Chemical corrosion passes at the interaction of metals with the dry gasses and vapor.

Electrochemical corrosion passes at the action of the liquid electrolytes on the metals. It is conditioned by the metal non-uniformity in the contact with the electrolytes. This non-uniformity appears in different forms.

In some machines it is possible to see the contact corrosion, at which the corrosion damages concentrate in the gap between the surfaces.

Fretting – is the corrosive-mechanical destruction of the metal constructions in the places of sliding of the close fitted details at the oscillations with the small amplitude, rotations and vibrations [9].

For the aeronautical engineering, as analysis showed, the loss or details workability in the friction nodes is most often associated with the fretting developing [10].

## 1.2 Fretting

Fretting – is corrosion that occurs during friction [11]. Most often sliding has oscillation character, objects obtain the extra loading, which are enough great. Fretting can appear during the contact of two metal materials, or metal and non-metal (rubber, plastic, that can serve as the gasket material). Destruction consists in formation of small dimples and corrosion products in the form of coatings, spots and powder on the conjugated surfaces. The destruction process – is the dispersion of surface, without moving away of wear products [12, 13].

Appearance of fretting is caused by the action of different atmospheric conditions, and also by the insufficient details protection from the environmental. Water can get between the friction surfaces and cause the corrosion, which strengthened by micro-friction between these surfaces.

As the result of small amplitude of travel of conjugate surfaces the damages concentrate on the non-great area of the real contact. Wear products cannot leave the contact zone, in such way the high pressure appears and their abrasive influence on the main metal increases. Torn metal parts are exposed to quick oxidizing. Destruction of oxide films are accompanied by jamming of conjugate metals [14].

For the arising of fretting it is enough surface travel with amplitude of 0.025 mkm. If the amplitude is great (about 2.5 mm), then the area of fretting destruction increases (picture of wearing out reminds of those, observed during the unidirectional sliding). Because of this the conclusion can be made that the amplitude of travel of surfaces about 2.5 mm – is the upper margin of amplitude, at which the fretting can be caused [15].

The whole set of factors influence on the regularity of fretting development – amplitude of travel of conjugated details, specific loads, oscillation frequency, contact form, etc. Changing of these factors leads to the changing of the processes at friction that become apparent in the character of surfaces destructions.

### 1.2.1 Process of fretting development

Fretting appears as the result of continuous destruction of oxide film at the points of moving contact. The most dangerous consequence from fretting – is the details bursting due to the decreasing of corrosion-fatigue resistance.

Corrosion of contact metal pairs is conditioned by changing of physic-chemical peculiarities of the conjugated surfaces in consequence of plastic deformation or relative displacement, destruction of protective oxide films, adsorptive interaction of material and medium [16].

Under the influence of surrounding corrosion medium the oxide film (corrosion products) forms on the metal surface. During friction this film are mechanically destroyed. Since the interacted surfaces are not separated during the fretting, in such a way the destroyed products of corrosion still remain between them (in some cases they are forced out), further the materials wear faster and the fretting passes intensively. Destruction of protective film can be the reason of corrosion' action, conditioned by the work of concentrated element, or it can cause the contact corrosion. Transformation of metal surface into oxide leads to malfunctions, clogging of the system by the corrosion products, jamming and fault of mechanism's work.

During the action of fretting the metal surface becomes colorless, and during the oscillatory loading influence the pits are formed on it, in which further the fatigue cracks arise.

Fretting occurs not on electrochemical mechanism. The most important fact is the applied loading, in result of which the intensive pitting formation takes place on the contact surfaces. During the oscillatory sliding (friction) the formed oxides could not be moved off from the contact surface. It leads to increasing of stresses between the contacting details and fretting in places of oxides accumulation passes much intensively.

Nowadays it is considered that the reason of fretting – is the specific character of mechanical interaction between the contacting surfaces, which accompanied by deformation and oxidizing. However there is no the single thought about the role of mechanical and chemical factors, it means that the nature of wearing products is interpreted in different ways. A few mechanisms of fretting were suggested [17].

One group of researches considers the mechanical processes mainly are responsible the development for fretting. According to these notions, destruction of metal surfaces takes place in such sequence: formation of small particles of juvenile material; chemical interaction of these parts and surrounding medium, with the creation of hard abrasive powder; abrasive wearing of surfaces.

Next to the theories, which give preference to the jamming and mechanical destruction, several researchers think that at the surplus oxygen the fretting, in most cases, is conditioned by chemical factor. Role of mechanical action leads to the continuous removal of oxides, as far as their formed and to the permanent revealing of juvenile surface.

Complex analyze of accumulated damages allowed to separate three main stages in this process:

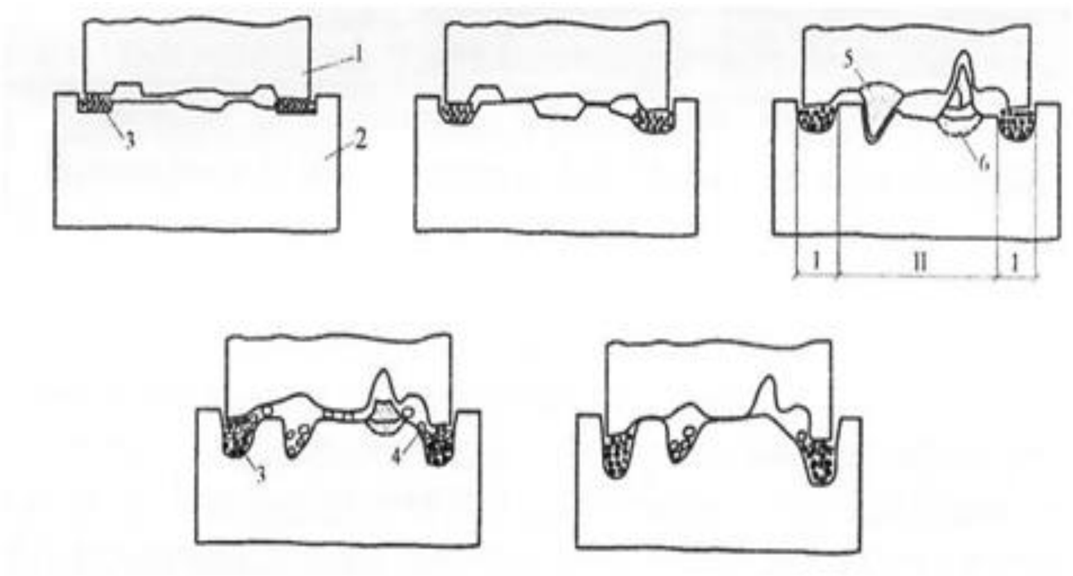
1) interaction between the irregularities, destruction of adsorptive and natural oxide films with the further prehension of juvenile surfaces takes place. Destruction due to fatigue of contact lugs and clipping of prehension' nodes, lead to the formation of primary wear products, the greatest part of which oxidize;

2) corrosively active medium occurs in the friction zone due to the absorption on the oxides of oxygen and humidity. Interaction between the articulated surfaces takes place through the layer of wear products, which play a protective role, decreasing the intensity of destruction. Reinforced, at the first stage, surface layers receive more restrained cyclical loadings, where the fatigue destruction starts to accumulate, which is increased by corrosive processes;

3) metals' surface layers during a long time are subjected to the cyclical loading, after they becomes softening and their progressive separation starts, which reveals in the wearing speed increasing.

Peculiarities of fretting process (small displacement amplitudes, firm adherence of surface) form conditions for the differential airing – free oxygen access to the edges of friction zones and difficult access to the middle part of friction track. This causes the effect of various leading mechanisms of dissipation of mechanical energy input according to the width of the friction track: for the peripheral areas – tribochemical, and for internally – rheological. Mechanism of surfaces destruction is shown in figure 1.4. The free access of the oxygen to the activated by the friction peripheral material contributes its intensive oxidation. In this case the oxide film does not protect the metal, which has been subjected to fretting, as any oxide film it is effaced between the vibrated surfaces, and the powder-like parts of oxides, which are between the surfaces, act as powerful abrasive. Due to this fact the ledge, formed on the boundary of the friction track, prevents the oxide wear products from leaving the friction zone. Taking into account that the volume of oxides are usually greater than the volume of metal, used for their formation, some mutual removal of contacting surfaces and redistribution of loads will happen (figure 1.4). In the middle part of the friction track the specific pressures decrease slightly, but they increase along the edges.

Increased specific pressures on the peripheral area, high-abrasive peculiarities of the powder-like particles of oxides and their uninterrupted transference will lead to the wear of metal and creation of the additional deepening along the edges of contacting zone. This process will continue until the specific pressures, along the whole width of the contact, are smoothed out. Formed peripheral layer of wear products becomes the effective barrier for the oxygen coming in into the inner contacting zones. The further vibratory displacement will lead to the partial removal of oxide products from the edges of friction zone. In the result the support function will decrease and redistribution of pressures will take place in the transverse direction of the friction track with its increase in the middle part that will contribute to the more firm adherence of the surfaces and additional limitation of the oxygen access to this zone (figure 1.4).



I – peripheral; II – internal: 1 – movable sample; 2 – immovable sample; 3 – oxide products of wear; 4 – particles of pure metal; 5 – adhesion pit; 6 – fatigue fracture

Figure 1.4 – Mechanism of surfaces destruction at fretting, zones of contact

The speed of fretting depends on nature of used metals (materials), temperature, content of corrosion medium and active loads, amplitude of slippage, contact pressure, quantity and frequency of cycles relatively to the displacement of contacting details, degree of conformity of the conjugated surfaces, temperature in the contact zone [18].

### 1.2.2 Protection of details from fretting

Measures reducing the risk of fretting can be follows: selection of materials of contacting pairs; selection of optimal design solutions; increasing of pulleys' tension and decreasing of slippage; reducing of aggressive medium (using of lubrications, retarding agents of corrosion); creation of compressed tension in the blankets of details by means of plastic deformation or chemic-thermal processing; plotting of protective metal coverings; division of conjugated surfaces by the non-metallic layers [18].

Correct selection of materials. It is advisable for the prevention of fretting arising to combine the soft metals with the hard one. It is proved that during the sliding of steel surface along steel one the destruction is much greater than at the sliding steel along steel, covered by lead. Even at the great loads the soft metal prevents contact with the surrounding medium. Destruction is also reduces due to the fact that the softer metal at the cut can “flow”, but not rub.

Application of lubricants in order to prevent of fretting. Here is the effective method, which frequently used at the conditions of small loads. Surface is previously subjected to phosphatizing. Obtained porous film is processed by the lubricant of low viscosity, which penetrates deep in the voids and due to this it remains on the product for a long time. The disadvantage of this method can be considered that it is a temporal protection, the lubricant sooner or later moves away as result of sliding.

Design of contacting surfaces with the removal of sliding. It is effective, but rather hard to achieve it.

Application of special coverings. In order to prevent the surface contact with the oxygen.

Application of materials with the low friction coefficient and layers. Such materials are used only at small loads, because of their small durability. Rubber, for example, amortizes the oscillations and prevents sliding.

Application of cobaltic alloys. It gives the positive result just in the case of water presence.

Generally, it can be noted that just those details are subjected to fretting wear, which work in various conditions of vibro-contacting loads. First of all it is a varied spectrum of contacting loads and possibility of relative vibro-displacements between the articulated surfaces. Development of physic-chemical processes in the zone of contact, that means also the character and intensity of wear depend, in general, on these factors.

### 1.3 Methods of hardening of steels and alloys

Methods of surfaces hardening can be classified into a number of groups:

1) according to the deformation speed (static, dynamic, combined); according to the kind of friction in the contact of tool and detail (contacting indentation, sliding friction, rolling friction, rolling friction with sliding);

2) according to the conditions of friction in the contact with the processed surface (dry and with the lubrication); according to the form of deformed bodies (balls, rollers, bodies of arbitrary forms);

3) according to the connection of deformed bodies with the sources of energy and movements (with the rigid connection; with the elastic connection; with the flexible connection; without connection); according to the method of energy transmission to the deformed bodies (mechanical; pneumatic; hydraulic; electro-magnetic; explosive; combined).

Material hardening of billets and products is achieved by mechanical, thermal, chemical and others influences, and also by combined methods (thermo-chemical, thermo-mechanical, etc.) [19].

Most of machines details work in the conditions of wearing out, cavitation, cyclic loads and corrosion at the cryogenic and high temperatures, at which the maximal stresses appear in the blankets of metals, where the main stress thickeners are accumulated. Thermal spraying, welding deposition, thermo-chemical processing increase hardness, cavitational and corrosive durability and, created the favorable residual voltage of compression on the surface, augment the reliability and service life of machines details. Besides in order to increase of strength and resistance to the fatigue it can be created the corresponding composition of alloys and technology of processing. At saving of rather high plasticity, viscosity and fracture strength, the given methods raise the reliability and service time of machines and reduce the consumption of metal for their production in consequence of decreasing of details cross section [20].

Hardening is provided by the application of electrophysical and electrochemical method of processing, ultrasonic, magneto-spark, electrical-hydraulic, electron-ray, photon-ray, anodic-chemical, electro-spark, and also by the impact of air-blast, laser, etc.

Hardening processing may be surface (for example, plastic deformation with the occurrence of the surface cold-hardening), volumetrical (for example, isothermal tempering) and combined (for example, thermal processing with the further surface plastic deformation). Volumetric and surface hardening processing can be carried out consistent by a few methods.

During the coverings plotting the additional layer of materials is formed on the product surface, which, in most cases, differs by its content from the main material of detail. At this the overall dimensions of detail are increased on the thickness of the covering layer, it gives the possibility to use the methods of coverings plotting not only at the production of new one, but also at the renewal of old details and constructions.

At the surface alloying or modification of its structure the changing of the surface properties take place as result of changing of chemistry of the surface layer of the details' material or changing of its structural state (amorphization, creation of metastable structures, etc.). Dimensions of the product in this case do not change [21].

During the coverings plotting, as a rule, a new quality of the details is provided (service time increases, the special heat- and electro-physical properties improving, the attractive outward appearance is obtained, etc.). There are no practically restrictions on the connection of materials in the system base – covering.

Not only the metal can be used as a base, but also glass, highly glass pottery, wood, fabrics, paper, cardboard and etc.

Depending on the energy kind that is used for the processing, all methods of the processing (creation) of surfaces layers conditionally can be divided into 7 groups, shown in figure 1.5.

1) <u>Mechanical methods</u> utilize the pressure energy of tools or particles for the cold hardening of surface layer:

a) running-in, that is application of constant or alternating pressure to the detail surface, which is processed, using the tool with the smooth surface (without edges) in the form of roller, ball or disk with the purpose of surface layer strengthening by the cold deformation;

b) cold-hardening, that is using of the kinematic energy of steel, ceramic or glass particles in the form of balls or pellets, which are thrown out by the centrifuge force, pressure of compressed air (cold-hardening by pellets) or kinematic energy of tool with the smooth surface (hammer), that hits the detail surface, which is processed, with the purpose of cold hardening of surface layer [22].

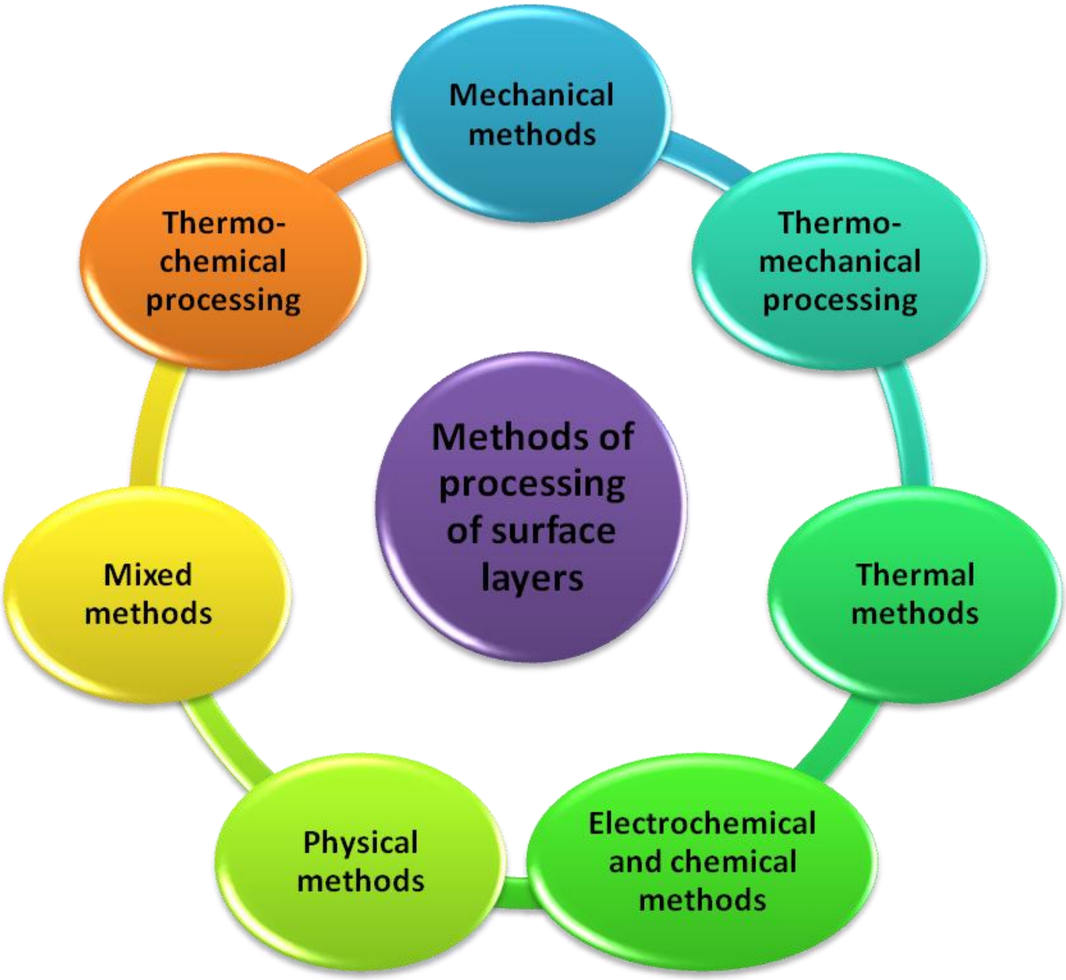



Figure 1.5 – Methods of processing (creation) of surface layers [22]

Also the mechanical properties of the details are improved by plastic deformation.

Surface plastic deformation – is simple and effective method of increasing of carrying capacity and durability of machines details and parts of constructions, especially those, which work in the conditions oscillatory loads (axes, shafts, gears, etc.) [20]. Depending on the structure, materials peculiarities, dimensions and character of details' operational loads the different kinds of surface plastic deformation are applied: knurl and expansion by rollers and balls, running-in toothed cylinder, diamond smoothing, burnishing, hydro-abrasive, vibrating, pellets-resistant and others methods of processing. Often surface plastic deformation, except hardening, greatly reduces surface roughness, increases details wear resistant and improves their outward appearance (hardening-finishing processing) [23].

Increasing of durability, by means of surface plastic deformation of working surfaces of steel details, consists in creation of the residual voltages of compression and microrelief in plastic deformed metal layer. Nowadays surface plastic deformation is applied as the intermediate stage everywhere at the production and repair of details from the steel alloys, also new technologies of improvement of this hardening method are developing.

2) Thermo-mechanical processing. One of the technological processes of hardening' processing is thermo-mechanical processing. The plastic deformation and thermal processing (tempering of preliminary deformed steel in the austenitic state) combine at thermo-mechanical processing, it means that thermo-mechanical methods use the mutual influence of heat and kinematic energy with the purpose of coverings obtaining, rarely surfaces layers, by means of:

a) sputtering (gas-thermal), that is forming of materials' layer by means of interaction with the basis of flow of heated and accelerated in the stream of high-temperature gas particles on the detail surface;

b) surface cladding, that is covering of metal' basis by another metal or alloy with the help of pressure on the covering material (for example, rolling, detonation, shrinkage) at the corresponding higher temperature; in case of heating of basis up to the temperature, value of which is lower, than the changing temperature in the solid state – the process can be related to the mechanical methods;

c) hardening of metal or alloy by means of air-blast, which occurs as the result of ultra-fast vaporization of basis material due to the work of strong concentrated flow of electrons (hardening by electrons) or photons (laser hardening) [22].

Depending on the temperature, at which the deformation takes place, there are the high-temperature thermo-mechanical processing and low-temperature thermo-mechanical processing.

The essence of high-temperature thermo-mechanical processing is in the heating of steel up to the temperature of austenitic state. Deformation of steel takes place at this temperature that leads to the cold-hardening of austenite. Steel with such state of austenite is subjected to the tempering. High-temperature thermo-mechanical processing can be effectively used for the carbonaceous, alloyed, structural, spring and tool steels.

Low-temperature thermo-mechanical processing (ausforming). Steel is heated to the austenitic state. After this it is kept at the high temperature, then cooling up to the temperature higher than the temperature of beginning of martensite transformation (400 – 600 °C), but lower than the temperature of recrystallization, takes place, and at this temperature the pressure processing and tempering accomplish. Although, the low-temperature thermo-mechanical processing gives the higher hardening, but it does not reduce the turn of the steel for the temper brittleness. Besides, it requires the high levels of deformation (75 – 95 %), therefore the powerful equipment needed. Low-temperature thermo-mechanical processing is applied to the medium-carbon alloyed steels, which are tempered on martensite, which have the secondary stable austenite.

Gas-thermal coverings. During the production and repair of details of aeronautical engineering in the form of wear resistance coverings the coverings, obtained by the methods of gas-thermal sputtering, are the widest used. In recent years, increasingly began to develop this type of coverage, which has the significant advantages: insignificant temperature (200 – 300°C), up to which the product surface heats, it allows to save the initial structure and properties of materials' basis; universality of using of materials with thermal spraying (metals and alloys, without oxygen and oxygen refractory connections, plastics, porous and other composite materials); possibility of coverings plotting of 0.02 to 10 mm and more; high productivity of processes, relatively small labour-intensiveness; sputtering of different materials into some layers, it allows to obtain the layered coating with the special characteristics.

Gas-thermal coverings can be subdivided into [24]:

a) high-speed gas-flame spraying;
b) plasma spraying;
c) arc spraying;
d) detonation spraying;
e) gas-flame spraying;
f) sprayfusing.

One of the most developing directions in the area of protective coverings is the method of plasma spraying. Having the high productivity of sputtering, this technological method allows to apply coverings with the wide spectrum of characteristics, and also to use it for the sizes renovation of wear details.

3) Thermal hardening methods. Thermal processing – is one of the simplest, most effective and economical methods of metals hardening. At this treatment the chemical and physical properties are often changed, for example, conductance, magnetic properties, corrosion resistance. Approximately 8 – 10 % of general steel melting are subjected to the thermal hardening [20].

Hardening at the metals thermal processing is ensured partially at the temper hardening.

Tempering – is the most widespread type of thermal processing, including the heating up to the optimal temperature, holding and further quick cooling with the purpose of obtaining of nonequilibrium structure. As the result of tempering the durability, hardness, wear resistance and elastic limit are increased, but the plasticity is decreased. Structure of the tempered steel consists of martensite, non-dissolved carbides and retained austenite.

There are next main methods of tempering: full, broken, isothermal, through quenching, surface, thermal and with cold processing.

4) Electrochemical and chemical methods are used in order to obtain the metal or non-metal coverings on the metal surfaces by deposition. These methods include electrochemical (electrolytical and chemical conversion coatings) and chemical (chemical and chemical conversion coatings) restoration. Coverings have higher corrosive- and wear

resistance, which differ from the basis material be physico-chemical properties, great coefficient of radiation reflection [25].

5) Physical methods are used for the coverings deposition on the surfaces of metals and non-metals, which are connected with the basis adhesively (at least – the diffusion), or for the processing of the surface layer with the help of different physical effects that take place at the reduced pressure, in most cases for participation of ions (deposition from the vapour, sputtering, spraying, ion implantation of metal and non-metal substances).

6) Mixed methods.

a) Thermo-magnetic treatment is concluded in the hardening of ferromagnetic material by mutual influence of two sources of internal voltages in the crystal latitude – tempered and magnetostriction, in other words the process of tempering is provided in the electromagnetic field, created by the solenoids and electric solenoids. Due to the thermo-magnetic treatment the durability properties are improved, the steel plasticity is increased and the sensitivity to the cut is decreased.

b) Thermal mechanic-magnetic processing is concluded in the combination of three processes at the processing (tempering, plastic deformation and magnetostriction), which create the internal voltages in the crystal latitude of steel and distort the periodicity. Such mixed processing allows increasing the durability properties in 30 – 60 % at the simultaneous increasing of plasticity indications in 20 – 40 %.

7) Thermo-chemical processing consists of combination of thermal and chemical influence with the purpose of changing of chemical content, structure and properties of product surface layer.

## 1.4 Thermo-chemical processing. Nitriding

Thermo-chemical processing – is the saturation process of details surfaces by some chemical element through the diffusion of this element from the external specially created medium, in which the details are placed that are subjected to the thermo-chemical processing. It includes the diffusive saturation by non-metals (carbon, nitrogen, boron, others); metals (diffusive metallization by aluminium, chrome, titanium, others); and also the diffusive removal of admixtures (carbon, oxygen, hydrogen).

Thermo-chemical processing is possible, if the saturated element together with the main component create the hard solutions [26].

### 1.4.1 Classification of thermo-chemical processing

In the practice of thermo-chemical processing in the production scale the next methods of thermo-chemical processing of metals (steels, grey irons, nonferrous metals and alloys) are used: nitriding, cementing, boronizing, cyanide (case) hardening (carbonitriding and different methods of diffusion metallization – chromium-plating, alitizing, siliconizing, titanizing and etc.).

Cementing is called the process of diffusive saturation of details by carbon. Cementing is appointed to the details, working “at impact and wear”: details should have the “viscous” kernel and solid wear resistive surface layer. They are made of the mild steel 0.1 – 0.25 % of carbon. In the individual cases, for the heavy stressed details, the steels, comprising 0.25 – 0.30 % of carbon, are applied.

Cementing steel grades: Ст1, Ст2, Ст3, 10, 15, 20, 25, 15Х, 18ХГТ, 12ХН3А, 18Х2Н4ВА and others. Steel cementation in most cases is executed at 930 – 950 ºC, that is in the austenite area, as the dissolubility of the carbon in the austenite is great. The thickness of the cementing layer depending on the details sizes is equaled to 1.5 – 2.5 mm.

In the practice of the thermo-chemical processing, mainly, “box carburization” and “gas carburizing” are used. However, there are also methods of “bath carburization” and cementation “with the paste using”.

Boronizing – is the process of diffusive saturation of metals surfaces by boron with the formation of iron borides $Fe_2B$ и $FeB$ for the structural steels and alloys and other structures. It is implemented for the increasing of products wear resistance and red hardness, worked at the low temperatures, oscillatory loads and load impact or in the abrasive and aggressive mediums. The most important feature of the boronizing layer is the rather high hardness.

The critical thickness of boronizing layer is: for the low-carbon steel – 0.3 mm, medium-carbon steel – 0.25 mm, for the high-carbon steel – 0.18 – 0.2 mm.

The main method of the boronizing are electrolysis borating, liquid, gas and in the hard medium.

During the hard boronizing the products are packed up in the steel boxes, filled up with the powder from every quarter, which comprises boron (ferroboron or boron carbide, grounded in the ball crusher) and heated in the furnace to 950 – 1050 ºC with the holding of 5 – 10 hours.

Liquid boronizing can be of two kinds – without electrolysis and with it. At the liquid boronizing without electrolysis the products are dipped into the flux of neutral salts ($BaCl_2$ and NaCl), to which the powder comprising boron are added. Liquid boronizing with electrolysis is ensured by the electrolysis of melted borax, the products are served as the cathodes in such cases.

Gas boronizing is made: in the gas mixture $H_2B_6$ + 25 $H_2$ during one hour; in the gas mixture $BCl_3$ + $H_2$; at the temperatures: 800 – 850, 1050, 1100 ºC; with the obtaining of layers with the thicknesses: 0.10 – 0.20, 0.035 mm on the details from the steel 30ХГСА [27].

Cyanide (case) hardening. The solid, liquid (cyanide) and gaseous (carbonitriding) mediums, and also the pastes, applied on the places that are subjected to the thermo-chemical processing are used for the cyanide (case) hardening. It is the process of mutual diffusive saturation of the details surfaces by carbon and nitrogen. The hard, liquid and gaseous cyanide hardening are known.

1) The hard cyanide hardening is carried out as the cementation, the only difference is that the urea or the other substance, which includes the nitrogen, is added to the carbonizer.

2) Liquid cyanide hardening is made in the molten salt: 8 % of NaCN, 82 % of $BaCl_2$ and 10 % of NaCl, the bath surface is covered by the mineral carbon. Details after the extraction from the bath are cooled on the air, after this the thermo processing is obligatory. In 1.5 – 6 hours the layer with the thickness of 0.5 – 2 mm is obtained.

3) Gaseous cyanide hardening, called carbonitriding, is carried out in the mixture of gases $NH_3$ and $CH_4$ at 550 – 600 ºC, instead of the wear resistant nitriding.

Diffusion chromizing – is the process of saturation of the metal surface by the chrome and its combinations for the increasing of the heat resistance, cavitational and corrosive resistance, scale resistance up to the temperature 800 ºC, at the chrome containing in the surface layer at 0.3 – 0.4 % – increasing of hardness and wear resistance. Chromizing is carried out in high-temperature furnaces for the products made of any steel grade.

Siliconizing – is the diffusive saturation of the steel surface layer by the silicium for the increasing of the resistance against the corrosion in the sea water and acids, and also for the increasing of the wear resistance at the low hardness (200 – 250 HV). The process takes place in the powder-like mixtures, gaseous and liquid mediums.

### 1.4.2 The process of nitriding

Nitriding – is the technological process of thermo-chemical processing, at which the surface of different metals and alloys is saturating by the nitrogen in the special nitriding medium. The surface layer of the product that is saturated by the nitrogen has in its containing dispersed nitides and obtains the increased corrosive resistance and the highest microhardness. According to the microhardness the nitriding is inferior just the boronizing, but at the same time it predominates the cementing and carbonitriding [28].

Metals and alloys, subjected to nitriding, are shown in the table A.1 and table A.2:

1) carbon, alloy, structural and instrument steels;
2) high-chromium irons, high-chromium wear resistance irons, chrome;
3) titanium and its alloys;
4) beryllium;
5) wolframium;
6) columbium alloy;
7) powdered materials.

Functionality of the nitriding:

1) surface hardening, increasing of the surface hardness;

2) increasing of the wear resistance;

3) increasing of the heat resistance (up to 450 – 500 ºC);

4) protection from the corrosion in the river and sea water, atmosphere and other low-aggressive mediums;

5) increasing of the fatigue and contact strength.

Depending on the application the used technological processes of the nitriding can sufficiently differs [29].

### 1.4.3 Classification of the nitriding methods

In the practice of the nitriding such methods are implemented: wear resistive (durable) nitriding – for the “nitralloies” – it increases the hardness, wear resistance and fatigue strength; anticorrosive (design) nitriding – for any steels – it increases the corrosive resistance in the humid atmosphere and fresh water; and also the nitriding in the liquid mediums; gaseous nitriding; catalytical gaseous nitriding; plasma nitriding; nitriding from the electrolyte solutions.

Wear resistive (durable) nitriding – is applied for the details made of the steels type 38ХМЮА, 38Х2МЮА, 38ХМФА and others that is for the “nitralloies”. It is explained by the fact that the high hardness and high wear resistance are reached just at the nitriding of the “improving” steels, alloying by the chrome, molybdenum, aluminum, vanadium: as the nitrides of chrome, molybdenum, aluminum and vanadium are characterized by the high hardness. The disadvantage of such nitriding is the fact that due to the low temperature the speed of the process is small, for example, the layer with the thickness of 0.2 – 0.4 mm is obtained for 30 – 60 hours. As the advantage of this nitriding we can consider that the thermal processing is not needed after it, as it is obtained the layer with all listed peculiarities.

To the anticorrosive nitriding mainly the carbon steels are subjected at the higher temperatures (600 – 700 °C) with the holding of 0.5 – 1.0 hour [30].

Nitriding in the liquid mediums – “Tenifer process”. It exists at the temperature 570 ºC in the molten salt: 85 % of the sum (40 % KCNO + 60 % NaCN), 15 % $Na_2CO_3$ or 53 % of carbamide, the dry air is passed through the last. The nitrogen is diffused into the steel. The general thickness of the layer is 0.15 – 0.5 mm. As the result the fatigue limit is increased, the deformation and buckling of the details are decreased.

Gaseous nitriding. Saturation of the metal surface is taking place at the temperature from 400 ºC (for some steels) up to the 1200 ºC (austenite steels and refractory metals). The medium for the saturation is the dissociated ammonia.

Catalytical gaseous nitriding. It is the last modification of the technology of the gaseous nitriding. The medium for the saturation is the ammonia, dissociated at the temperature 400 – 600 ºC on the catalytic agent in the working area of the furnace. The changing of the saturation potential is used for the control of the structure and mechanical properties of the layer at the catalytical gaseous nitriding of the steels. In whole the lower temperatures are applied than at the gaseous nitriding.

Plasma nitriding – consists in the technology of the saturation of the metal products in the nitrogenous vacuum (approximately 0.01 atm.), in which the smoldering electrical discharge forming. Walls of the heat chamber serve as the anode, and as a cathode – processing products. Advantages of the plasma nitriding: time decreases, deformations reduces, cost effectiveness of the thermo-chemical processing increases, the diffusive layer with the controlled content and structure is received.

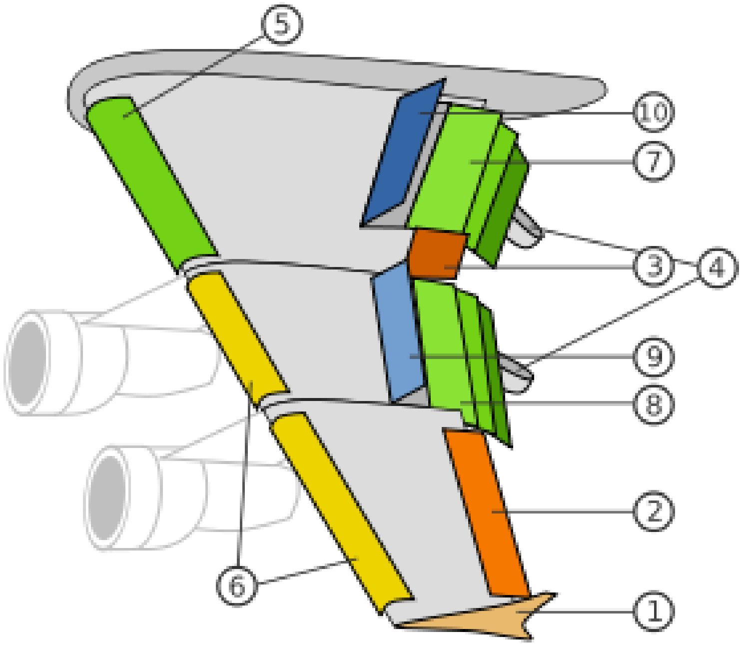
Nitriding from the electrolyte solutions – uses the anodic effect for the diffusive saturation of the processed surface by the nitrogen in the multicomponent electrolyte solutions. One of the types of the speed electro-chemical processing is the anodic electrolyte heat for the small-size products. For the providing of the nitriding other substances except the electrically conductive component – donor, usually nitrates – are input into the electrolyte [31].

## 1.5 Damages of the aircraft wing lift devices screw by fretting

### 1.5.1 Wing lift devices

Improving of the takeoff and landing characteristics of the aircraft and first of all decreasing of its landing speed and lift-off speed are provided by means of wing lift devices using. These means include the devices that allow changing of wing bearing capacity and wing resistance [32].

Flaps, fender guards, slats deflect before the landing at the maximal angles, ensuring the surplus of the wing bearing capacity due to the increasing of the profile curvature, some increasing of the wing area and due to the slot effect (figure 1.6). Growth of the wing bearing capacity decreases the landing speed of the aircraft. During take-off these wing lift devices deflect at less angles, ensuring some increasing of the wing bearing capacity at the small growth of the resistance, as the result of which the length of aircraft run reduces. Brake flaps and lift dumpers are usually deflect during the run, ensuring the sharp drop of the wing lift force, that allows using the brakes of the wheels more effectively and reduce the length of the run. They do not influence on the landing speed and lift-off speed. Brake flaps and lift dumpers also can be used at flight for the reducing of the aerodynamic quality and increasing of the glide angle during landing [33].




1 – wing tip; 2 – wing-tip aileron; 3 – inner aileron; 4 – fillets of flap drive mechanism; 4 – leading-edge slat; 6 – leading-edge slats; 7 – inner triple-slotted flap; 8 – external triple-slotted flap; 9 – spoiler; 10 – spoiler

Figure 1.6 – Main parts of wing lift devices [33]

### 1.5.2 Places of fretting formation

Fretting comes into being in the atmosphere, and also in the mediums of vacuum, oxygen, nitrogen and helium. Intensity of wearing during the fretting in the air atmosphere is higher, than in the vacuum and nitrogen medium [34].

Details, pressed to each other, on which the oscillatory, rotation and vibration stresses affect, are subjected to the fretting [35].

Bolt joins, mounting surface in the rolling bearings, plate springs, gears, metal ropes and rope pulleys, contact surfaces of rolling bearings, bow springs, springs, valves and pushers, camshaft mechanism are subjected to the fretting [32].

Damages from fretting are met practically in any movable or nominally immovable connection, details of which are subjugated to the vibrations or influence of repeated variable stresses, enough to the occurring of the relative displacements.

Studies of damaged details found [36] that the following units and groups of the details are damaged in the fretting conditions:

1) in frame construction: elements of skin, fitting nodes of structural panels, joint of cargo and technical hatches, nodes of engine hinges, steering wheels, landing gears, etc.;
2) in the control system structure: elements of thrust rods, hinges of levers connections, screw pairs of elevators, supports of leading edge slats and trailing edge flaps, etc.;
3) in the structure of gas-turbine engines: shaft supports, places of connections and junctions of working and directing blades, discs, rings, flame tubes, fuel nozzles, supports and valves of thrust reverser, etc.;
4) in the units of fuel and hydraulic systems: suspension assembly of pendulums, spray nozzles, inner cylinders and spool and sleeve, etc.

Due to the developing of fretting the details sizes change, the quality of surface becomes worse, gaps increase and jamming in the coupling appear, which cause malfunctions and failures of structures and aggregates of aeronautical engineering. During the influence of cyclical loads, the places, damaged by fretting, are the centres of fatigue destruction. Under the influence of fretting the durability of structural alloys can decrease more than 50 %, and endurance, at the stresses, close to the fatigue limit, can drop in hundred times. In whole it can be pointed that approximately 60 – 65 % of details of friction nodes of aeronautical engineering are damaged in the fretting conditions.

Elevators of leading-edge and trailing-edge flaps are one of the most responsible units of aircraft wing lift devices. The main function of elevators is the moving of leading-edge and trailing-edge flaps after take-off and before landing. The elevator is the pair of screw-nut (figure 1.7) with the intermediate marbles, the main purpose of which is to transmit the effort from the screw of the drive on a nut, which, in its turn, is fastened on the carriage of the flap. A carriage moves on the rail of wing lift devices and pulls out a wing flap on a certain trajectory.

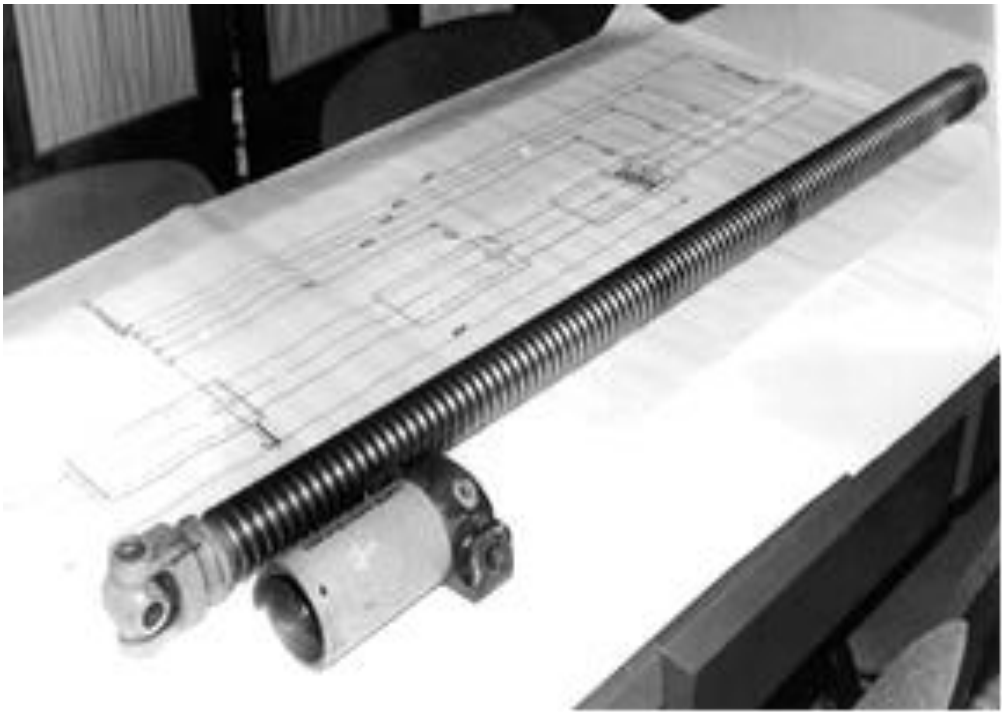


Figure 1.7 – General view of screw and nut of the wing flaps elevator of the aircraft AN-124

One of the especially responsible units on an aircraft are the elevators of leading-edge and trailing-edge flaps. They usually work in non-insulated from the external environment space. So it means that they work under the influence of complete operating of temperatures range and in the conditions of all atmospheric influences. The refuse of any elevator in the process of flight results to the special situation [37].

During the extraction and retraction of flap it moves along the directing steel rails on the attached to them carriages. Each of the directing rails is attached to the rear spar with the help of two brace struts. Displacement of the flap along the directing rails is carried out by means of elevators of actuating screw with the help of special nuts, connected with the levers of the extension flap by means of hinges. At the rotation of actuator screw the nuts move and transfer the flap in the corresponding position. The actuator screws are powered by the reverse electromotor, connecting with the actuator screws by tubular shaft with the bevel gears [38].

Wing lift devices (slats, slots, flaps, etc.) should have the fit control mechanisms, reliable fittings, normal adjustment of deflections from the initial positions, correct warning that fix the limit position; it should not have the slots more that it is established.

**Conclusion to part 1**

1) One of the kinds of wing lift devices damages of aircraft AN type, which defines its further serviceability, is fretting.

2) Screw of the wing lift devices provides the extraction and retraction of the flaps, at the same time, it is the most responsible and expensive detail of aircraft AN type.

3) There are great amount of hardening methods of high-resistance steel, which give the increase of durability, wear resistance from a few percentage up to the few time.

4) For the choosing of the optimal friction pair of wing lift devices (screw-nut) it is necessary to provide the comparative researches of materials ВКС-170 and 30Х2НВФА without surface hardening and with the hardening of the surface layers at the mechanic-pulse hardening and nitriding processing.

# PART 2
# RESEARCH METHODOLOGY

## 2.1 Fractography

Fractography (from lat. fractus – break and ...graphy) – is the description of surfaces of metallic breakages with the purpose of reasons analysis and flowing of the breakage process. The fractography researching is carried out by naked eye, and also with the help of magnifying glass, optical or electrical microscopes [39].

Fractography is the study of fracture surfaces of materials. One of the aims of fractographic examination is to determine the cause of failure by studying the characteristics of a fracture surface [40, 41]. 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 [42]:

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.

## 2.2 Metallography

Metallography – is the direction in metallurgy, classical method of investigation and control of metal materials, preparing and studying of metallographic sample structure in the optical microscope. The structure is revealed with the help of etching or a cutting, polishing and smoothing of the sample.

Measuring of microhardness is one of the analysis means of structural changing occurring in the surface layers in the friction process. Microhardness of the materials surface layers in the cross-section is determined on the metallographic samples, manufactured in the special clamping screws, which protect the edges of the metallographic samples from the collapse during the smoothing. Metallographic samples allow providing the measurement of micro-hardness in the thinnest surfaces layers of metals near the edges from the friction surfaces.

## 2.3 Procedures analysis of experimentation on fretting

The research performance on fretting differs with the different methods used, the scheme of loading and type of contact, and in the evaluation of surface damage. The method is chosen in accordance to the two basic requirements [43]:

1) simulation of fretting in the laboratory should maximally approach the conditions of this type of surface damage in the real constructions;

2) the selected method should be such that you can compare obtained results with the data from other works.

The followings requirements are set to the test devices in connection with the specifics of fretting [44]:

1) backlash-free mounting of samples in the clamping devices;

2) torsion rigidity and low deforming of the device;

3) availability of vibration skidding movement of the controlled frequency and amplitude;

4) availability of controlled normal force to create the necessary pressure in the contact;

5) the possibility to supply the lubricant or other medium.

Domestic and foreign researchers use such types of the contact as: sphere-plane, cylinder-plane, cylinder-sphere, cylinder-cylinder and plane-plane. Investigations are carried out, as a rule, on the laboratory facility, the constant contact of the samples under the proper loading is supported.

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 this scheme is proportional to distance from the axis of rotation. This disadvantage is eliminated with the choice of the optimal geometry of one of the samples. In other types of contact is the uneven pressure distribution in contact zone, leading to the different wear conditions.

The basis of the accepted methods of work contains a comprehensive study of the qualitative parameters of friction parameters.

## 2.4 Installation for the testing on fretting

The contact scheme of plane-plane type is used on the installation МФК – 1 (ГОСТ 23.211-80), the general view of which is shown in figure 2.1.

The main advantages of this method are:

1) quick assessment of wear resistance of the materials and coatings under fretting;

2) satisfactory reproducibility of test results with a minimum number of test samples;

3) simplicity of the method and corresponding equipment;

4) possibility of smooth control of the frequency, normal load and amplitude of micro shifts;

5) tests using the plastic and liquid lubricants;

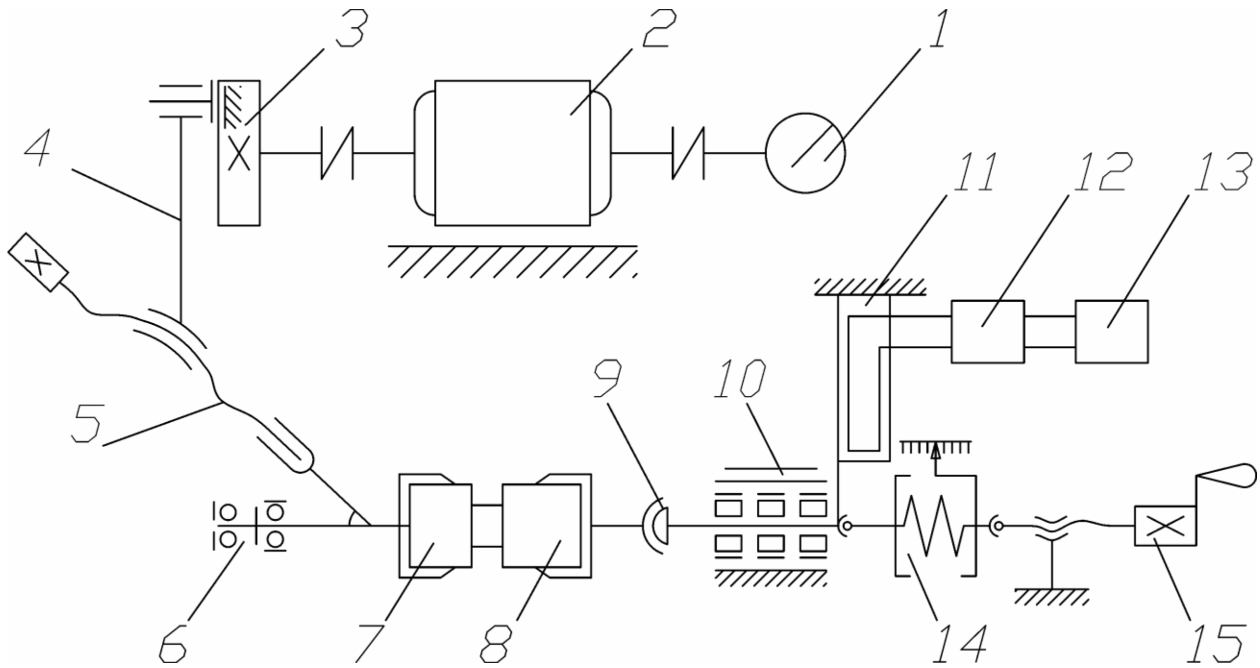
6) registration of the friction force during testing.


Figure 2.1 – General view of the МФК – 1 installation for the testing on fretting

The choice of a flat circular contact and swing-rotation movement of the contact surfaces is stipulated by the necessity of the control of normal load and elimination of edge effect.

### 2.5 Kinematical scheme and installation description

The essence of the method is that the rolling cylindrical sample (control sample), adjacent by edge with the immovable cylindrical sample at a given pressure is driven to the swivel-rotary motion with the given amplitude and frequency. The wear of stationary sample is measured for a given number of cycles, by the value of which the wear resistance of the investigated material is determined.  Layout of the installation is shown on figure 2.2.




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 2.2 – 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).

It is known that the friction coefficient in the process of running in is usually higher than the established friction coefficient, which characterises the friction properties of the concrete pair.

### 2.6 Samples for the testing on the МФК – 1 installation

Samples for the testing are shown in figure 2.3. The contact of tested samples is performed on the surface, which is a closed loop with the nominal contact area of 0.5 cm$^2$, inner diameter of 11 mm and the outer diameter of 13.6 mm.

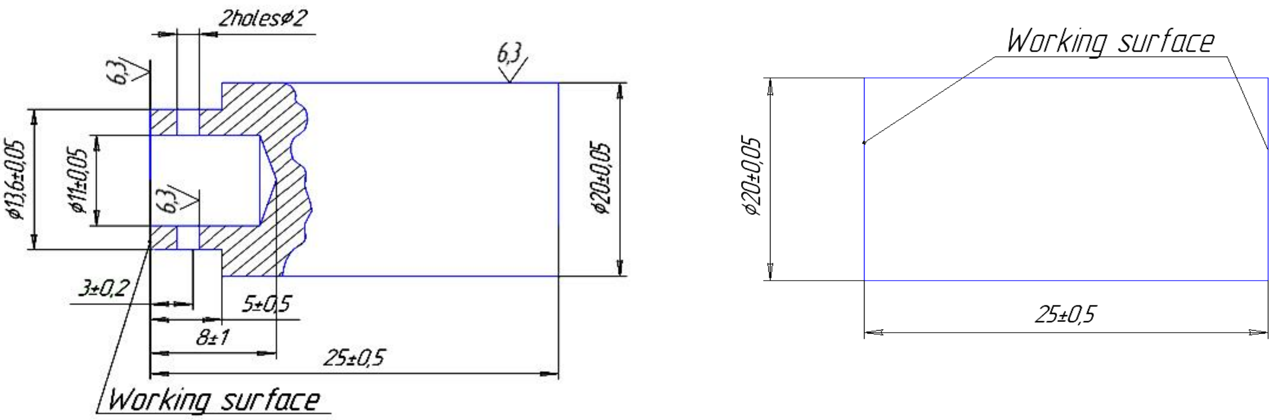



Figure 2.3 – Samples for the testing on fretting

Samples should be washed and dried before and after the experiment [45]. For the washing such liquids can be used: gasoline ГОСТ 443-76, acetone ГОСТ 2603-79, ethyl ГОСТ 18300-72. Before the test the measuring and recording equipment should be checked and marked.

Installation allows providing testing at the next parameters [46]:

1) loading of the samples in the axial direction by 200 – 1000 N;

2) swivel-rotary motion of the control sample according to the fixed sample with a frequency of 10 – 30 Hz and amplitude 10 – 1000 microns;

3) measuring system settings during the testing provides the continuous registration of swivel-rotation cycles quantities of control sample with an error less than 50 cycles.

## 2.7 Preparing and experiment carrying out

1) Samples are washed consequentially in the liquids, described earlier, and dried in the air;

2) sample and control sample are fixed in the collets of the testing installation;

3) sample and control sample are pressed to each other by their working areas with the effort not less than 200 N, ensuring their mutual adjoining with the help of the self orienting collet of the sample, after that the position on the sample collet is fixed rigidly;

4) samples are resulted in contact and applied the compressed force;

5) the drive is turned on;

6) after the reaching of the given quantity of testing cycles, the drive is turned off, provide the unloading, free the samples from the collet clamps, wash consequently in the liquids, described earlier, and dry in the air;

7) testing is repeated not less than for the five pairs of samples.

## 2.8 Determination of the wear

Measuring of the sample and coating have carried out with the help of profilometer depth recorder Калібр-201 of the 253 model according to ГОСТ 19300–86 up to 50 microns and the vertical type optimeter ІКВ more than 50 microns, by taking the profilohrams of eight equidistant sections of the working surface of the sample in the radial direction (figure 2.4).

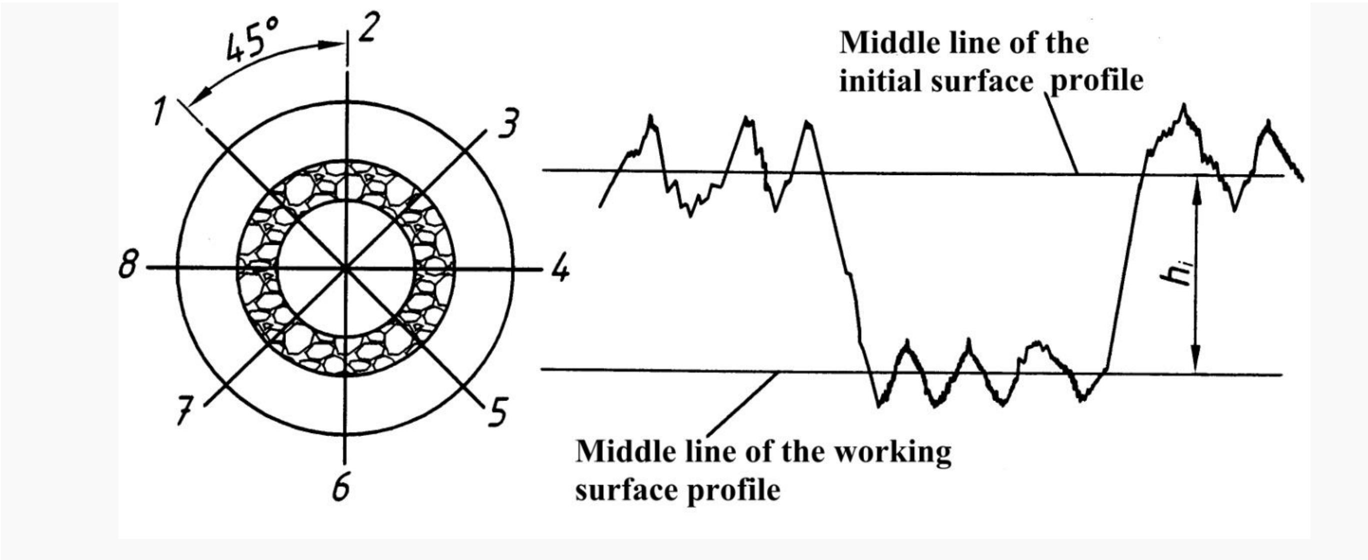



Figure 2.4 – Scheme of wear measurement of the samples after testing on fretting

Sample wear $h_j$ is defined by the formula (2.1):

$$h_i = \frac{\sum_1^8 h_i}{8} \tag{2.1}$$

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

Thus, the unique unit for the materials wear resistance testing at fretting conditions is developed. The unit enables to carry out the comparative tests of fretting of steels, alloys, coverings and composite materials. Using the standard specimens for fretting – ГОСТ 23.211-80 the unit allows providing the tests in the range of the loading from 1 to 40 MPa and in the wide range of sliding speeds.

An important advantage of the determining of wear by the linear depreciation method is that the magnitude of wear does not depend on the specific weight of material and possible changes in the masses of patterns.

**Conclusion to part 2**

1) There exist a great amount of methods for the testing on wear, which allow to carrying out the experiments in the wide range of the conditions.

2) The method has been determined (executed on friction machine МФК – 1), which will allow to choose the optimal covering for the restoration of the screw of wing lift devices of aircraft AN type and to develop the methodical recommendations about their restoration.

3) Friction machine МФК – 1, which simulates the wear resistance in the fretting conditions, is the most suitable for the testing of structural material ВКС-170 with mechanic-pulse hardening and without surface processing and structural material 30Х2НВФА with the hardening of the surface layer by nitriding and without surface processing.

# PART 3

# SCIENTIFIC RESEARCH PART

## 3.1 Fractographic investigations of the damaged screw and nut

It is established that on aircraft AN-124 with flight experience about 10 thousand hours on the threaded part of the screws and nuts of the flaps elevators the damages are formed (figure 3.1) in the places corresponding 2°, 10° and 15° of flaps position:

1) 0° and 2°– corresponds to the flaps position in flight;
2) 15° – corresponds to the flaps position during landing in the conditions of high-mountain;
3) 30° – corresponds to the flaps position during the take-off and landing.

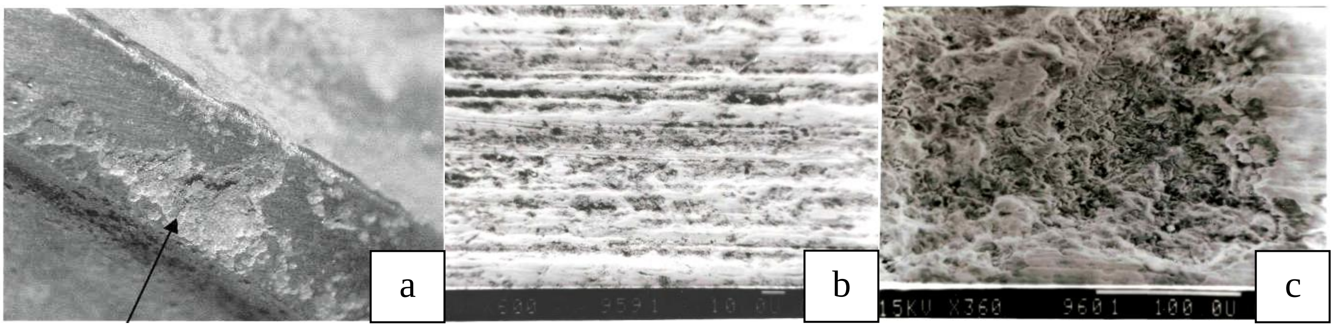
Sometimes during the long stand of the aircraft and during the routine maintenance for the convenience of the maintenance the flaps are set in the intermediate position 10°. Under the action of the wind stress the maximal pleiocyclic loadings take place exactly in this position (figure 3.1, b).

Due to this fact the decision was accepted to provide the disassembling of the mentioned nodes. As the result of this the worst screw pair of “screw” and “nut” of the flap elevator was chosen, which were spitted with the purpose of fundamental analysis.


a) – the screw pair with the dimension affixment; b) – damages of screw at the flap position equalled to 10°; c) – visible damages on the nut

Figure 3.1 – Damages of the threaded part of the screw and nut of the flaps elevator of wing lift devices of aircraft AN-124

The performed fractographic investigations of the damaged details of screw and nut show that on the surface both the working area and flow fence of the screw there were corrosive spots and separate pits of various sizes as in the area, so in the depth (figure 3.2, a). On some area the surface of the screw had the black tint. On the surface of the screw working area, which answers for the flap position of 2º, the petal-shaped spots from the working balls were observed, that get by their edges on the surface of the screw chamfers.




a) – external damages of the screw; b) – microrelief of the screw working surface in the damaging zone; c) –microrelief in the pit of the screw at the flap deflection of 10º

Figure 3.2 – Fractographic damages of the surfaces of screw and nut of flat elevator of aircraft AN-124:

At the micro researches of the working surface of the screw on the damaged zone the microrelief was observed, which is typical for the primary stage of wear (running in) of the rolling pairs. Outlet polished flow fence have been subjected to the plastic deformation (flat compression) with the creation of so-called carrying tracks (figure 3.2, b). The surfaces of pits in the area, to which the flap position of 10º corresponds, was covered with the thick layer of corrosive and wear products (figure 3.2, c), which hide the real surface relief.

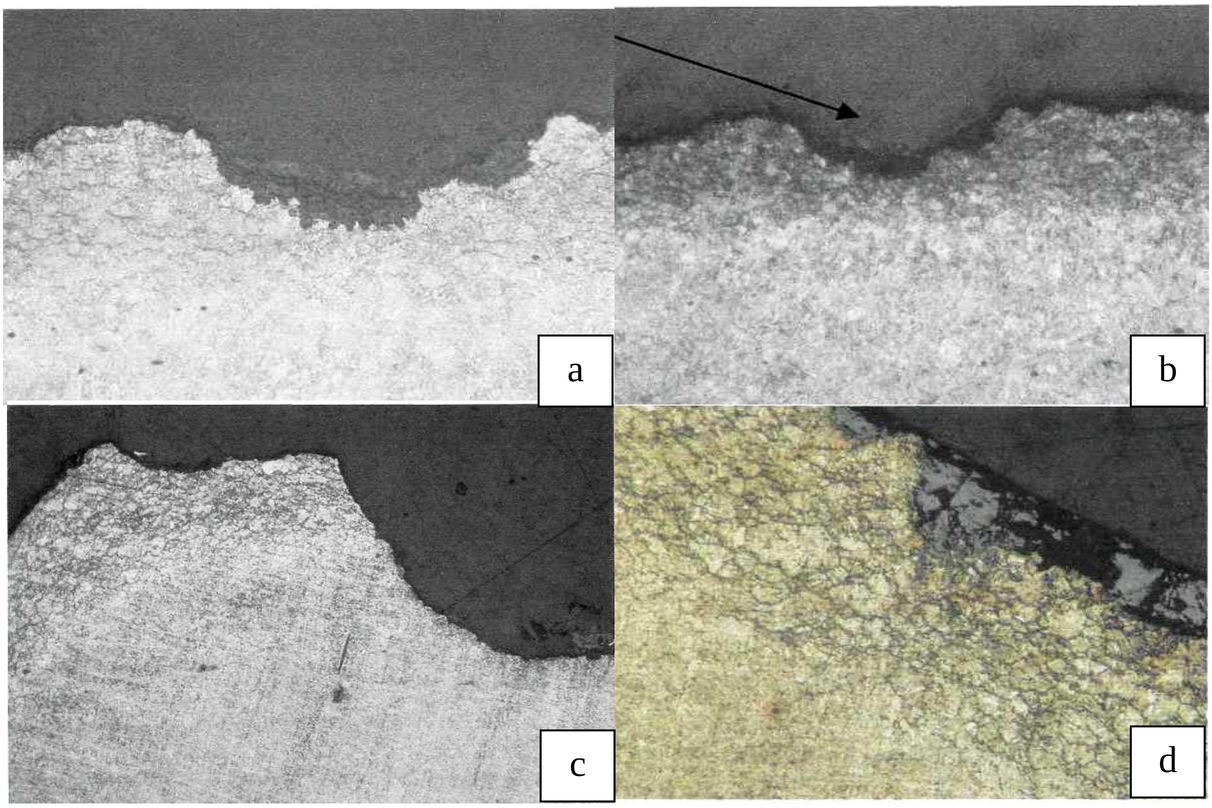
Results of the geometric parameters control of the details “Screw” and “Nut”, and also the corresponding quantities from the drawings are shown in the table 3.1.

Table 3.1 - Geometric parameters

| Detail | Controlled parameter | Requirements of the drawing, mm | Wear, mm (one-sided) | |
|---|---|---|---|---|
| | | | damaged zone | clear surface |
| «Screw» | $D_H$ | $51{,}93^{\pm 0{,}02}$ | – (0,005 – 0,015) | – (0,01 – 0,02) |
| | $D_B$ | $57{,}9^{\pm 0{,}06}$ | in the allowable area | |
| | $R_B$ | $4{,}12^{\pm 0{,}02}$ | 0,05 – 0,1 | 0,03 – 0,05 |
| | $H_B$ | 2,985 – 3,025 | in the allowable area | |
| «Nut» | $R_Г$ | $4{,}12^{\pm 0{,}015}$ | 0,015 – 0,055 | |
| | $H_Г$ | 3,498 – 3,55 | in the allowable area | |

As it is seen from the Table 3.1, the external diameter of the cavities ($D_H$) and the depth of the cavities ($H_B$) of the threaded part of the screw are inside the allowable area of the drawings requirements (reserve is 0.03 and 0.028 mm correspondingly). The depth of the cavity of the nut thread ($H_Г$) has also the reserve of 0.02 mm to the lower limit. The radius of the screw cavities (RB) in the corrosive zone is bigger on 0.05 mm, than on the clear surfaces. The inner diameter of the cavities ($D_B$) of the screw thread has the wear on 0.05 mm more in the clear surface, than in the damaged zone, that is evidently connected with the surface imperfections, that was subjected to the wear, corrosive and presence of the metal oxides products.

As the result of microstructural researches it is established that the found defects on the details surfaces are the working-out of the different depths – maximal is in the form of deep pits and minimal is in the form of dents. The depth of the nitriding layer is 0.2 mm (figure 3.3, a). Microhardness of the nitriding layer on the surface of the screw tooth is 824 kg/mm$^2$. The frangibility of the nitriding layer of the screw corresponds to the first number of the frangibility scale of the direction ПІ 1.2.052-78.




a) – nitriding layer of the screw; b) – c) – damages of the nitriding layer of the screw surface; d) – corrosion products on the screw surface

Figure 3.3 – Metallographic researches of the screw damaged surfaces of the flap elevator of the AN-124 aircraft

In the main the working-out does not exceed the depth of the nitriding layer (figure 3.3, b). Maximal depth of the working-out reaches up to 0.7 mm (figure 3.3, c), that is sufficiently exceeds the depth of the nitriding. Corrosion products are in others working-out (figure 3.3, d). Micro-cracks were not found.

Performed researches showed that the surfaces damages of the screw and nut of the flap elevator on the flow fence of thread and also in the zone, corresponding to the flaps retraction angle 10º, are took place as the result of the general and pitting corrosion of the metal, conditioned by the fretting process. Damages of the screw surface in the zone, corresponding to the flaps retraction angle 2º, are the spots of fretting wear.

During the visual inspection of the details of the elevator on the thread surface of the screw and nut there were found the places of corrosion and corrosive spalling of the material, and also the dark lags (traces of the rollers), placed along the axis of the screw and nut.

In connection with this the analysis of the flaps elevator damages of the wing lift devices of the aircraft AN-124 was done. The fractographic and metallographic researches of the surfaces damages of the friction pair screw-nut were carried out. The equipment for the testing on wear resistance in the fretting condition of the high-strength materials, used for the producing of the responsible nodes details of wing lift devices of the aircraft was developed.

### 3.2 Preparing of the samples for the testing

Tests on fretting were conducted at the installation МФК – 1 that simulates the vibration on the scheme plane to plane contact. The essence of the method is that the movable cylindrical sample, which faces the end face with the real cylindrical sample at a given load, is driven to back-rotating motion with the given amplitude and frequency.

Investigation was performed at the constant load, corresponding to 20 and 30 MPa and the amplitude 175 mcm. The vibration frequency of the mutual movement of samples remained unchanged and amounted 30 Hz. The investigation base consisted of 500 thousand cycles. The sample’s temperature was equal to 293 K.

Investigation of the reasons of the corrosive pits occurring of the screw pair of the aircraft AN-124 was performed on the details “Screw” 1.4000.5737.103.000 and “Nut” 1.4000.5737.106.000 of the “Flap elevator” 1.4000.5737.000.005.

In accordance with the requirements of the drawings, the mentioned details, for the providing of the wear resistance and contact strength, are made of the nitriding on the depth of 0.15 – 0.35 mm 30Х2НВФА steel. Hardness of nitriding layer is HV ≥ 700 MPa (frangibility of the nitriding layer should correspond to the scale I – III according to the regulations ВИАМ ПИ1.2.052–78); the centre is thermo-processed for the strength (1000 – 1200 MPa).

The chemical composition, determined on the investigated details “screw” and “nut”, is shown in the table 3.2, that correspond to the steel grade 30Х2НВФА in accordance with ТУ 14-1-950-86.

Table 3.2 - Chemical composition of the “Screw” and “Nut”

| Steel grade | Content of the alloying elements, % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | Cr | Ni | W | V | Cu |
| 30Х2НВФА | 0.27–0.34 | 0.17–0.37 | 0.3–0.6 | 1.6–2.0 | 1.4–1.8 | 1.2–1.6 | 0.18–0.28 | ≤0.25 |
| «Screw» | 0.28 | 0.23 | 0.38 | 1.73 | 1.55 | 1.33 | 0.22 | 0.08 |
| «Nut» | 0.29 | 0.22 | 0.44 | 1.76 | 1.51 | 1.32 | 0.21 | 0.10 |

Highly strong materials 30Х2НВФА and ВКС-170 with the mechanical-pulse strengthening and nitriding were used in the experiments. Also the tests were carried out on the clean materials without superficial treatment.

Researches in the studying of changes of the linear wear and wear intensity of the coverings were conducted on the air at the friction without lubricating material. The wearing of immobile sample is measured for the set amount of the cycles, the value of which determines the wearability of the probed material.

Testing of the nitriding layer quality was performed on the samples, cut from the damaged places, and also in the places, where there was no any surface changes.

The sample was manufactured from the same material as the screw (steel 30Х2НВФА with the using of further nitriding processing in accordance with the requirements set to the product).

The linear wear of the immovable sample was determined with the help of the optimeter of the vertical type IKB. The maximal average depth of the point contact was accepted as the criteria of the wearability.

After coating application the samples were subjected to the grinding to smooth the surface on the flat grinding machine ШПХ 40.61. Samples were washed and dried before and after the experiment. After processing the samples were installed into МФК – 1 installation, the necessary parameters for the experiment were calculated and adjusted.

### 3.3 Processing of the experiment results

Measuring of the sample wear and coating were conducted using the vertical type optimeter ІКВ, which is more than 10 microns, by taking the profilohrams from eight equidistant sections of working surface of sample in the radial direction (see figure 2.4). Immovable sample wear was measured for the given number of cycles, which determines the value of the studied material wear resistance. For the greater reliability of the results, at least three tests results we used in one histogram.

Sample wear $h_j$ is defined (see formula 2.1).

After the test has been conducted, fractographic and photographing the samples surfaces was done with the help of the microscope МБС-9.

### 3.4 Results of the test

The results of tests of high-strength materials are presented in figure 3.4.

It is seen from the histogram that the high-strength steel 30Х2НВФА is less wearability than steel ВКС-170. The mechanic-pulse strengthening of high-strength steel increases the wearability in the conditions of fretting: for the steel 30Х2НВФА it is in 15 %, and for the steel ВКС-170 it is only in 5 %. At the comparison of fastening superficial treatments it is possible to conclude that, nitriding and the mechanic-pulse strengthening of steel 30Х2НВФА practically does not differ between itself by its wearability. The difference among these superficial treatments lies within the limits of error.

The most interesting fact after the analysis of the got results is that steel ВКС-170 almost in two times more wear resistive than the steel 30Х2НВФА. Even the superficial processing do not substantially influence on the order of the wearability of these materials. It enables us to recommend to the factories-producers of aviation products to use the steel ВКС-170 for making the aircraft wings lift devices units (screw-nut) in place of the nitrided steel 30Х2НВФА, even without superficial strengthening treatment, which gives an increase wearability of friction pair in two times.

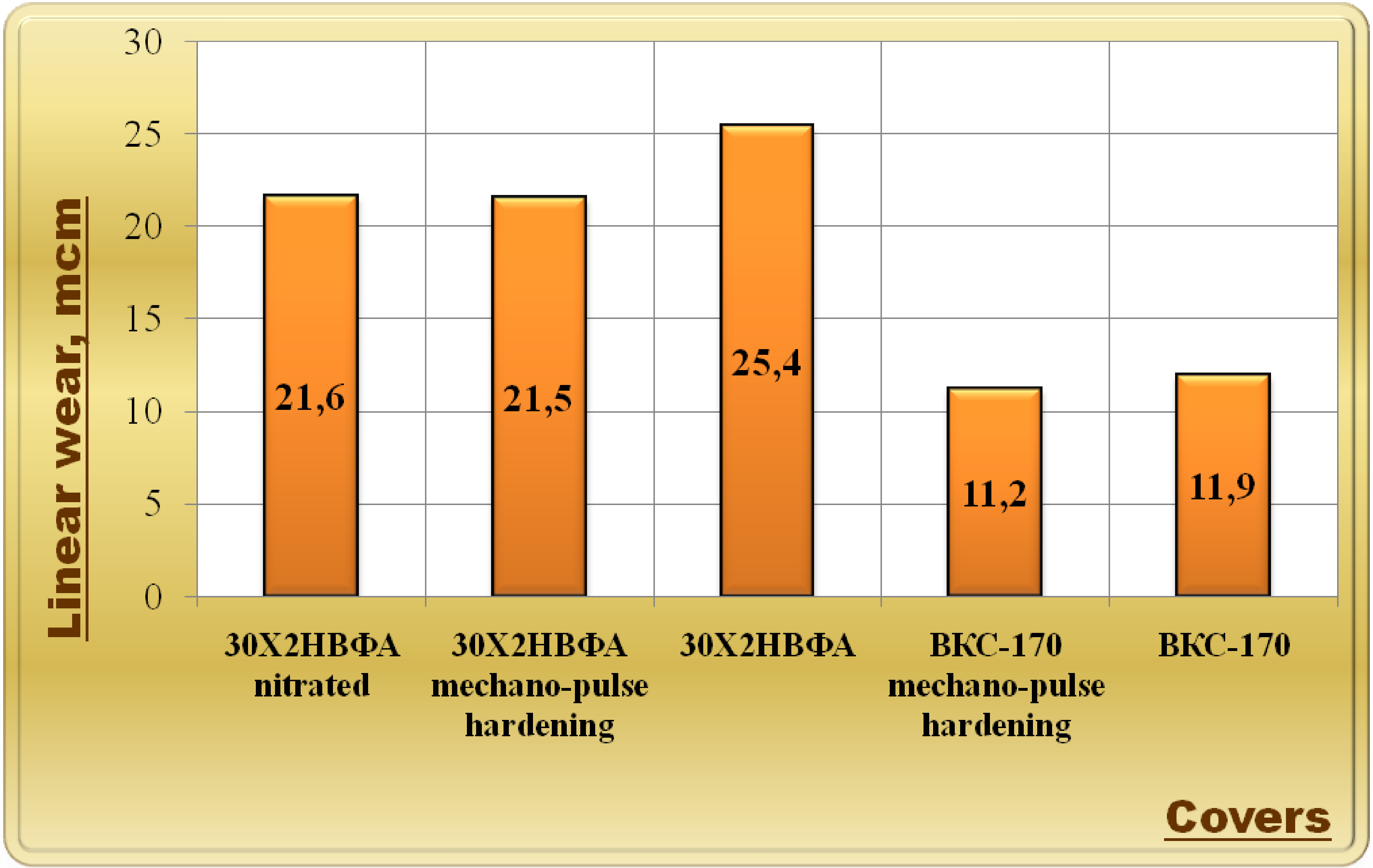
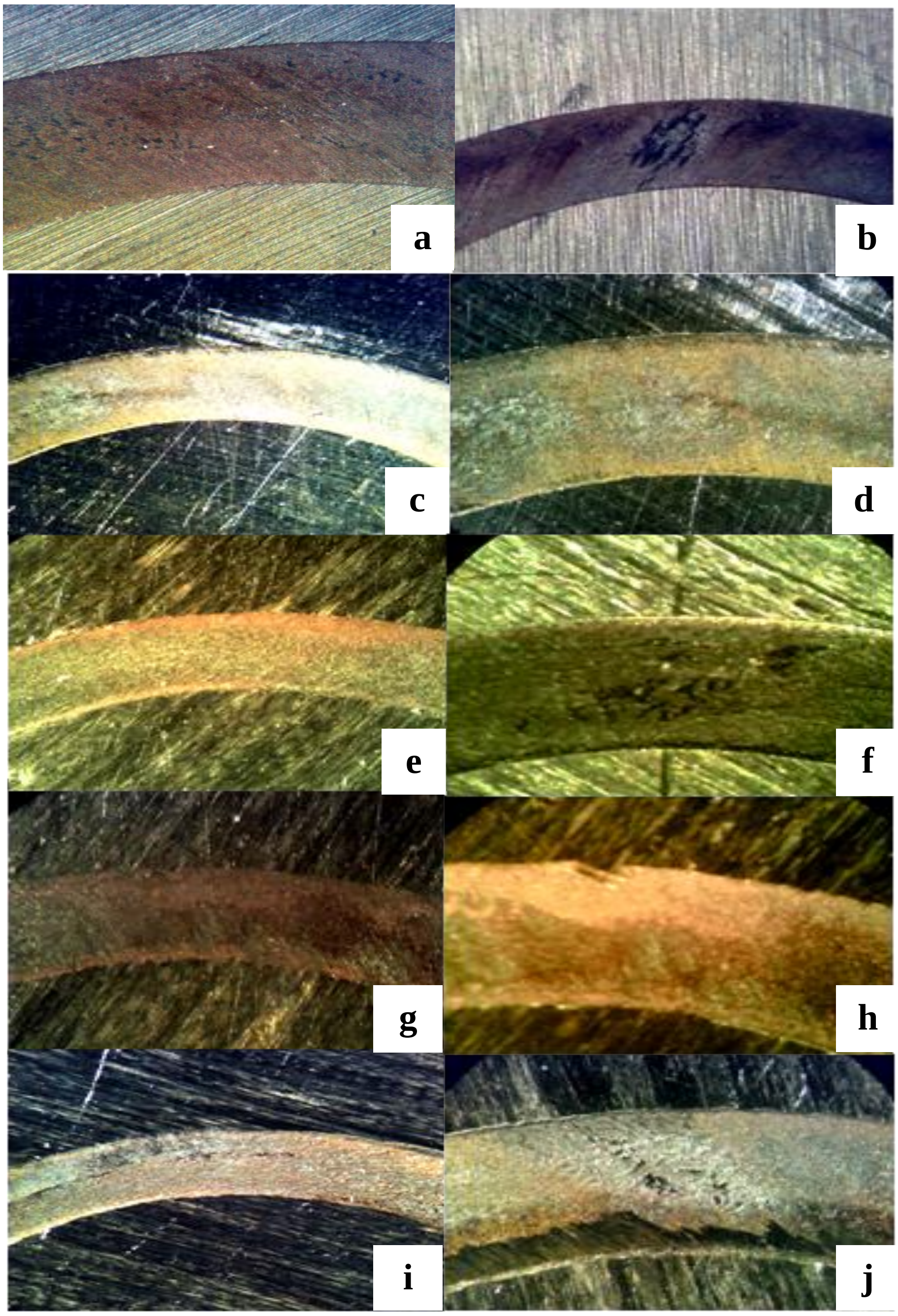



Figure 3.4 – The wearability of high-strength steels at the fretting tests

The fractographies of the friction tracks of high-strength steels with the surface hardening and without it are presented in figure 3.5.




a), b) – steel 30Х2НВФА with nitriding layer; c), d) – steel 30Х2НВФА with mechanic-pulse hardening; e), f) – steel 30Х2НВФА without surface processing; g), h) – ВКС-170 with mechanic-pulse hardening; i), j) – ВКС-170 without surface processing

Figure 3.5 – Fractography of friction tracks of high-strength steels at the testing on wearability in the fretting conditions:

In the figure 3.6 the surface of the damaged nitriding steel 30X2HBΦA at the testing without lubrication is shown.

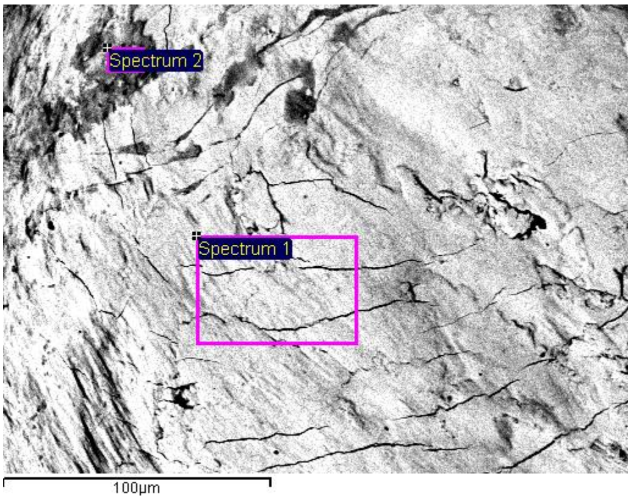



Figure 3.6 – Topographies of the damaged surfaces of the nitriding steel 30X2HBΦA at the testing without lubrication

After the analyzing of the samples friction surfaces it is possible to conclude that almost all friction tracks have the identical reliefs. The friction tracks are without scraps, ulcers, and places of fights. It all testifies to that the friction surfaces have the mechanochemical nature of wear.

The steel 30X2HBΦA with the nitriding layer in 200 mcm has the same wear as the steel BKC-170 without additional surfaces hardening. The surfaces that worked in the friction pair with these materials are almost identical, without scratches and clutches.

So, such conclusions can be made according to the fractography of the screw:

1) the surfaces damages of the screw in the zone, corresponded to the flaps retraction angle of 10°, have been progressed as the result of continuous corrosion and pitting corrosion;

2) the surfaces damages of the screw in the zone, corresponded to the flaps retraction angle of 2°, are the fretting spots.

**Conclusion to part 3**

1) The surfaces damages of the flaps elevator in the area, corresponded to the flaps retraction angle of 10°, happened as the result of metal corrosion, and damages in the area, corresponded to the flaps retraction angle of 2°, are the fretting spots. It is approved by the fact that screw outside the researched zones was clean, without damages.

2) At the insufficient lubrication of the friction surfaces or at the drying up of the lubricant the contact of the friction pair without oil can happen, it causes the gripping on the surfaces as the result of high contact pressure and as the effect the creation of micro-cracks.

3) It is inappropriate to use the mechanic-pulse hardening instead of nitriding of the steel 30Х2НВФА and in general on the steel ВКС-170 with the purpose of increasing of wearability. Small improving of wearability that takes place during the surface processing is inappropriate and economical insufficient.

4) The high-strength steel ВКС-170 without surface processing is almost in two times more wear resistive than the steel 30Х2НВФА with the surface hardening processing.

# PART 4
# LABOUR PRECAUTION

## 4.1 Dangerous production factors acting during coatings application on aircraft details

The modern aviation enterprises are the establishments of very wide operation sphere with versatile activities. The main aim of aviation is carriage of cargo and passengers. In order to achieve this task the whole army of facilities is used. They are not only transport facilities, like airliners or helicopters, but the number of ground installations, terminals, hangars, warehouses, runways, etc. It is natural that aircraft operation and maintenance are connected with dangerous and hazards. A lot of serious industrial factors negatively impact the human health.

Let’s introduce general characteristics of developed topic, concerning labour precaution, mainly dangerous and harmful production factors.

Coatings application on aircraft details is usually provided in laboratories. In such way, the subject of the labor precaution is a man, who makes experiments and with the help of special equipment applies appropriate coatings on the details, he is the mechanic. And the object of labour precaution is the laboratory, where the subject works.

Working in the production sphere a man can be subjected to one or several dangerous and harmful production factors. The safety of technological process can be determined by their amount and danger degree of each of them separately. Dangerous and harmful production factors are divided into physical, chemical, biological and psycho-physiological. The last are subdivided, relatively to the character of influence, into physical and nervous – mental overloads. The other are divided on the specific dangerous and harmful production factors.

During application of coatings the following dangerous harmful production factors can influence:

1) high or lower air temperature and humidity in the laboratory (affecting the mechanic thermoregulation);
2) absence or lack of natural light;

3) insufficient illumination of working zone;

4) lowered contrast range of the objects upon the background;

5) raised luminosity;

6) moving hardware, work pieces and materials;

7) unprotected mobile elements of machines, mechanisms and production equipment;

8) flying away smithereens, elements, details of production equipment;

9) raised dust and air contaminants in the laboratory room;

10) raised noise level;

11) raised electric voltage, shorting of chain can happen over man body;

12) raised static electricity;

13) surfaces sharp edges and roughness of equipment and tools;

14) chemical matters, included in composition of applied materials, fuels, special liquids;

15) physical overloads (static and dynamic) and nervously-psychic overloads (emotional, overstrain of analyzers).

## 4.2 Measures on prevention of dangerous factors influencing. Lightning calculation of working environment in the laboratory room

The air temperature in production condition depends on quantity of heat emission from heating source and by workers, office volume, air exchange and intensity of heat convection throughout the walls. The room temperature is very important because it affects the human thermoregulation. Thermoregulation is the process in human body that causes heat exchange between the organism and environment. Thermoregulation contributes to support the body temperature between 36.5 – 37 $^{o}$C. For example, at low ambient temperature the vessels narrows that decrease blood circulation and heat exchange decreases also. So it is of vital importance to provide the correct air temperature. The air humidity has impact on human body also. For example high air humidity inhibits normal sweating. Of course, ensuring of good ventilation is obvious, because it is the one mean by which we can support the room temperature, humidity and speed of air flow at desirable level.

Features of labour character and regime, considerable mental stress and other loadings cause a change for the workers functional condition of central nerve system, hands motility (during work with the keyboard). The inefficient design of furniture and uncomfortable location of elements of workplace forces the operators to accept an uncomfortable position. The protracted discomfort is caused by the overvoltage of muscles and causes the development of general fatigue and decline of capacity. During the protracted work near the screen of display the visual stress, head ache, fatigue and sickly feelings in eyes, back, in the neck area, hands are observed. For prevention of the unfavorable affecting by harmful factors the sanitary rules and norms are ratified.

At wrong calculated and chosen lighting the eyes tired faster, lose their ability to distinguish objects with the further appearance of occupational diseases. But not only natural lighting in the room must be corrected. The absence of artificial lighting in the room also affects the human mind.

As it was said above, trying to develop the preventive measures, it is necessary to solve some tasks, directed on improving of working conditions. So, the power of the lighting installation and the number of lamps has to be determined. Solving the problem we use the specific power computational method [49].

It is supposed to establish the lamp appliances with light sources LBR2–40 Wt hanged at altitude *Hp*, which is equaled to 2.5 m. The area of the laboratory room is $S = (6 \cdot 8)$ m$^2$. Reflectance values of ceiling $\rho_c = 0.5$, walls $\rho_w = 0.3$, working surface $\rho_s = 0.1$. The line voltage is 220 V. The assurance factor $K = 1.8$.

The standard luminance in the laboratory room depending on the condition of the executed work is chosen in accordance with the sanitary regulations of luminance of working surfaces in working environment (ДБН В.2.5-28-2006), and in our case for the application of luminescent lamps with degree I is $E_n = 400$ l$_x$.

With the help of the table of specific power value of general even light for luminescent lamps, knowing the value of general light luminance, equaled to 400 l$_x$, the room area, equaled to 48 m$^2$, we can find the specific power of lighting installation for voltage 220 V:

$$W = 29\ \left(\frac{\mathrm{Wt}}{\mathrm{m}^2}\right).$$

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

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

where $K_1$ is equaled to 1.5.

$$W_s = 29\frac{1.8}{1.5} = 34.8\ (\mathrm{Wt/m^2}).$$

Let us evaluate the power of a lighting installation:

$$W_{li} = W_s \cdot S\ [\mathrm{Wt}], \tag{4.2}$$

$$W_{li} = 34.8 \cdot 48 = 1670.4\ (\mathrm{Wt}).$$

The number of required lamp appliances:

$$n = \frac{W_{li}}{N P_1}, \tag{4.3}$$

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

$P_1$ – power of a lamp LB, Wt.

$$n = \frac{1670.4}{2 \cdot 40} \approx 22.$$

Approximating to an integer we find the number of a lamp appliances $n$ = 22 pieces. This number of lamp appliances is enough for providing of labour precaution in the coating application laboratory room, regarding the sufficient illumination of working zone.

**4.3 Fire and explosive safety in the laboratory room**

In accordance with the Law of Ukraine "ДСТУ 3855-99 " (the articles 4 – 7) the Rules of the fire safety in Ukraine is obligatory for implementation by all state executive power all of central and local organs, by enterprises, establishments, organizations, regardless the type of their activity and patterns of ownership, public servants and citizens.

Rules set general requirements on fire safety, the action of which spreads at the enterprises, establishments, organizations and other objects (buildings, technological lines and others), and also dwelling-houses, which are exploited or are built, reconstructed, technically retooled, with except for underground buildings and transport vehicles, requirements to which are determined according to the other normative documents.

Providing of fire safety it is necessary to follow the standards, building norms, rules of electric equipment, norms of the technological planning and other normative acts, going out from a sphere of their actions, which regulate the requirements of fire safety.

Fire safety – is a state of the object, at which with the established probability the possibility of beginning and conflagration development and influence on people of dangerous conflagration factors is excluded, and protection of material valuables is also provided.

The following requirements must be followed:

1) smoking in organization is accepted in strictly certain places, properly equipped and provided with the facilities of fire extinguishing;

2) every worker must strictly observe the set fire-prevention regime, he should be able to use the primary facilities of fire extinguishing and to know an order and ways of evacuation in case of fire;

3) persons, not passing the primary fire-prevention instructing are unable to work;

4) persons, violated the requirements of fire safety, are brought to the administrative responsibility.

There is a person responsible for the fire safety in the laboratory room. Employees must know the fire hazard of substances and materials used in the laboratory and comply with the fire safety measures during working with them. Before starting the work on a new theme, manager must conduct unscheduled instruction on fire safety, fixed in the Instruction Journal.

In the laboratory rooms the computers are usually used for the different works conduction, for processing the experiments results. And during computer work there are possible the following emergencies:

1) short circuits;
2) overloads;
3) transient resistance increasing in electrical contacts;
4) overvoltage;
5) leakage current appearance.

For the prevention of all these risks every mechanic in the working hours must:

1) keep the workplace in a cleanness and order;
2) not to block the passage-ways and outputs by different objects and equipment. Laboratory equipment should be installed so that it does not prevent the evacuation. Minimum allowable width of passages between the equipment should not be less than 1 m.
3) strictly observe in the workplace the set norms of storage of production materials and prepared products;
4) prevent the rules violation by extraneous persons;
5) keep the oiled clothes, rags and combustible off cuts only in metallic boxes with the closed cap;
6) not to clean floors, walls and equipment by combustible solutions;
7) store combustible liquids, flammable liquids in the designated places, observing the requirements of fire safety;
8) carry combustible and flammable liquids only in the special containers. In case of liquid leakage it is necessary to clean it immediately;

9) not to connect the electric equipment or repair electric network without permit;

10) not to use the open fire in service and workings apartments;

11) not to smoke, not throw down the cigarette-ends and matches in workings apartments;

12) not to accumulate and not throw a paper and other flammable materials and garbage;

13) not to keep in table shelves the petrol, kerosene and other flammable liquids;

14) not to use electro heating devices in the personal aims with the open spirals;

15) not to leave the electric devices into the current network without a supervision;

16) not to hang placards, clothes and other objects on the wall with the electro-outlets, switches [48].

After finishing the work it is necessary:

1) to clean carefully the workplace;

2) to check the condition of primary facilities of the fire extinguishing;

3) to leave the evacuation passage ways free;

4) it is forbidden to leave the oiled cloth in the workplace, to leave turned on electronic equipment.

In order to prevent the fire and explosion the organizational, operational, technical and secure works are conducted: fire safety training of workers; instructions, lectures; correct operation of machines, internal transport, equipment, buildings and territories; observance of the fire regulations and standards during installation of heating and ventilation devices; banning of smoking in the prohibited places, welding and other hot work in fire zones.

In the case of fire in the laboratory room it is necessary to notify immediately the fire department by telephone "101", indicating the exact address of the object, where the fire is, the name of the sender; organize fire-fighting with available means; evacuate people and property; as well as to organize a meeting of fire departments.

Explosion – is the fast exothermal chemical transformation of explosive environment that is attended with the extraction of energy and formation of constricted gases, capable to execute the work. Gasified with strongly heating, filling in a volume with huge pressure – all of these are the consequence of explosion. Explosion is possible only at certain concentration of air-gas.

To prevention of the explosion beginning is possible with the help of exclusion of possibility of explosive environment formation and beginning of explosion initiation source. Prevention of formation of explosion initiation source must be provided:

1) by application of explosion-proofed equipment;

2) by application of fast-acting methods of protective cutting off of possible electric sources of explosion initiation;

3) by limitation of electromagnetic and other thermal radiation powers.

### 4.4 Fire extinguishing means and rules of their application

Laboratory rooms should be provided with primary fire extinguishing means. All laboratory workers must know the location of the fire extinguishers and know how to use them.

One of the most effective primary means of extinguishing is the fire extinguisher.

Extinguishers, as a primary means of fire fighting, take one of the main places in the system of fire protection. On the effectiveness and reliability of fire extinguishers, as well as their skillful using depends not only on the nature of the further development of the fire, the amount of damages that they can cause, but also people's lives. Fire statistics show that most fires are usually extinguished before the arrival of fire brigade units.

There such fire extinguishers:

1) ВХП–10, ВП–М, ВП–9ММ – hand chemical foam fire extinguishers. ВХП-10 is intended for extinguishing of inflammation and small fires of hard materials and combustible liquids. ВХП-10, is shown in the figure 4.1, it is the steel welded cylinder the mouth of which is closed with a plug-forming device. The charge of fire-extinguisher consists of acid and alkaline part. Distance of stream is 6 – 8 meters. For

applying of fire-extinguisher it is needed to bring him to the place of inflammation, to turn the handle of the valve on 180 degrees completely, to invert a fire-extinguisher upwards by a bottom and to point the stream of foam to the fire. It is strictly forbidden to extinguish by foam fire-extinguishers to the electrical wiring and electrical equipment;

2) ВВ–2, ВВ–5 and ВВ–8 – hand carbon dioxide fire extinguisher. They are intended for extinguishing of small initial inflammation of different matters and materials, except that matters burning of which takes place without access of air. Carbon-dioxide fire-extinguishers, shown in the figure 4.2, are steel cylinders, in the mouths of which the brass valves are screwed with siphon tubes, the fly-wheels of valves must be sealed. For extinguishing of fire it is necessary to direct the fire-extinguisher to the fire and unscrew completely the valve anticlockwise. During work of fire-extinguisher it is not recommended to hold a balloon in horizontal position because such position obstructs the output of carbonic acid through a siphon tube;

3) ВВП–10 and ВВП–5 – hand air-foam fire extinguishers;

4) ВВБ–3 and ВВБ–7 – hand ethyl bromide, carbon-dioxide fire extinguishers are designed to extinguish small sources of fire of fuel materials.

ОХП-10 ОУ-8 ОУ-2

Figure 4.1 – Different fire extinguishers types

Primary means of extinguishing fire may be placed on boards. Manual fire tool on the boards should be periodically cleaned from dust, dirt and traces of corrosion and repair needs sharpening angles and painting tool for use after fire or during practice.

All requirements used in this chapter meet the standards ДСТУ 2272–93, ДСТУ 2273–93.

**4.5 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.

**Conclusion to part 4**

1) The different harmful and dangerous production factors for the mechanic in the laboratory room were identified and described. The measures of fire and explosion safety in laboratory room were considered. Lightning calculations of working environment were carried out.

2) On the basis of carried out analysis of dangerous and harmful production factors that can take place during application of coatings on aircraft details in laboratory room the measures are developed for increasing the labour safety during work in laboratory room.

# PART 5

# ENVIRONMENTAL PROTECTION

## 5.1 Environmental contamination by aviation industry

Pollution is the introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem, i.e. physical systems or living organisms [50]. Ecological problems become more vital in connection with the existence of harmful consequences of interaction between the person and nature.

An ecological problem is of very important, because the condition of environment directly influences on the processes of human organism, its normal functioning. The presented ecological situation in Ukraine is possible to describe as the complicated that formed during the protracted period through ignoring the objective laws of development. The high specific weight of resource intensive and power-intensive technologies, introduction of which was carried out by the most "cheap" method – without building of the proper cleaning installations – is inherent to the economy of Ukraine.

Considerable contaminant of the environment is a transport industry, in particular, is its mobile facilities (cars, locomotives, marine and river ships, air transport), which use the different types of petroleum as fuel. The significant harm causes the exhaust gases of aviation transport, drain water after washing of cars, aircraft and their aggregates, vapors of different harmful matters, acids, materials which are utilized in the technological processes of repair.

## 5.2 Laws requirements in Ukraine in ensuring of environmental protection

Environmental protection, rational use of natural resources, environmental safety of human life – is an essential condition for sustainable economic and social development of Ukraine. For this purpose Ukraine carries on its territory environmental policy aimed at the preserving for the existence of living and inanimate nature safe environment, for protection the lives and health from the negative impact, caused by the environmental pollution, achieving of harmonious interaction between the nature and society, protection, rational use and reproduction of natural resources [51].

At present, the main regulations governing the organization of environmental protection in Ukraine are:

1) the Law of Ukraine "About Environmental Protection";
2) Agrarian Code of Ukraine;
3) Water Code of Ukraine;
4) Law of Ukraine "About Air Protection";
5) Law of Ukraine "On objects of assigned risk";
6) Law of Ukraine "On State Program of Toxic Waste";
7) Law of Ukraine "On the area of environmental emergency";
8) Law of Ukraine "On Wastes";
9) Law of Ukraine "About management Radioactive Waste Management" and many others.

Unfortunately, all these legal documents have a serious drawback. They are formed for the separate regulation of land, water, mining, forestry, atmosphere protection. This approach does not provide the regulation of relations on the environment as a single organism.

Ukraine's Law "About Environmental Protection" is the fundamental legal act, it defines the concept of environmental protection and measures for their security, environmental requirements for the disposition, designing, engineering, reconstruction, putting into the operation of enterprises and other objects, on the application of fertilizers; provides measures for protecting the environment from harmful biological effects, harmful effects of physical factors and radioactive contamination, from contamination by industrial, household and other wastes. This law not only states, but also provides the guarantee system of human ecological protection, makes certain orderliness in the management system in branch of the nature use, and it affirms the right of Ukrainian citizens on safe for human life environment. This inherent right is realized by the participation in discussion of draft laws and other decisions in the branch of environmental protection; participation in the development and implementation measures for environmental protection, rational use of natural resources; unification in public organizations for environmental protection; receiving full and reliable information about the state of the environment [51].

In the Declaration on State Sovereignty of Ukraine in the section VII “Environmental Security" it states that Ukraine has the right to prohibit the construction or stop the operation of any enterprises, institutions, schools, facilities that threaten the ecological safety. Ukraine concerned about the environmental safety of citizens and the gene pool of people.

In the Law of Ukraine on economic independence among the main objectives of achieving economic independence are listed security achievements, creating healthy and safe living and working conditions.

In the Law on Enterprises in Ukraine the next position is fixed – all businesses must perform nature-conservative measures. Enterprises are responsible for the compliance with the requirements and regulations on environmental protection, rational use and restoration of natural resources.

The one of the main laws that has to be followed by the aviation enterprises is the Law of Ukraine “About Air Protection”. This Law is directed on the protection and renewal of natural atmospheric air condition, creation of favorable terms for vital functions, providing of the ecological safety and prevention of harmful influence on atmospheric air on people health and environment.

Standardization and rating of norms in the sphere of atmospheric air are held with the purpose of establishment of obligatory norms system, rules, requirements to the protection of atmospheric air against contamination and providing of ecological safety. Standardization and rating of norms in the sphere of atmospheric air protection are directed on:

1) providing of safe natural environment and prevention of ecocatastrophes;
2) realization of single scientific and technical policy in the sphere of atmospheric air protection;
3) establishment of the unique requirements to the equipment and installation in relation to the air protection from the contamination;

4) ensuring of household objects safety and prevention of technogenic catastrophes;

5) introduction and usage of modern ecologically safe technologies.

**5.3 Thermo-chemical processing (nitriding) as the source of pollution**

At the thermo-chemical processing of metals the action of different hazardous and harmful production factors is possible. They can be:

1) aerosols of fibrogenic action (dust);

2) unfavourable microclimate;

3) increased level of electromagnetic radiation (ultraviolet, visible, infrared, laser, microwave, radio-frequency);

4) increased tension of magnetic field;

5) increased level of noise;

6) chemical factors of general toxic, irritative, carcinogenic influence, etc.

It is necessary to give the permanent attention to these factors, as they direct affect not only a person, but also on climate change.

At the thermal sections the content of harmful substances is usually higher than the permitted level: nitric oxide is approximately 20 mg/m$^2$, according to the norm of Maximum Permissible Concentration this value must be 5 mg/m$^2$; barium chloride is approximately 1.8 mg/m$^2$, according to the norm of Maximum Permissible Concentration – 0.3 mg/m$^2$; hydro-potassium oxide is approximately 2.5 mg/m$^2$, according to the norm of Maximum Permissible Concentration – 0.5 mg/m$^2$; potassium nitrate is approximately 15 mg/m$^2$, according to the norm of Maximum Permissible Concentration – 5 mg/m$^2$; industrial oils (И–12А, И–20А) is approximately 25 mg/m$^2$, according to the norm of Maximum Permissible Concentration – 5 mg/m$^2$.

In the diploma work one of the methods of surface hardening of aircraft parts is nitriding. Ammonia is used at the nitriding processes. Ammonia is a corrosive gas attacking moist skin, mucous membranes and eyes. Ammonia at 100 ppm causes irritation of the eyes and nose after a few minutes’ exposure and at 700 ppm causes severe eye and nose irritation but no permanent effects, if the exposure is lower than half an hour.

Concentrations above 1700 ppm cause serious coughing, bronchial spasm, acute pulmonary oedema and asphyxia and at these levels death can occur within half an hour.

Supply of ammonia is usually performed from the cylinders, which are installed in the special ramps. Handling with ammonia requires special care because it is toxic and explosive. Transportation of cylinders with the ammonia takes place in the horizontal position in the special wooden containers. Also it is necessary to provide the elimination of any cylinders' pushes or bumps into each other. Storage of cylinders is carried out in vertical position at the continuous cooling with water, as at the increasing of temperature the liquid ammonia vaporises, and it leads to the dangerous increasing in pressure.

The salt bathes are used for the thermal processing at the section, which in case of overheating can be the reason of explosion, fire dangerous situation and, of course, separation of hazardous substances in the atmosphere, occurance of blast wave. Furnaces for the nitriding are equipped with the devices for the removal and post-combustion of the exit gas and absorption of undecomposed ammonia.

Increased level of ammonia also has consequences for the climate changes. Excess of nitrogen can influence on the temps of climate changes in different and opposite directions. From one hand it leads to the greater warming through the greenhouse gases of nitrogen protoxide, but on the other hand it can decrease the warming through the expanding the additional growth of the plants by forming the substances that are called reflected aerosols in the atmosphere. Excess of nitrogen also has great and unclear consequences for some air and water pollution.

### 5.4 Methods for reducing the negative impact of thermo-chemical processing (nitriding) on the environment

Thermal processing and operation of electrical facilities in a varying degree have a harmful impact on environment, as it is accompanied by the forming of great quantity of harmful gasses, dust, contaminated water. That is why it is necessary to account the degree of negative impact of these factors on the environment.

To the main factors, which have the harmful impact on the environment, in the thermal production relate [50-51]:

1) release of heat into biosphere – almost all electrical energy, used by furnaces, transform into the heat and dissipate in biosphere in the form of losses or during the cooling of heated details. The more powerful electrical furnaces, the more essential this factor. In order to decrease the useless heat dissipate it makes sense: improving of heat isolation and reduction of all kinds of losses, using of heat of exit gases and cooling water for the technological and municipal purposes;

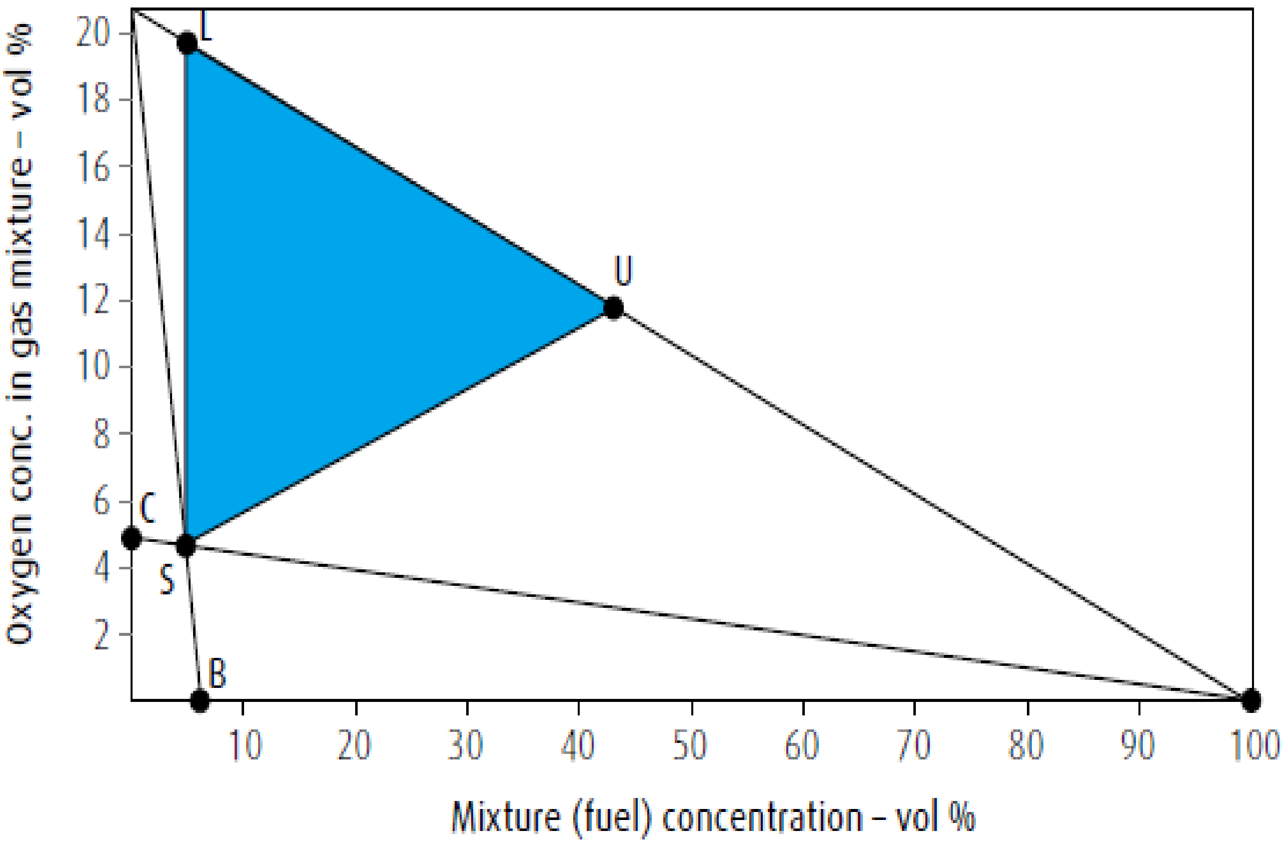
2) pollution of water reservoirs by the industrial wastewater – acids, alkali and salts solutions, used for the etching processes of details, and water, used for the cold hardening and details wash and cooling of furnaces, get to the wastewater in the thermal sections. For the wastewater sterilization the next measures are accepted: wastewater before its rejection should pass different kinds of sewage treatment, which ensures the maximum permissible concentration in water; after the processing, settling and filtration the wastewater is thrown down to the common sewerage system;

3) using of water resources – electrical equipment is a large consumer of water, expendable to the cooling of furnace units and devices. The high requirements are made for it: in order to decrease of water, taken away from the sources, and providing of its quality it is necessary to use the recirculated water system;

4) release of harmful gases – the gassing takes place in the thermal sections at the heating, drying and some other operations. For the reduction of the atmosphere pollution the next measures are applied: using of gas trapping system and fume-cleaning plant, replacement of technological processes with the great gas evolution to another, which are more perfect.

As it was written before, ammonia – is one of the dangerous gases. Safety Triangle is proposed below, with the help of which it is possible to avoid or at least decrease the influence of harmful gases on the atmosphere.

The Safety Triangle in figure 5.1 shows how to operate safely. The flammability triangle is depicted in the area L-S-U and this area should always be avoided. This is done as follows. When starting up a process, where the furnace is partly or wholly filled with air, ammonia must not be introduced until the oxygen concentration has been lowered to point C. This may be done by purging the furnace with nitrogen. When point C in figure 5.1 is reached, ammonia can be safely introduced.




L – Lower flammability limit in air (5.1 volume percentage mixture);

U – Upper flammability limit in air (43.5 volume percentage mixture);

S – Minimum concentration of $O_2$ for flammability (4.6 volume percentage mixture) and Fuel (5.1 volume percentage mixture);

C – Start up (maximum 4.9 volume percentage mixture);

B – Shut down (maximum 6.5 volume percentage mixture)

Figure 5.1 – For mixture in air at 200 °C:

If nitrocarburising is performed in a furnace that will be opened to air access after nitriding or nitrocarburising, i.e. in a pit furnace, a reversed sequence is required before closing the process and opening the furnace. By purging with nitrogen the ammonia concentration must now be lowered to point B in figure 5.1 before the furnace can be opened and exposed to air.

**5.5 Measures that should be involved in order to prevent the negative impact of thermochemical processing on environment**

Technological processes of metals thermo-chemical processing should provide:

1) removal of direct contact of workers with the chemical substances, materials, details and production waste, affecting on them negatively;

2) replacement of operations, at which the harmful and dangerous productive factors arise, by the operations, where the mentioned factors are absent or have less intensity;

3) using of automated methods for the determination of substances concentration of the first class of danger in air;

4) applying of comprehensive mechanization and automation, remote control of setting and adjustment of technological processes parameters (temperature, pressure in the working area of furnace, content of components in gas medium, etc.);

5) using of blockers (with the purposes of elimination of accidents occurring) and means of warning lights and chime about the violation of technological process;

6) equipment capsulation, from which the harmful substances separate into the atmosphere;

7) timely moving off and sterilization of production waste, which are the sources of dangerous and harmful productive factors;

8) maintenance of prescribed periodicity of cleaning of hardening tank, reservoirs and heating furnaces;

9) at the operation of the flow gages of alternate overfall pressure it is necessary to provide the rejection of the expulsion products into the drain or effluent disposal line for the prevention of air pollution;

10) at the work on electrothermal equipment with the controlled atmospheres it is prohibited to mix the burning gases, used at the preparing of controlled atmospheres with air, in order to avoid the formation of explosive mixture;

11) for the furnaces expulsion the rare gas should be used;

12) removing of gases from the working area that have the strong smell should be accompanied by the local ventilators with the suction.

## Conclusion to part 5

1) According to the Law of Ukraine on Environmental Protection (from 26.06.91) the degree work has been complied with all requirements, summarized above and proposals, concerning reduction of hazardous influence of thermochemical processing for the ecosystem.

2) During the hardening of details by the thermo-chemical processing the safety requirements about the prevention of environment pollution by the productive waste must be executed (collection and neutralization or necessary dilution of gaseous, liquid and solid, including dust waste, and they removing in accordance with the established rules).

3) Nitriding coating is one of the most dangerous sources of pollution, mainly surface and groundwater reservoirs, due to large volume of wastewater, as well as large quantities of solid wastes, especially from the reactive method of sewage disposal. The creation of a complete water cycle should not be an end in itself, because both in terms of environmental safety and economic feasibility the main goal should be the rationalization of water consumption and optimization of treatment systems.

4) During working to reduce environmental hazards of thermo-chemical processing first it is needed to analyze the range of applicable solutions and chemical substances, and possibly to replace the toxic solutions to less toxic or reduce the concentration of toxic components in the applied solutions. If the replacement of toxic substances to less toxic is limited by the requirements of the coatings obtained, then reduction of water consumption for washing is possible in a wide range. In this case, great importance has where the reduction of water consumption is carried out: in the existing, reconstructed or under construction shop.

## GENERAL CONCLUSIONS

1) We have analyzed the operational damageability of aircraft details (especially the friction pair (screw-nut), produced from the high-strength steel and their restoration methods.

2) The main function of the screw of the wing lift devices is to provide the extraction and retraction of the flaps, and it is necessary to pay attention at the fact that it is the most responsible and expensive detail of the aircraft AN type.

3) Fretting is one of the kinds of wing lift devices damages of the aircraft AN type, which defines its further serviceability.

4) In order to chose the optimal pair of wing lift devices (screw-nut) the comparative researches of materials ВКС-170 and 30Х2НВФА without surface hardening and with the hardening of the surface layers at the mechanic-pulse hardening and nitriding processing on the friction machine МФК – 1were performed.

5) Metal corrosion is the reason of surfaces damages of the flaps elevator in the area, corresponded to the flaps retraction angle of 10°, and damages in the area, corresponded to the flaps retraction angle of 2°, are the fretting spots. Screw outside the researched zones was clean, without damages.

6) The contact of the friction pair without oil can happen at the insufficient lubrication of the friction surfaces or at the drying up of the lubricant. It causes the gripping on the surfaces as the result of high contact pressure and as the effect the creation of micro-cracks.

7) So, it is inappropriate to use the mechanic-pulse hardening instead of nitriding of the steel 30Х2НВФА and in general on the steel ВКС-170 with the purpose of wearability increasing. Small improving of wearability that takes place during the surface processing is inappropriate and economical insufficient.

8) The high-strength steel ВКС-170 without surface processing is almost in two times more wear resistive than the steel 30Х2НВФА with the surface hardening processing.

9) The issues of the labour precaution were described. The major issues on labour precaution make it possible to obtain the necessary and sufficient information for the decision making.

10) Section of the environmental protection reveals hazards of the nitriding processing on the environment. Also in this section, methods of reducing adverse impacts on the environment are described.

# RECOMMENDATIONS

The following recommendations were developed:

1) To check regularly the presence of the oil on the working area of the screw pair and to refresh it periodically.

2) To avoid the getting of the atmospheric precipitations on the screw pair at the long parking of the aircraft.

3) To control the state of the elements connected with the screw pair and avoid their excessive working out that causes the developing of the vibrations and as the result the occurring of the fretting.

4) To replace in the production of wing lift devices of the aircraft AN type the nitrided material 30Х2НВФА, from which the screw and nut are made of, to the material ВКС-170 without surface hardening, that gives the wearability increasing in two times.

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

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**Addendum A**

Modes of the nitriding processing

Table A.1 – The compositions of the major media and modes of thermo-chemical processing at nitriding

| Compositions of the major media | Modes of the nitriding processing | | Depth of the layer, mm |
|---|---|---|---|
| | T, °C | τ, hours | |
| Isothermal nitriding processing | | | |
| 1. Ammonia $NH_3$; pressure 192 – 721 Pa; degree of dissociation: | | | |
| 1) 20 – 40 % | 500 – 520 | 6 – 90 | 0.1 – 0.8 |
| 2) 30 – 55 % | 560 – 580 | 1 – 10 | 0.15 – 0.4 |
| 2. 20 % $NH_3$ + 80 % $N_2$ (или $N_2$ + $H_2$) [1] | 500 – 520 | 6 – 90 | 0.1 – 0.8 |
| Two-phase nitriding processing | | | |
| 3. 20 % $NH_3$; degree of dissociation: | | | |
| 1) 20 – 40 % | 500 – 520 | 15 – 20 | 0.5 – 0.8 |
| 2) 40 – 45 % | 540 – 560 | 25 – 40 | 0.5 – 0.8 |
| Nitriding with the addition of the carbonaceous gasses | | | |
| 4. Ammonia $NH_3$ + 50 % endogas (40 % $H_2$ + 20 % CO + 40 % $N_2$) [2] | 570 | 0.5 – 3.0 | |
| 5. Ammonia $NH_3$ + 50 % endogas (20 % $H_2$ + 20 % CO + 60 % $N_2$) | | | |
| 6. Ammonia $NH_3$ + 50 % endogas (10 % CO + 90 % $N_2$) in the ratio 1 to 2 | | | |
| 7. 58,6 % $N_2$ + 17,9 % $H_2$ + 14,3 % $NH_3$ + + 3,5 % CO + 2,2 % $CO_2$ + 3,5 % $H_2O$ | | | |
| 8. Ammonia $NH_3$ + 50 % $C_2H_8$ (propan) [3] | 570 | 2 – 10 | |

Continuation of the table A.1

| Compositions of the major media | Modes of the nitriding processing | | Depth of the layer, mm |
|---|---|---|---|
| | T, °C | τ, hours | |
| 9. Products of the kerosene pyrolysis reaction, spirit (50 %) + Ammonia $NH_3$ (50 %) | 570 | 1 – 6 | |
| Anti-corrosive nitriding processing [4] | | | |
| 10. Ammonia $NH_3$; pressure 192 – 721 Pa; degree of dissociation: 40 – 60 % | 600 – 700 | 0.25 – 10 | 0.02 – 0.08 |

Notices

1) The process of short-duration nitriding at the temperature 570 °C – instead of the liquid nitriding. Diluting of the ammonia by the nitrogen decreases the frangibility of the layer.

2) Application of the endogases at the temperatures less than 700 °C is dangerously explosive. It is necessary to use the special protective measures.

3) The degree of the ammonia dissociation – 30 – 60 %.

4) The details made of the carbon steels, working in the condition of the atmospheric corrosion, are subjected to the anti-corrosive nitriding processing.

Table A.2 – Nitriding processing modes of structural and instrument steels

| Steel grade | Nitriding processing mode | Depth of the layer, mm | Hardness of the layer, HV |
|---|---|---|---|
| 38Х2МЮА | 500 – 520 °C, 48 – 60 h | 0.40 – 0.50 | 1000 – 1100 |
| | 540 °C, 40 h | 0.5 – 0.6 | 900 – 1000 |
| | 1 stage – 510 °C, 15 h + 2 stage – 550 °C, 25 h | 0.5 – 0.6 | 850 – 1000 |
| 38ХВФЮА | 510 °C, 24 – 48 h | 0.30 – 0.40 | 850 – 950 |
| 18Х2Н4ВА | 490 – 510 °C, 40 – 50 h | 0.35 – 0.40 | 750 – 850 |
| 40ХНМА | 1 stage – 510 °C, 25 h + 2 stage – 550 °C, 35 h | 0.5 – 0.6 | About 600 |
| 30Х3МФС1 | 560 °C, 24 h | 0.5 | 900 – 950 |
| 25Х2Н2МФ | 560 °C, 25 h | 0.4 | 750 |
| 30Х2Н2ВА | 1 stage – 510 °C, 25 h + 2 stage – 550 °C, 35 h | 0.5 – 0.6 | About 750 |
| 40ХНМА | 500 – 520 °C, 50 – 60 h | 0.5 – 0.6 | More 640 |
| 40ХНВА | 500 – 520 °C, 50 – 60 h | 0.5 – 0.6 | More 700 |
| 30Х2Н2ВА | 500 – 520 °C, 50 – 60 h | 0.5 – 0.6 | More 700 |
| 30Х2Н2ВФА | 500 – 520 °C, 50 – 60 h | 0.5 – 0.6 | More 700 |
| 30Х2Н2ВФМВА | 500 – 520 °C, 50 – 60 h | 0.5 – 0.6 | More 700 |
| 40ХНВА | 1 stage – 510 °C, 25 h + 2 stage – 550 °C, 30 h | 0.6 – 0.7 | More 640 |
| 30Х2НВА | 1 stage – 510 °C, 25 h + 2 stage – 540 °C, 30 h | 0.6 – 0.7 | More 700 |
| 30Х2Н2ВФА | 1 stage – 510 °C, 25 h + 2 stage – 540 °C, 30 h | 0.6 – 0.7 | More 700 |
| 30Х2Н2ВФМА | 1 stage – 510 °C, 25 h + 2 stage – 540 °C, 30 h | 0.6 – 0.7 | More 700 |

Continuation of the table A.2

| | | | |
|---|---|---|---|
| 30Х3ВА | 500 – 525 °C, 60 – 80 h | 0.35 – 0.55 | 750 – 800 |
| 12Х13 | 500 °C, 48 h | 0.14 – 0.16 | 100 – 1050 |
| | 500 °C, 48 h | 0.25 – 0.30 | 900 – 950 |
| | 600 °C, 48 h | 0.35 – 0.40 | 800 – 850 |
| 20Х13 | 500 °C, 48 h | 0.10 – 0.12 | 100 – 1050 |
| | 500 °C, 48 h | 0.25 – 0.30 | 900 – 950 |
| | 600 °C, 48 h | 0.30 – 0.40 | 780 – 830 |
| 15Х11МФ | 1 stage – 550 °C, 10 h + 2 stage – 580 °C, 20 h | 0.35 – 0.40 | 900 – 950 |
| 15Х12ВМФ | 1 stage – 550 °C, 10 h + 2 stage – 580 °C, 20 h | 0.35 – 0.40 | 900 – 950 |
| 5Х14Н14В2М | 560 °C, 60 h | 0.10 – 0.12 | 800 – 900 |
| | 600 °C, 48 h | 0.10 – 0.12 | 750 – 800 |
| 25Х18Н8В2 | 560 °C, 24 h | 0.12 – 0.14 | 950 – 1100 |
| | 560 °C, 40 h | 0.16 – 0.20 | 900 – 950 |
| | 600 °C, 24 h | 0.12 – 0.16 | 900 – 950 |
| 17Х18Н9 | 560 °C, 50 – 60 h | 0,2–0,25 | 1000–1100 |
| 40Х14Н9Х3ЮФ2 | 560–600 °C, 48 | 0,2–0,3 | 1300–1400 |
| Р9 | 510–520 °C, 0.25 – 1.0 h | 0.01 – 0.025 | 1340 – 1460 |
| Р18 | 510–520 °C, 0.25 – 1.0 h | 0.01 – 0.025 | 1340 – 1460 |
| Р6М5 | 510–520 °C, 0.25 – 1.0 h | 0.01 – 0.025 | 1340 – 1460 |
| Р12 | 510–520 °C, 0.25 – 1.0 h | 0.01 – 0.025 | 1340 – 1460 |
| Х12М | 510 – 520 °C, 8 – 12 h | 0.08 – 0.12 | 1100 – 1200 |
| Х12Ф1 | 510 – 520 °C, 8 – 12 h | 0.08 – 0.12 | 1100 – 1200 |
| 3Х2В8Ф | 530 – 540 °C, 12 – 16 h | 0.2 – 0.25 | 1100 |
| 4Х5В2ФС | 530 – 540 °C, 12 – 16 h | 0.2 – 0.25 | 1100 |