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КАФЕДРА ПІДТРИМАННЯ ЛЬОТНОЇ ПРИДАТНОСТІ ПОВІТРЯНИХ СУДЕН

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри
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КВАЛІФІКАЦІЙНА РОБОТА
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«МАГІСТР»
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема: «Розробка методики випробувань шарнірних підшипників на зносостійкість»

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MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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AIRCRAFT CONTINUING AIRWORTHINESS DEPARTMENT

PERMISSION TO DEFEND
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MASTER DEGREE THESIS
(EXPLANATORY NOTE)
GRADUATE EDUCATIONAL DEGREE
«MASTER»
FOR EDUCATIONAL-PROFESSIONAL PROGRAM
«MAINTENANCE AND REPAIR OF AIRCRAFT AND AVIATION ENGINES»

Theme: « Development of method for testing spherical bearings for wear resistance »

Performed by: __________ **O.O. Skvortsov**

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Graduate Student's Degree Work Assignment
SKVORTSOV OLEKSANDR OLEKSIYOVICH

1. The thesis theme: «**Development of method for testing spherical bearings for wear resistance»** approved by the Rector's order of October 11, 2021 № 2196/ст.
2. The work fulfillment terms: since October 25, 2021 until December 31, 2021.
3. Initial data for the thesis: literature data on materials and advanced technologies on the analysis of bearing test methods for durability and performance
4. Content of the explanatory note (the list of problems to be considered): analysis of the study of the operation of bearings in aviation, the use of articulated bearings in aircraft components, the study of test methods for articulated bearings, the development of test methods for articulated bearings, calculation of air ventilation in a production room, analysis of the impact of hazardous and harmful factors on the environment
5. The list of mandatory graphic materials: analysis of the use of bearings in aviation, study of the types of bearings, analysis of methods for diagnostics of hinge bearings, results of tests of hinge bearings

6. Time and Work Schedule

Assignment	Completion dates	Remarks on completion
Search and study of the literature	25.10.2021-28.10.2021	
Analysis and generalization the material collected	29.10.2021-30.10.2021	
Analysis of landing gear units defects	01.11.2021-08.11.2021	
Analysis of coating methods, their advantages and disadvantages	09.11.2021-15.11.2021	
Execution of special sections (Labour Precaution, Environmental Protection)	16.11.2021-20.11.2021	
Test methods on fretting and corrosion installations	21.11.2021-30.11.2021	
Conducting of an experiment and processing its results	01.12.2021-10.12.2021	
Writing the explanatory note	11.12.2021-15.12.2021	
Preparation off illustrative material, writing the report	16.12.2021-18.12.2021	
Explanatory note checking, editing and correction	19.12.2021-24.12.2021	

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

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

8. Assignment issue date 25 th of October, 2021 year

Thesis Supervisor: ________________________ A.M. Khimko
(signature)

Assignment is accepted for performing: ________________ O.O. Skvortsov
(signature)

ABSTRACT

The explanatory note to master's degree work «Development of a method for testing spherical bearings for wear resistance» :

98 pages, 41 figures, 3 tables, 65 literature sources.

Object of study – is the processes of wear of the articulated bearings during their operation, the test methods of articulated bearings.

Subject of study – is hinge bearings.

The purpose of degree work – is the development of methods for testing articulated bearings for wear.

Research method – original methods for testing the hinge bearings for wear resistance have been developed. The durability and axial clearance tests of hinge bearings are analyzed. Improved installation for research on fretting corrosion in the installation for research of hinge bearings for wear resistance.

The materials of the thesis are recommended to be used in the educational process and the practical activities of engineer -mechanics of aviation equipment.

BEARINGS, HINGE BEARINGS, DEFFECTS, FRETTING, SPHERICAL BEARINGS.

CONTENT

LIST OF ABBREVIATIONS

DF – duplex bearing face-to-face

DB – duplex bearing back-to-back

DT – duplex bearing tandem

USA – United States of America

PTFE – teflon type

EBC – European Bearing Corporation

OSH – labor protection

ICAO – International Civil Aviation Organization

CNS – central nervous system

NLC – natural lighting coefficient

PC – personal computer

CC – computer center

AFA – automatic fire alarm

GHG – greenhouse gas

APU – auxiliary power unit

GSE – ground support equipment

SAF – sustainable aviation fuel

CAAF – Conference on Aviation Alternative Fuels

GFAAF – Global Framework for Aviation Alternative Fuels

CDA – continuous descent approach

ATM – air traffic management

GANP – global air navigation plan

ASBU – aviation system block update

GPU – ground power unit

CDM – Clean Development Mechanism

PCA – pre-conditioned air

Fe – equivalent load

L – the nominal durability

p – exponent of the life equation

n – the rotation frequency

Lh – nominal bearing life

X, Y – are the coefficients of radial and axial loads

V – rotation coefficient

Cs – safety coefficient

Ct – temperature coefficient

Fi – equivalent loads acting

L – is the supply air volume

k – is the air exchange rate

S – is the area of the room

H –is its height

L10 – basic rating life

n – shaft speed

C – basic dynamic load rating

P – equivalent dynamic boarding load

aISO – advanced life factor

Fr – radial load

Fa – axial load

Co – static load capacity

Fe – equivalent static load

INTRODUCTION

The aircraft industry, as one of the most high-tech sectors, is currently undergoing major transformations. This is due before total deep and rapid changes global economy and the new nature of competition.

The technology portfolio of the sector is changing very dynamic, replenished with new samples products and not always "open" developments. Some after some time lose their relevance, and not having time to realize their potential, due to the acceleration of the cycle, others move into the category of breakthroughs and become the basis future aviation.

A characteristic trend in the current stage of development of aviation technologies is their migration from the military to the civilian sector and vice versa. In other words, technology is evolving "Dual purpose".

Currently, several segments in which the turning points of technological sector evolution: aircraft engines, new structural materials and coatings, on-board equipment, aviation fuel.

Historically, aviation development has focused on overcoming two barriers – maximum heights and flight speeds.

Today, aviation is actively exploring ever new heights in near-Earth space, supersonic and hypersonic speed ranges. But no matter how progressive and courageous there were decisions, the fate of a particular aviation development is nevertheless solved by the market context, which is determined by the paradigm of economic development.

It manifests itself primarily in new business models and the different nature of competition, at the same time leaving no chance to previous models development. Competition is no longer determined "Unlimited" budgets and technological perfection, and the best ratio “price– quality".

For the operation of the aircraft, an important factor is the quality of its parts as well as assembly, in general. An important role in the design of the aircraft is performed by bearings, which are present in almost every structural part of the aircraft

Bearing – a product that is part of a support or emphasis that supports a shaft, axis or other movable structure with a given stiffness. It fixes the position in space, provides rotation, rolling or linear displacement (for linear bearings) with the least resistance, senses and transfers the load from the movable unit to other parts of the structure.

The scope of the bearings is huge – almost no industry is complete without the use of bearings. In other words, everything that rotates on bearings. There are a lot of varieties of bearings, and they are used depending on the operating conditions in a particular mechanism.

In aviation, there is a specificity due to difficult operating conditions. First of all, these are temperature differences (at a flight level, the temperature is up to –70℃, meanwhile, temperatures in an aircraft engine's high-pressure turbine are extremely high), pressure drops, and high revolutions (in gas turbine engines).

Also in this industry are extremely high safety requirements, and, as a consequence, the quality of components. In view of this, in the aircraft industry their own groups of bearings are used, as a rule, with special certificates.

The types of bearings used are very diverse – miniature ball (gyroscopes, avionics, on-board electronic equipment), radial ball (electric motors of drives, wing mechanization), roller conic (chassis), roller (wing mechanics).

Here, the range of bearings is the most diverse – from miniature ball bearings and high-speed precision spindle bearings to roller giants with a diameter of several meters.

The sliding bearing is a housing having a cylindrical bore into which a liner or sleeve of antifriction material is inserted (non-ferrous metals are often used) and a lubricating device.

Between the shaft and the bore of the bearing sleeve there is a gap that allows the shaft to rotate freely. For successful operation of the bearing, the clearance is pre-calculated.

Depending on the design, circumferential speed of the spigot, operating conditions, sliding friction can be:

–liquid, when the surfaces of the shaft and bearing are separated by a layer of liquid lubricant, there is either no direct contact between these surfaces, or it occurs in separate areas;

–boundary – the surface of the shaft and bearing are in full contact or in areas of great length, and the lubricant in the form of a thin film;

–dry – direct contact of the surfaces of the shaft and bearing along the entire length or in long sections, there is no liquid or gaseous lubricant;

–gas – the shaft and bearing surfaces are separated by a gas layer, friction is minimal.

Plain bearings have the following advantages:

–allow high rotation speed;

–allow you to work in water, with vibration and shock loads;

–economical with large shaft diameters;

–the ability to install on shafts, where the bearing should be split (for crankshafts);

–allow the regulation of various clearance and, therefore, the exact installation of the geometric axis of the shaft.

Disadvantages of plain bearings:

–high friction losses and, consequently, reduced efficiency (0.95 ... 0.98);

–the need for continuous lubrication;

–uneven wear of the bearing and journal;

–application for the manufacture of bearings of expensive materials;

–relatively high complexity of manufacturing.

Now there are methods for testing bearings for load, but they are not provided for specific conditions, but are provided for by specified standards. It remains relevant to develop new and improved old methods for testing hinge bearings

1 APPLICATION OF BEARINGS IN AVIATION

1.1 Use of bearings in aircraft

A bearing is any surface which supports, or is supported by, another surface. A good bearing must be composed of material that is strong enough to withstand the pressure imposed on it and should permit the other surface to move with a minimum of friction and wear. The parts must be held in position within very close tolerances to provide efficient and quiet operation, and yet allow freedom of motion. To accomplish this, and at the same time reduce friction of moving parts so that power loss is not excessive, lubricated bearings of many types are used [2].

Bearings are required to take radial loads, thrust loads, or a combination of the two. An example of a radial load would be a rotating shaft being held or contained in one position on a radial plane. Thrust load would be the rotating shaft being contained from moving axially along the shafts axis. These radial and thrust loads are illustrated in Figure 1.1. There are two ways in which bearing surfaces move in relation to each other. One is by the sliding movement of one metal against the other (sliding friction), and the second is for one surface to roll over the other (rolling friction). The three different types of bearings in general use are plain, roller, and ball (figure 1.2).

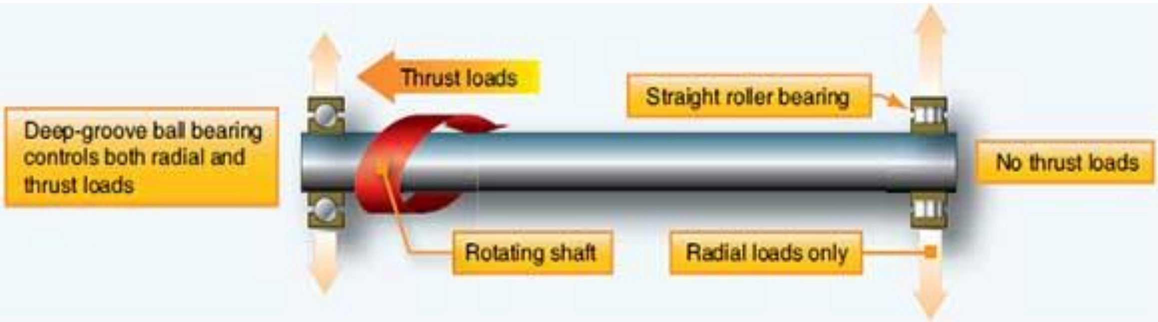


Figure 1.1 – Radial and thrust loads

Plain Bearings

Plain bearings are generally used for the crankshaft, cam ring, camshaft, connecting rods, and the accessory drive shaft bearings. Such bearings are usually subjected to radial loads only, although some have been designed to take thrust loads. Plain bearings are usually made of nonferrous (having no iron) metals, such as silver, bronze, aluminum, and various alloys of copper, tin, or lead. Master rod or crankpin bearings in some engines are thin shells of steel, plated with silver on both the inside and the outside surfaces and with lead-tin plated over the silver on the inside surface only [3]. Smaller bearings, such as those used to support various shafts in the accessory section, are called bushings. Porous Oilite bushings are widely used in this instance. They are impregnated with oil so that the heat of friction brings the oil to the bearing surface during engine operation.

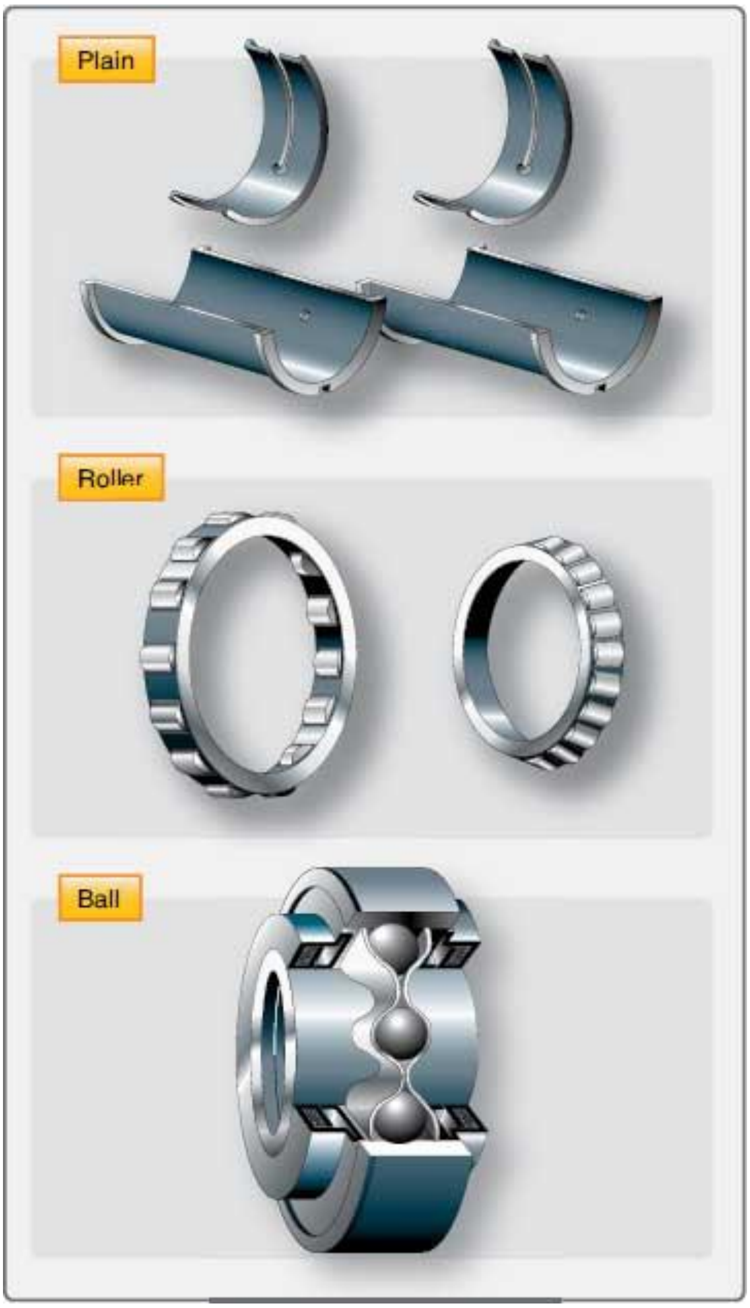


Figure 1.2 – Bearings

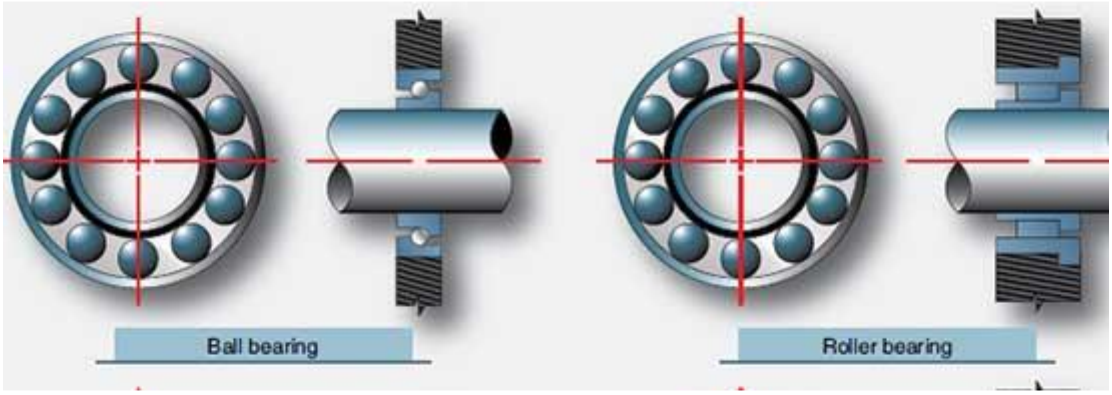
Roller Bearings

Roller bearings are made in many types and shapes, but the two types generally used in the aircraft engine are the straight roller and the tapered roller bearings. Straight roller bearings are used where the bearing is subjected to radial loads only. In tapered roller bearings, the inner- and outer-race bearing surfaces are cone-shaped. Such bearings withstand both radial and thrust loads [4]. Straight roller bearings are used in high power reciprocating aircraft engines for the crankshaft main bearings. They are also used in gas turbine applications where radial loads are high. Generally, a rotating shaft in a gas turbine engine is supported by a deep-groove ball bearing (radial and thrust loads) on one end and a straight roller bearing (radial loads only) on the other end.

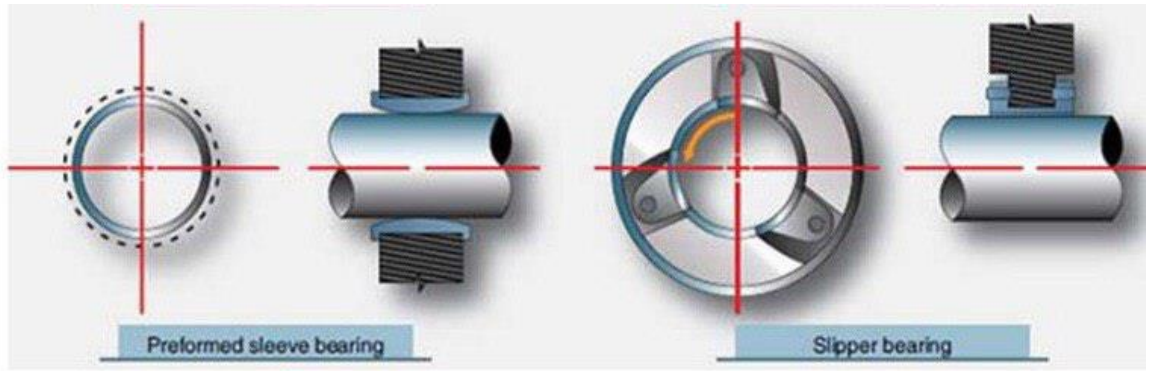
Ball Bearings

A ball bearing assembly consists of grooved inner and outer races, one or more sets of balls, in bearings designed for disassembly, and a bearing retainer. They are used for shaft bearings and rocker arm bearings in some reciprocating engines. Special deep-groove ball bearings are used to transmit propeller thrust and radial loads to the engine nose section of radial engines [5]. Since this type of bearing can accept both radial and thrust loads, it is used in gas turbine engines to support one end of a shaft (radial loads)and to keep the shaft from moving axially (thrust loads).

The main bearings have the critical function of supporting the main engine rotor. The number of bearings necessary for proper engine support is, for the most part, determined by the length and weight of the engine rotor. The length and weight are directly affected by the type of compressor used in the engine. Naturally, a two-spool compressor requires more bearing support. The minimum number of bearings required to support one shaft is one deep groove ball bearing (thrust and radial loads) and one straight roller bearing (radial load only). Sometimes, it is necessary to use more than one roller bearing if the shaft is subject to vibration or its length is excessive. The gas turbine rotors are supported by ball and roller bearings, which are antifriction bearings (figure 1.3). Many newer engines use hydraulic bearings, in which the outside race is surrounded by a thin film of oil. This reduces vibrations transmitted to the engine.



a b



c d

a– ball; b– roller;c– performed sleeve; d– slipper bearings

Figure 1.3 – Types of main bearings used for gas turbine rotor support

1.2 Types and kinds of bearings

Rolling bearings fall into two main classifications: ball bearings and roller bearings. Balls geometrically contact the raceway surfaces of the inner and outer rings at “points,” while the contact surface of rollers is a “line” contact. Rollers come in four basic geometric styles: cylindrical, needle, tapered and spherical.

Single row radial ball bearings are the most widely used bearings and utilize an uninterrupted raceway, which makes these bearings suitable for radial loads, or a combination of thrust and radial loads [6]. This design permits precision tolerances even at high speed operation. The cage in this bearing is pressed steel.

For high speed bearings, machined brass cages are available. Bearings with locating snap rings are also available

Prelubricated bearings have integral seals, or shields, which are packed with long-life grease. In many applications, these bearings may be used without supplementary seals, closures, or protective devices. This design offers the lowest possible manufacturing cost to the consumer. The boundary dimension of this type is the same as the corresponding bearings without the seals or shields.

Shielded ball bearings are protected on one, or both sides (suffixes Z and ZZ, respectively) by metal shields fastened to the outer ring. This close clearance labyrinth seal retains the lubricant and prevents the entrance of foreign matter [7].

Sealed ball bearings incorporate steel reinforced rubber seals securely fastened to a groove on the outer ring. Contact with the inner ring is by sealing lip or, non-contact with the inner ring is by labyrinth seal (to provide positive sealing at all times.

Single row angular contact ball bearings feature raceways with high and low shoulders. These opposing raceways are designed to carry thrust load in one direction. These bearings may be preloaded at the factory so that the correct preload will develop within the bearing. The bearings in this series are assembled with a specific internal clearance so that they will have a specified contact angle under load.

Double row angular contact ball bearings have an inner and outer ring with a double raceway. The two rows are so related that the contact angle is similar to a pair of back-to-back single row bearings [8]. Some series offer continuous races and can carry thrust loads in either direction. Other series have filling slots, it is necessary to mount them with the thrust load acting against the unnotched face of the rings.

Double row self-alighning bearings utilize an inner ring with two rows of balls in two deep raceways, and an outer ring with a single spherical raceway. In this way, the inner and outer rings can be misaligned relative to each other.

The resulting effect is a comparatively large angle imposing moment loads upon the balls.

Cylindrical roller bearings have rollers which are essentially cylindrical in shape. This provides a modified line contact with the cylindrical inner and outer ring raceways, while the rollers are guided by ground ribs on either the inner or outer ring.

Tapered roller bearings are utilize conical rollers and raceways arranged so that the rollers and raceways meet at a common apex. The rollers are guided by contact between the large end of the roller and a rib on the inner ring. This provides high capacity for radial and single thrust loads.

Spherical roller bearings have two rows of rollers in separate raceways which allows the bearing to compensate for angular thrust errors. They have large radial and thrust load capacity for heavy shock and impact loads, making them suitable for heavy industrial equipment.

Duplex bearings use a set of two on a common shaft with the inner and outer rings clamped solidly together. They are used to gain axial shaft control, rigidity and extra capacity.There are three fundamental combinations in duplex bearings: face-to-face (DF), back-to-back (DB), and tandem (DT).

Double direction angular contact thrust ball bearings are back-to-back duplex bearings with a larger contact angle than that of normal angular contact ball bearings. These bearings are primarily designed as thrust bearings for machine tools. They utilize machined brass cages.

Spherical roller thrust bearings are similar to double row spherical roller bearings, but have a greater contact angle. They are guided by ground flanges on the inner ring and operate against the spherical raceway in the outer ring. The contact angle is approximately 45°. Machined cages are normally used, and oil lubrication is recommended.

Bearing units are consist of a ball or roller bearing installed within a housing. The housings are most commonly made of cast iron but may also be made of other metals or nonmetallic materials. The housing provides rigidity and secure positioning for the bearing within the application. It also simplifies the task of replacing the bearing as the housing and bearing can be replaced as a complete unit.

All kinds and types of bearings can be seen in Figure 1.4 .

a – single row radial ball; b – prelubricated; c – shielded ball; d – sealed ball; e– single row angular contact ball; f– double row angular contact ball; g– double row self–alighning; h– cylindrical roller; i– tapered roller; j– spherical roller; k– duplex; l– double direction angular contact thrust ball; m– spherical roller thrust; n–roller bearing; o– bearing units

Figure 1.4 – Different types of bearings

1.3 Defects of bearings

The most characteristic malfunctions of three–layer plain bearings: natural wear of the babbit layer, cracks, spalls, lagging and squeezing out of the babbitt, wear of the shoulders and the thrust shoulder of the bearing housing, its spalls and cracks, spalls and cracks of the reinforcement, weakening of the reinforcement and the formation of gaps between it and the housing.

Plain bearings are inspected with a hammer before repair [9]. A rattling indicates a lagging babbitt layer or reinforcement.

The weakening of the babbitt layer and reinforcement is a consequence of the unreliability of their fastening in the grooves and undercuts with the form of a "dovetail". Cracks in the babbit layer appear when there are gaps between the reinforcement and the babbit.

Porosity and shells in babbitt, which are formed as a result of improper charge composition and violations of the melting temperature, as well as increased or decreased sodium content in the alloy, lead to cracks [10]. The extrusion of babbitt is accompanied by the occurrence of cracks and spalls and occurs with increasing pressure on the bearing.

This can happen, for example, with a small angle of coverage of the neck bearing or with an increase in axle load.

Reduced calcium content in babbitt increases the extrusion. The design of double–layer bearings is more reliable compared to three–layer bearings [11].

Friction of axle boxes in most cases contributes to damage to the axle journal bearing and, if the train stops late, can lead to a fracture.

Reasons for heating axleboxes with sliding bearings can be:

– poor-quality adjustment of bearings along the neck of the axis – non-compliance with the established tolerances for the length (run-up) and diameter of the neck, absence or incorrect sizes of refrigerators, the presence of shrinkage shells between the babbitt filling and reinforcement;

– low quality babbitt layer;

– chipping and extrusion;

– incorrect assembly of the axle box (for example, misalignment of the bearing in the axle box);

– poor filling of axle boxes with polster or pad rollers, malfunction of polster, subsidence, freezing and contamination of the rollers;

– the presence in the axle box of contaminated or flooded oil, lack of oil, the use of non-seasonal oils; hit in the axle box of sand or other foreign matter.

The most common rolling bearing defects, symptoms, causes and solutions

Each of the different causes of bearing failure produces its own characteristic damage. Such damage, known as primary damage, gives rise to secondary, failure-inducing damage – flaking and cracks [12]. Even the primary damage may necessitate scrapping the bearings on account of excessive internal clearance, vibration, noise, and so on. A failed bearing frequently displays a combination of primary and secondary damage. The types of damage may be classified as follows:

Primary damage :wear, identations, smearing, surface distress, corrosion, electric current damage;

Secondary damage: flaking, cracks.

Wear

In normal cases there is no appreciable wear in rolling bearings. Wear may, however, occur as a result of the ingress of foreign particles into the bearing or when the lubrication is unsatisfactory [13]. Vibration in bearings which are not running also gives rise to wear.

Wear caused by abrasive particles

Small, abrasive particles, such as grit or swarf that have entered the bearing by some means or other, cause wear of raceways, rolling elements and cage (figure 1.5). The surfaces become dull to a degree that varies according to the coarseness and nature of the abrasive particles. Sometimes worn particles from brass cages become verdigrised and then give light-coloured grease a greenish hue. The quantity of abrasive particles gradually increases as material is worn away from the running surfaces and cage. Therefore the wear becomes an accelerating process and in the end the surfaces become worn to such an extent as to render the bearing unserviceable.

However, it is not necessary to scrap bearings that are only slightly worn. They can be used again after cleaning. The abrasive particles may have entered the bearing because the sealing arrangement was not sufficiently effective for the operating conditions involved [14]. They may also have entered with contaminated lubricant or during the mounting operation.

Wear caused by inadequate lubrication

If there is not sufficient lubricant, or if the lubricant has lost its lubricating properties, it is not possible for an oil film with sufficent carrying capacity to form. Metal to metal contact occurs between rolling elements and raceways. In its initial phase, the resultant wear has roughly the same effect as lapping (figure 1.6).

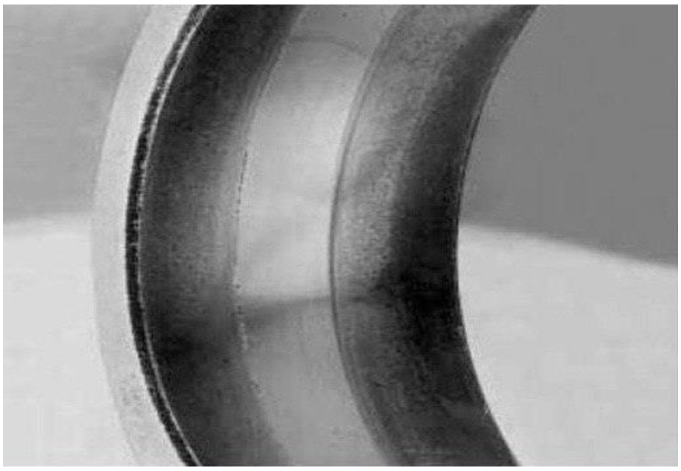


Figure 1.5 – Outer ring of a spherical roller bearing with raceways that have been worn by abrasive particles. It is easy to feel where the dividing line goes between worn and unworn sections

The peaks of the microscopic asperities, that remain after the production processes, are torn off and, at the same time, a certain rolling-out effect is obtained. This gives the surfaces concerned a varying degree of mirror-like finish. At this stage surface distress can also arise. If the lubricant is completely used up, the temperature will rise rapidly [15]. The hardened material then softens and the surfaces take on blue to brown hues. The temperature may even become so high as to cause the bearing to seize.

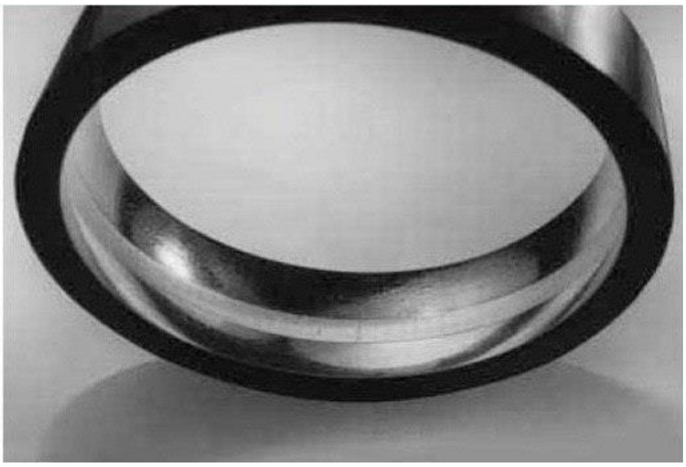


Figure 1.6 – Outer ring of a spherical roller bearing that has not been adequately lubricated.The raceways have a mirror finish

Wear caused by vibration

When a bearing is not running, there is no lubricant film between the rolling elements and the raceways. The absence of lubricant film gives metal to metal contact and the vibrations produce small relative movements of rolling elements and rings [16]. As a result of these movements, small particles break away from the surfaces and this leads to the formation of depressions in the raceways.

There is never any visible damage to the rolling elements (figure 1.7). The greater the energy of vibration, the more severe the damage [17]. The period of time and the magnitude of the bearing internal clearance also influence developments, but the frequency of the vibrations does not appear to have any significant effect.

Roller bearings have proved to be more susceptible to this type of damage than ball bearings. This is considered to be because the balls can roll in every direction. Rollers, on the other hand, only roll in one direction; movement in the remaining directions takes the form of sliding.

Bearings with vibration damage are usually found in machines that are not in operation and are situated close to machinery producing vibrations. Examples that can be cited are transformer fans, stand-by generators and ships' auxiliary machinery. Bearings in machines transported by rail, road or sea may be subject to vibration damage too.

Figure 1.7 – Vibration damage to the ring of cylinder roller bearing.

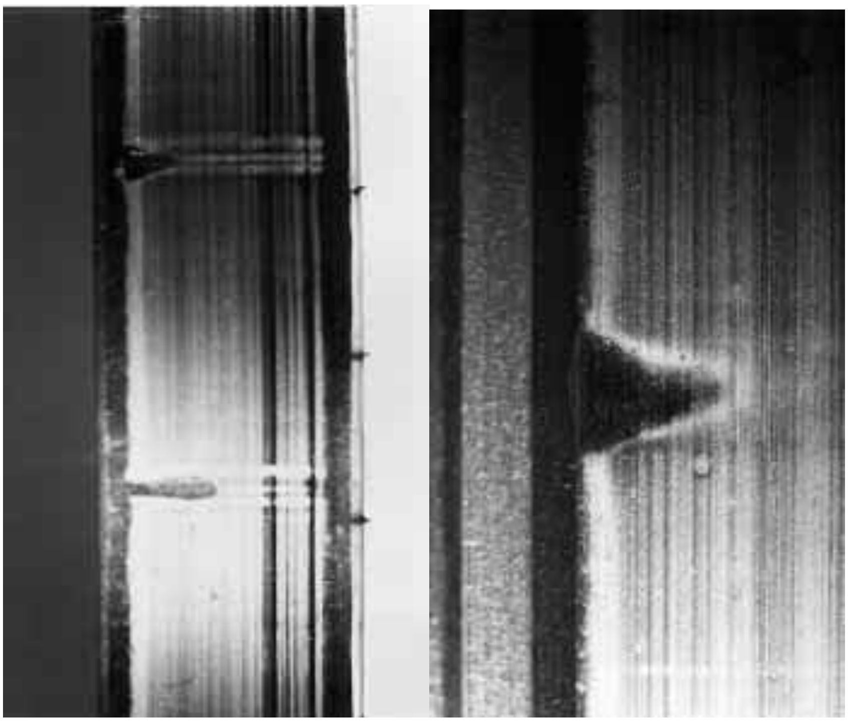
Indentations raceways and rolling elements may become dented if the mounting pressure is applied to the wrong ring, so that it passes through the rolling elements, or if the bearing is subjected to abnormal loading while not running (figure 1.8). Foreign particles in the bearing also cause indentations.

Figure 1.8 – Washer of a thrust ball bearing subjected to overloading while not running. The indentations are narrow and radially aligned, not sphered as in radial ball bearings

This damage is known as false brinelling, sometimes also referred to as washboarding. Balls produce sphered cavities while rollers produce fluting. In many cases, it is possible to discern red rust at the bottom of the depressions. This is caused by oxidation of the detached particles, which have a large area in relation to their volume, as a result of their exposure to air.

However, in the latter case the bottom of the depression is dark in colour, not bright or corroded. The damage caused by electric current is also distinguishable by the fact that the rolling elements are marked as well as the raceways [18].

The damage has arisen while the bearing was not running. It is evident, from the fainter fluting discernible between the pronounced depressions with corrosion at the bottom, that the ring has changed position for short periods (figure 1.9).



a b

a – two diametrically opposed indentations, b– the roller has, in turn, dented the inner ring raceway

Figure 1.9 – A periphery camera view of the roller

Smearing

When two inadequately lubricated surfaces slide against each other under load, material is transferred from one surface to the other. This is known as smearing and the surfaces concerned become scored, with a “torn” appearance. When smearing occurs, the material is generally heated to such temperatures that rehardening takes place (figure 1.10).

This produces localised stress concentrations that may cause cracking or flaking. In rolling bearings, sliding primarily occurs at the roller end–guide flange interfaces. Smearing may also arise when the rollers are subjected to severe acceleration on their entry into the load zone [19]. If the bearing rings rotate relative to the shaft or housing, this may also cause smearing in the bore and on the outside surface and ring faces. In thrust ball bearings, smearing may occur if the load is too light in relation to the speed of rotation.

Figure 1.10 – Smearing on the surface of a roller from a spherical roller bearing – 100 × magnification

Smearing of roller ends and guide flanges

In cylindrical and taper roller bearings, and in spherical roller bearings with guide flanges, smearing may occur on the guiding faces of the flanges and the ends of the rollers. This smearing is attributable to insufficient lubricant between flanges and rollers. It occurs when a heavy axial load acts in one direction over a long period, for instance when taper roller bearings are subject to excessive preloading.(figure 1.11).

In cases where the axial load changes direction, smearing is much less common as the opportunity is provided for the ingress of lubricant when the roller end is temporarily relieved of load. Such smearing can be avoided to a considerable extent by selecting a suitable lubricant.

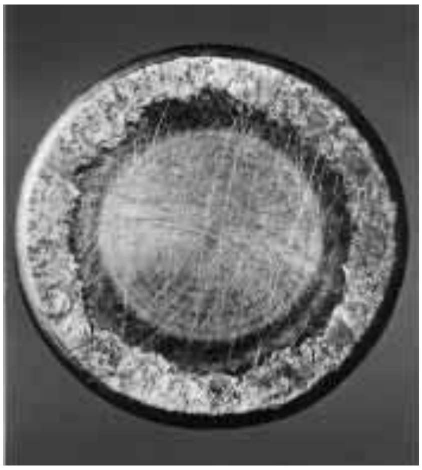


Figure 1.11 – A cylindrical roller with end smearing caused by heavy axial loading and improper lubrication

Smearing of rollers and raceways

In certain circumstances, smearing may occur on the surface of rollers and in raceways of spherical and cylindrical roller bearings. This is caused by roller rotation being retarded in the unloaded zone, where the rollers are not driven by the rings. Consequently their speed of rotation is lower than when they are in the loaded zone. The rollers are therefore subjected to rapid acceleration and the resultant sliding is so severe that in may produce smearing (figure 1.12).

Figure 1.12 – Outer ring raceway of a spherical roller bearing with smear streaks caused by a blow against the inner ring

Smear streaks may also be found in the raceways of spherical and taper roller bearings. These streaks are the result of careless handling or incorrect mounting practice [20]. Blows or heavy pressure applied to the wrong ring, without rotating the bearing, cause the rollers to produce narrow, transverse streaks of smearing in the raceways .

Smearing of external surfaces

Smearing may occur on the external surfaces of heavily loaded bearings. Here, the smearing is the result of movement of the bearing ring relative to its shaft or housing (figure 1.13). Increasing the axial compression does not result in any improvement

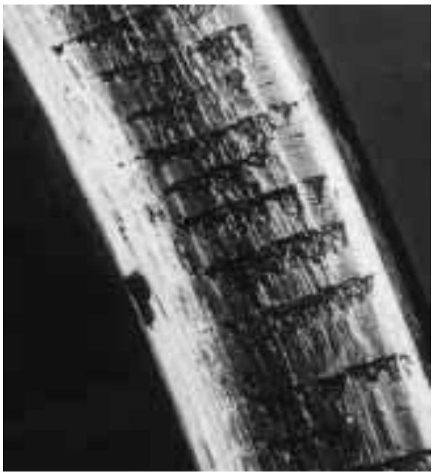


Figure 1.13 – Smeared face of a cylindrical roller bearing inner ring

Smearing in thrust ball bearings

Smearing may occur in the raceways of thrust ball bearings if the rotational speed is too high in relation to the loading. The centrifugal force then impels the balls to the outer part of the shallow raceways (figure 1.14).

There the balls do not roll satisfactorily and a great deal of sliding occurs at the ball-to-raceway contacts. This leads to the formation of diagonal smear streaks in the outer part of the raceway.

In the case of thrust ball bearings operating under light loads and at high speeds, such damage can be prevented by subjecting the bearings to extra loading, for instance by applying springs.

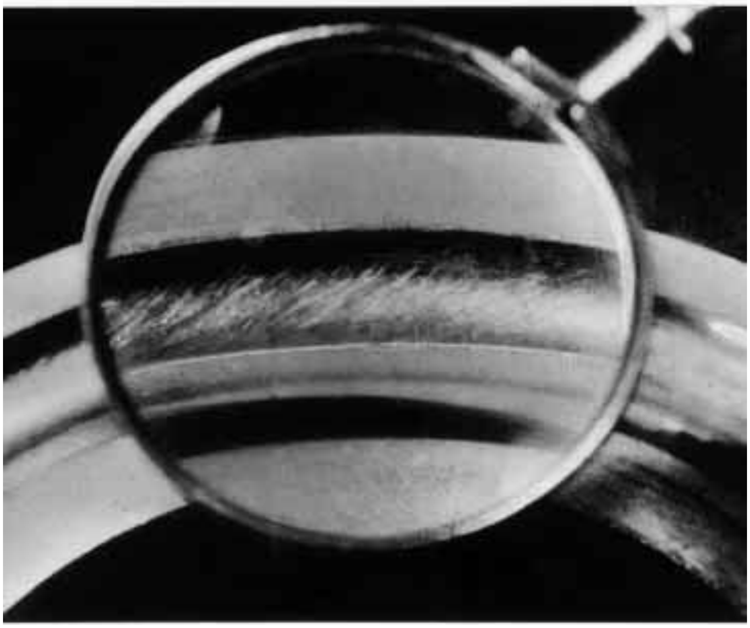


Figure 1.14 – Thrust ball bearing raceway with smear streaks on account of the rotational speed having been too high in relation to the load

Surface distress

If the lubricant film between raceways and rolling elements becomes too thin, the peaks of the surface asperities will momentarily come into contact with each other. Small cracks then form in the surfaces and this is known as surface distress.

These cracks must not be confused with the fatigue cracks that originate beneath the surface and lead to flaking. The surface distress cracks are microscopically small and increase very gradually to such a size that they interfere with the smooth running of the bearing [21].

These cracks may, however, hasten the formation of sub-surface fatigue cracks and thus shorten the life of the bearing If the lubrication remains satisfactory throughout, i.e. the lubricant film does not become too thin because of lubricant starvation or viscosity changes induced by the rising temperature or on account of excessive loading, there is no risk of surface distress.

Corrosion

Rust will form if water or corrosive agents reach the inside of the bearing in such quantities that the lubricant cannot provide protection for the steel surfaces.

This process will soon lead to deep seated rust. Another type of corrosion is fretting corrosion.

Deep seated rust

A thin protective oxide film forms on clean steel surfaces exposed to air. However, this film is not impenetrable and if water or corrosive elements make contact with the steel surfaces, patches of etching will form. This development soon leads to deep seated rust. Deep seated rust is a great danger to bearings since it can initiate flaking and cracks (figure 1.15). Acid liquids corrode the steel quickly, while alkaline solutions are less dangerous. The salts that are present in fresh water constitute, together with the water, an electrolyte which causes galvanic corrosion, known as water etching. Salt water, such as sea water, is therefore highly dangerous to bearings.

Figure 1.15 – Deep seated rust in the outer ring of a cylindrical roller bearing

Fretting corrosion

If the thin oxide film is penetrated, oxidation will proceed deeper into the material. An instance of this is the corrosion that occurs when there is relative movement between bearing ring and shaft or housing, on account of the fit being too loose. This type of damage is called fretting corrosion and may be relatively deep in places (figure 1.16).

The relative movement may also cause small particles of material to become detached from the surface. These particles oxidise quickly when exposed to the oxygen in the atmosphere.

As a result of the fretting corrosion, the bearing rings may not be evenly supported and this has a detrimental effect on the load distribution in the bearings. Rusted areas also act as fracture notches

Figure 1.16–Fretting corrosion on the outer ring of a spherical roller bearing

Damage caused by the passage of electric current

When an electric current passes through a bearing, i.e. proceeds from one ring to the other via the rolling elements, damage will occur. At the contact surfaces the process is similar to electric arc welding. The material is heated to temperatures ranging from tempering to melting levels. This leads to the appearance of discoloured areas, varying in size, where the material has been tempered, re-hardened or melted. Small craters also form where the metal has melted. The passage of electric current frequently leads to the formation of fluting (corrugation) in bearing raceways. Rollers are also subject to fluting, while there is only dark discolouration of balls (figure 1.17).

It can be difficult to distinguish between electric current damage and vibration damage. A feature of the fluting caused by electric current is the dark bottom of the corrugations, as opposed to the bright or rusty appearance at the bottom of the vibration-induced fluting. Another distinguishing feature is the lack of damage to the rolling elements of bearings with raceway fluting caused by vibrations [22]. Both alternating and direct currents cause damage to bearings. Even low amperage currents are dangerous.

Non-rotating bearings are much more resistant to electric current damage than bearings in rotation. The extent of the damage depends on a number of factors: current intensity, duration, bearing load, speed and lubricant. The only way of avoiding damage of this nature is to prevent any electric current from passing through the bearing.

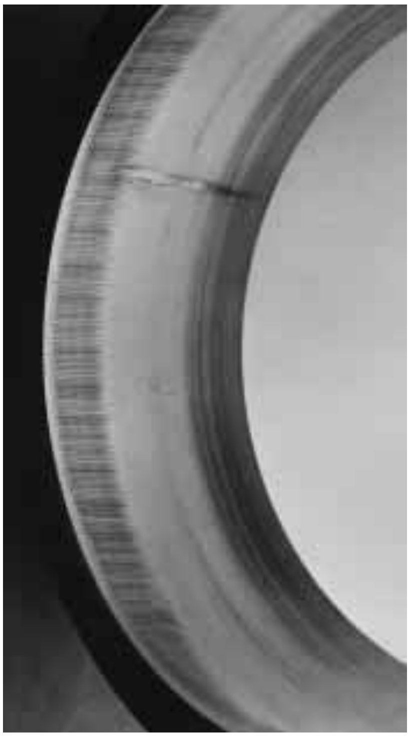


Figure 1.17– Fluting, caused by the passage of electric current, in the outer ring of a spherical roller bearing

Flaking (spalling)

Flaking occurs as a result of normal fatigue, i.e. the bearing has reached the end of its normal life span. However, this is not the commonest cause of bearing failure. The flaking detected in bearings can generally be attributed to other factors. If the flaking is discovered at an early stage, when the damage is not too extensive, it is frequently possible to diagnose its cause and take the requisite action to prevent a recurrence of the trouble. The path pattern of the bearing may prove to be useful (figure 1.18).

Figure 1.18– Flaked cone and rollers of taper roller bearing. Heavy loading and inadequate lubrication are the causes of this damage

When flaking has proceeded to a certain stage, it makes its presence known in the form of noise and vibrations, which serve as a warning that it is time to change the bearing. The causes of premature flaking may be heavier external loading than had been anticipated, preloading on account of incorrect fits or excessive drive-up on a tapered seating, oval distorsion owing to shaft or housing seating out-of-roundness, axial compression, for instance as a result of thermal expansion. Flaking may also be caused by other types of damage, such as indentations, deep seated rust, electric current damage or smearing (figure 1.19).

Figure 1.19 – Flaking in the outer ring outer ring of spherical roller bearing that has been mounted in a housing with oval bore

Corresponding area of advanced fretting corrosion on the outside surface (for this photograph the ring has been placed in front of a mirror,figure 1.19)

Development of the corrosion has been accompanied by an increase in volume that has led to deformation of the bearing ring and localised overloading. The results have been premature fatigue and flaking

Figure 1.19 – Flaking in the raceways of the outer ring of a spherical roller bearing

Cracks

Cracks may form in bearing rings for various reasons. The most common cause is rough treatment when the bearings are being mounted or dismounted (figure 1.20).

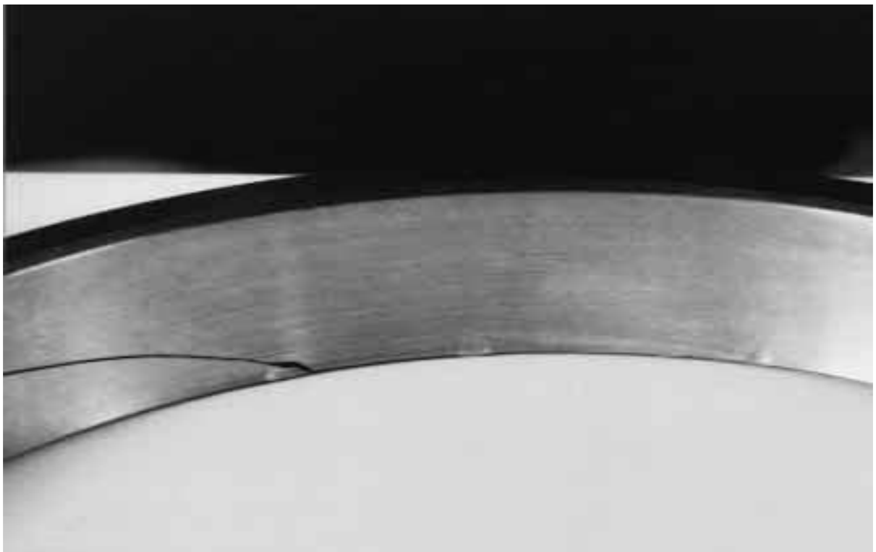


Figure 1.20 – Fractured outer ring of a self-aligning ball bearing.

Hammer blows, applied direct against the ring or via a hardened chisel, may cause fine cracks to form, with the result that pieces of the ring break off when the bearing is put into service. Excessive drive up on a tapered seating or sleeve is another cause of ring cracking.

The tensile stresses, arising in the rings as a result of the excessive drive-up, produce cracks when the bearing is put into operation. The same result may be obtained when bearings are heated and then mounted on shafts manufactured to the wrong tolerances. The smearing described in an earlier section may also produce cracks at right angles to the direction of slide (figure 1.21).

Cracks of this kind produce fractures right across the rings. Flaking, that has occurred for some reason or other, acts as a fracture notch and may lead to cracking of the bearing ring. The same applies to fretting corrosion.

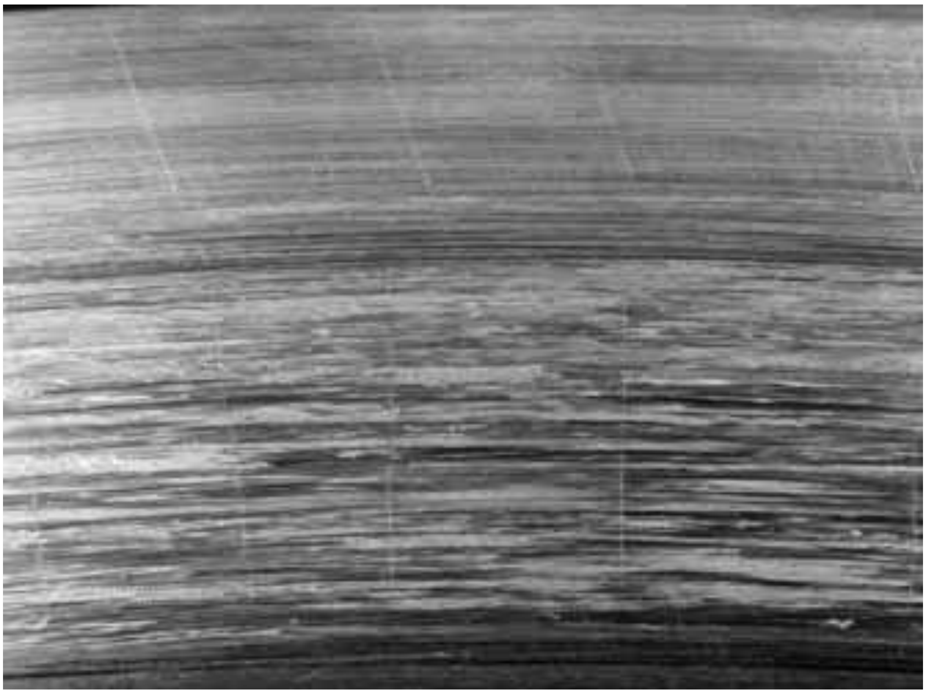


Figure 1.21 – Smearing damage on the face of a bearing ring. Note the incipient transverse cracks

Bearing vibration

Vibrations occurring in the bearing should be considered as a signal for speedy maintenance, since a serviceable bearing creates a minimum of vibration. A defective bearing, however, poses a threat to equipment performance and a danger to people.

The causes of vibration of bearings and a faulty condition of the equipment are unbalance, misalignment (misalignment), bending of the shafts, soft foot (clearance under the support) and loosening of fastenings, mechanical transmission defects and bearing defects.

Significant vibrations can be detected by the human senses. But this is already a potentially dangerous level, and then measures should be taken immediately.

Periodic checks of the vibration level of the bearing are a traditionally used method, reliable enough for non-critical equipment (figure 1.22).

Portable entry-level devices – vibrometers, pens – give a general assessment of the condition of machines and mechanisms.

The vibrohandle determines vibration velocity, vibration acceleration, and temperature — parameters that make it possible to evaluate the vibration level of a rolling bearing and its suitability for further operation [23]. There are applications for mobile devices that turn a smartphone into a vibrometer through the use of a built-in accelerometer.

Figure 1.22 – Bearing vibration measurement

1.4 Spherical bearings

A spherical plain bearing is a bearing that permits angular rotation about a central point in two orthogonal directions (usually within a specified angular limit based on the bearing geometry). Typically these bearings support a rotating shaft in the bore of the inner ring that must move not only rotationally, but also at an angle.

Self-aligning spherical bearings were first used by James Nasmyth around 1840 to support line shaft bearings in mills and machine shops. For long shafts it was impossible to accurately align bearings, even if the shaft was perfectly straight [24]. Nasmyth used brass bearing shells between hemispherical brass cups to align the bearings to self-align.

Spherical bearings can be of a hydrostatic or mechanical construction. A spherical bearing by itself consists of an outer ring and an inner ring and a locking feature that makes the inner ring captive within the outer ring in the axial direction only.

The outer surface of the inner ring and the inner surface of the outer ring are spherical (or more correctly, toroidal) and are collectively considered the raceway and they slide against each other, either with a lubricant, a maintenance-free (typically polytetrafluoroethylene or PTFE) based liner, or they incorporate a rolling element such as a race of ball-bearings, allowing lower friction.

Spherical bearings are used in countless applications, wherever rotational motion must be allowed to change the alignment of its rotation axis. A good example is the drive axle bearings of a vehicle control arm (or A–arm) suspension.

The mechanics of the suspension allow the axle to move up and down (and the wheel to turn in order to steer the vehicle), and the axle bearings must allow the rotational axis of the axle to change without binding.

While in practice, spherical bearings are rarely used here, it is a simple concept that illustrates a possible application of a spherical bearing. In fact, spherical bearings are used in smaller sub-components of this type of suspension, for example certain types of constant-velocity joints.

Spherical bearings are used in car suspensions, engines, driveshafts, heavy machinery, sewing machines, robotics and many other applications.

Spherical plain bearings are plain bearings whose inner and outer rings have spherical plain surfaces (figure 1.23).

Spherical bearings are designed to transmit radial, axial and combined loads in moving or stationary joints of machines and mechanisms.

It should be borne in mind that: a movable joint is a joint in which the spherical bearings operate when one ring moves relative to another, with a relatively low sliding speed; fixed connection – mounting joint, in which the spherical bearings operate with periodic unit shifts of one ring relative to another; designed primarily to compensate for misalignment of the shaft and housing [25].

All articulated bearings can be divided into two groups according to the method of lubrication of the working surfaces:

– spherical bearings requiring lubrication (with steel / steel sliding surface),

– spherical plain bearings without external lubrication

– self-lubricating (with asliding surface steel / metallofluoroplast, steel / organofibre).

Spherical plain bearings with steel / steel sliding surfaces are designed to withstand alternating heavy, shock or static loads. They are made of high-quality bearing steels ШХ15, ШХ15СГ or stainless steel 95Х18Ш. Self-lubricating spherical plain bearings are primarily intended for the perception of large loads of constant direction, at low sliding speeds.

They are used in units with increased requirements for durability and in difficult maintenance of bearings, when the use of bearings with a steel / steel sliding surface is impractical. Self-lubricating bearings are made of steel ШХ15, 95Х18Ш, 12Х18Н9Т.

Serial bearings are operable at temperatures up to + 120 ℃. Short-term operation of bearings at a temperature of + 150 ℃ is allowed. For more severe temperature conditions, special designs are available.

Unfortunately, it is impossible to draw up general rules for choosing the type of bearing, since usually many factors should be taken into account, which include a number of contradictions that must be resolved or optimally balanced. Therefore, in difficult cases, consultation with the articulated bearing manufacturer is required.

Spherical plain bearings steel / steel:

for movable joints:

- Executions Ш, ШП, ШЛ – without holes and grooves for lubrication;
- Execution of ШС, ШСП, ШСЛ– with holes and grooves for lubrication on the inner ring;
- Versions ШС ... К1, ШСП ... К1, ШСЛ ... К1 – with holes and grooves for lubrication on the outer ring;
- Versions ШС ... К, ШСП ... К, ШСЛ ... К – with holes and grooves for lubrication on the outer and inner rings;

for fixed joints:

- Executions of ШМ, ШМП, ШМЛ – without holes and grooves for lubrication.

The advantage of single-split bearings of ШП, ШСП, ШСП ... К1, ШСП ... К, ШМП types over versions of Ш, ШС, ШС ... К1, ШС ... К is that due to the absence of cylindrical belts (flats) on the inner rings and the absence of grooves on the outer rings, the working surface of the slide and, accordingly, the actual load capacity are increased (figure 1.24).

To increase wear resistance, bearings of a single-fault design can be coated with molybdenum disulfide (in the symbol, the letter I).

Bearings of types ШЛ, ШСЛ, ШСЛ ... К1, ШСЛ ... К have a two-fault outer ring. Bearings of ШМ, ШМП, ШМЛ types are manufactured with minimal internal clearances.

Spherical plain bearings for movable joints with a steel / metal fluoroplastic sliding surface (figure 1.25) :

– Execution of ШН .

Such bearings have an integral design. Spherical plain bearings for movable joints with a steel / fiberglass sliding surface:

– Execution of ШЛТ.

The outer rings have a two-fault design.Spherical plain bearings with inner rings made of composite material – a mixture of polyamide with fluoroplastic:

– Execution Ш ... Е.

Angular contact spherical plain bearings:

– Execution of ШУ, and spherical plain bearings with two outer half rings:

– Execution of ШР

Bearings are able to work in dusty conditions and limited lubrication. Spherical bearings are used in aircraft control mechanisms, mounted units of agricultural machinery mechanisms, excavators, and suspensions of heavy mining dump trucks.

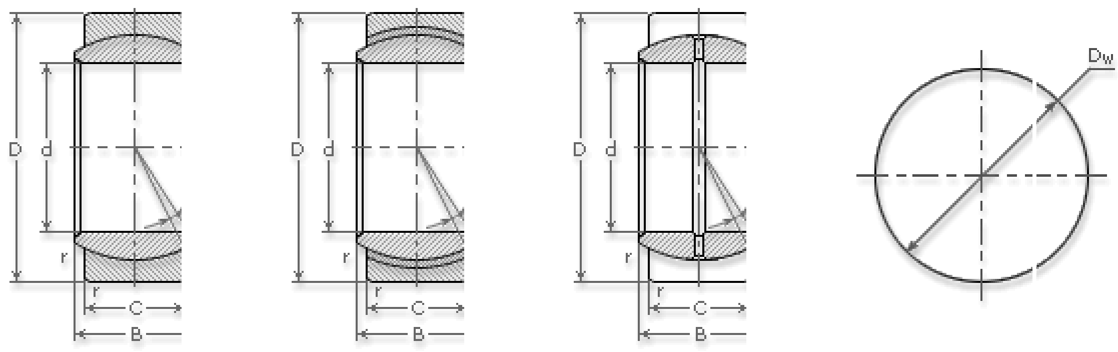


Figure 1.23 – Spherical bearings: Ш (ШМ), ШС, ШС…К types

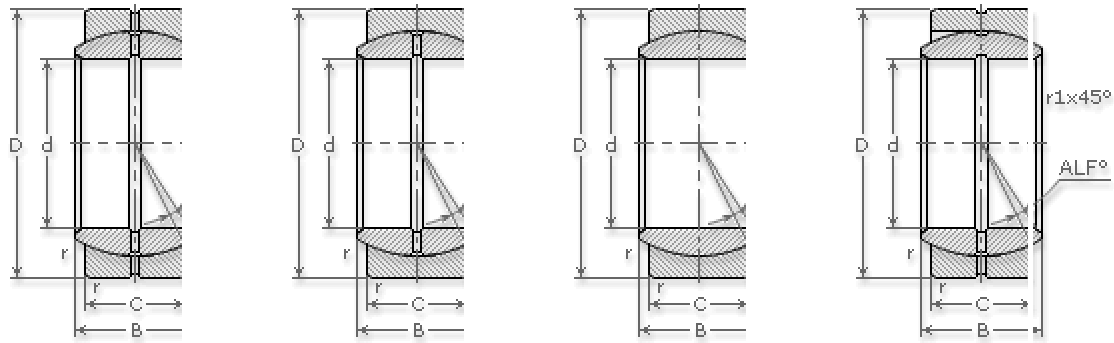


Figure 1.24 –Spherical bearings : ШП (ШМП), ШСП, ШСП…К, ШСЛ types

The most common material for rolling bearings is steel. Rings are usually made of carbon and chromium steels, chromium-nickel and chromium manganese steels for cementation, high alloy heat-resistant steels and stainless steels. Balls are made of bearing or stainless steel.

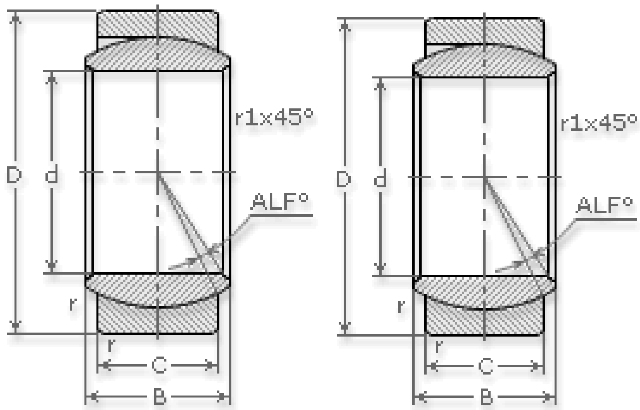


Figure 1.25– Sliding surface - steel / organ fiber (ШЛТ) and sliding surface steel / fluoroplastic (ШН) types of bearings

Steel parts of rolling bearings are manufactured by pressure or cutting, hardened to increase hardness (or other heat treatment to achieve the required characteristics), and ground to obtain the proper surface quality.

Other bearing materials are various metals and alloys, polymers and composites, ceramics and glass.

Also, bearings are coated to protect parts, reduce friction and wear.

Conclusion to part 1

Reliability in aviation is paramount. There is no room for error; the aircraft cannot be stopped on the sidelines in the event of a breakdown. Every detail, starting from the anchor of a turbojet engine and ending with the wing flaps, must function smoothly and work out a resource. Attention is paid to the movable hinge and bearing assemblies.

The selection of bearings for the aircraft industry is a responsible task. Bearings in aviation are used for: training fighters: engine shaft, gearbox, climate systems, electric generators, hydraulic, fuel pumps, flaps; turboprop engines of cargo, civil aircraft; civilian, cargo, combat helicopters: tail gear drive, fuel pump, air conditioning and gyroscopes, tilt sensors of parabolic antennas; chassis (wheel), control systems, etc.

Features of bearings for the aircraft industry

The harsh operating conditions of aircraft require the creation of bearings that can successfully cope with low or high temperatures, corrosive environments, extreme loads, and speeds of up to 100,000 rpm. At the same time, it is important to squeeze into limited dimensions, weight. In the manufacture of bearing assemblies for the aviation industry, special materials, lubricants are used:

– the main and connecting rod bearings of the aircraft ICE are filled with lead bronzes or silver with a surface lead (5–20 microns thick) or lead-indium (20–40 microns) layer;
– lead holds grease well, improves gliding, and has corrosion resistance;
– inner, outer rings are made of heat-resistant steels (with the addition of molybdenum, chromium, vanadium, niobium).

During long-term operation of molybdenum steels, an intermetallic compound (Fe_2Mo) is formed, due to which the material becomes up to 10–20% harder and stronger;

– separators are made of bronze, aluminum alloys, textolite, brass, polyamide;
– rolling elements – ceramic, or from highly pure steel, smelted in vacuum.

Aviation lubricants are used (based on mineral and synthetic base oils with the addition of lithium soap, molybdenum disulfide) – they retain properties at temperatures from –75 ℃ to + 232 ℃.

Bearings are classified according to the following criteria:

– in the direction of action of the perceived load – radial (perceive predominantly radial load), persistent (perceive mainly axial load) and angular contact (perceive combined load, moreover both radial and axial loads can be predominant); persistent radial (perceive mainly axial load);
– in the form of rolling bodies – ball and roller. Rollers can be short cylindrical and long cylindrical, twisted, needle, conical and spherical;
– by the number of rows of rolling bodies – single, double, four and multi-row;
– according to the main design features – self-aligning, non-self-aligning, with a cylindrical bore of the inner ring, single, double, built, quad, etc.

2 BEARING TEST DIAGNOSTICS

2.1 Principle of operation bearing

Bearing - an assembly that is part of a support or abutment and supports a shaft, axis or other movable structure with a given stiffness. It fixes the position in space, provides rotation, rolling with the least resistance, perceives and transfers the load from the moving unit to other parts of the structure.

Key bearing parameters:

– Maximum dynamic and static load (radial and axial).

– Maximum speed (revolutions per minute for radial bearings).

– Landing sizes.

– Accuracy class of bearings.

– Lubrication requirements.

– Bearing life before signs of fatigue, in revolutions.

– Noise bearing

– Bearing vibration

Bearing forces are divided into:

– radial, acting in the direction perpendicular to the axis of the bearing;

– axial, acting in a direction parallel to the axis of the bearing.

The bearing is essentially a planetary mechanism in which the carrier is a cage, the inner and outer rings perform the functions of the central wheels, and the satellites replace the rolling bodies.

Separator speed or ball speed around the bearing axis

A bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts. The design of the bearing may, for example, provide for free linear movement of the moving part or for free rotation around a fixed axis; or, it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts.

Most bearings facilitate the desired motion by minimizing friction. Bearings are classified broadly according to the type of operation, the motions allowed, or to the directions of the loads (forces) applied to the parts.

Rotary bearings hold rotating components such as shafts or axles within mechanical systems, and transfer axial and radial loads from the source of the load to the structure supporting it. The simplest form of bearing, the plain bearing, consists of a shaft rotating in a hole [26]. Lubrication is used to reduce friction. In the ball bearing and roller bearing, to reduce sliding friction, rolling elements such as rollers or balls with a circular cross-section are located between the races or journals of the bearing assembly. A wide variety of bearing designs exists to allow the demands of the application to be correctly met for maximum efficiency, reliability, durability and performance.

The term "bearing" is derived from the verb "to bear"; a bearing being a machine element that allows one part to bear (i.e., to support) another. The simplest bearings are bearing surfaces, cut or formed into a part, with varying degrees of control over the form, size, roughness and location of the surface. Other bearings are separate devices installed into a machine or machine part. The most sophisticated bearings for the most demanding applications are very precise devices; their manufacture requires some of the highest standards of current technology.

Reducing friction in bearings is often important for efficiency, to reduce wear and to facilitate extended use at high speeds and to avoid overheating and premature failure of the bearing. Essentially, a bearing can reduce friction by virtue of its shape, by its material, or by introducing and containing a fluid between surfaces or by separating the surfaces with an electromagnetic field.

By shape, gains advantage usually by using spheres or rollers, or by forming flexure bearings.

By material, exploits the nature of the bearing material used. (An example would be using plastics that have low surface friction.)

By fluid, exploits the low viscosity of a layer of fluid, such as a lubricant or as a pressurized medium to keep the two solid parts from touching, or by reducing the normal force between them.

By fields, exploits electromagnetic fields, such as magnetic fields, to keep solid parts from touching.

Air pressure exploits air pressure to keep solid parts from touching.

Combinations of these can even be employed within the same bearing. An example of this is where the cage is made of plastic, and it separates the rollers/balls, which reduce friction by their shape and finish.

Loads

Bearing design varies depending on the size and directions of the forces that they are required to support. Forces can be predominately radial, axial (thrust bearings), or bending moments perpendicular to the main axis.

Speeds

Different bearing types have different operating speed limits. Speed is typically specified as maximum relative surface speeds, often specified ft/s or m/s. Rotational bearings typically describe performance in terms of the product DN where D is the mean diameter (often in mm) of the bearing and N is the rotation rate in revolutions per minute.

Generally there is considerable speed range overlap between bearing types. Plain bearings typically handle only lower speeds, rolling element bearings are faster, followed by fluid bearings and finally magnetic bearings which are limited ultimately by centripetal force overcoming material strength.

Play

Some applications apply bearing loads from varying directions and accept only limited play or "slop" as the applied load changes. One source of motion is gaps or "play" in the bearing. For example, a 10 mm shaft in a 12 mm hole has 2 mm play.

Allowable play varies greatly depending on the use. As example, a wheelbarrow wheel supports radial and axial loads. Axial loads may be hundreds of newtons force left or right, and it is typically acceptable for the wheel to wobble by as much as 10 mm under the varying load. In contrast, a lathe may position a cutting tool to ±0.002 mm using a ball lead screw held by rotating bearings. The bearings support axial loads of thousands of newtons in either direction, and must hold the ball lead screw to ±0.002 mm across that range of loads

Stiffness

A second source of motion is elasticity in the bearing itself. For example, the balls in a ball bearing are like stiff rubber, and under load deform from round to a slightly flattened shape. The race is also elastic and develops a slight dent where the ball presses on it.

The stiffness of a bearing is how the distance between the parts which are separated by the bearing varies with applied load. With rolling element bearings this is due to the strain of the ball and race. With fluid bearings it is due to how the pressure of the fluid varies with the gap (when correctly loaded, fluid bearings are typically stiffer than rolling element bearings).

Service life. Fluid and magnetic bearings

Fluid and magnetic bearings can have practically indefinite service lives. In practice, there are fluid bearings supporting high loads in hydroelectric plants that have been in nearly continuous service since about 1900 and which show no signs of wear.

Rolling element bearings

Rolling element bearing life is determined by load, temperature, maintenance, lubrication, material defects, contamination, handling, installation and other factors. These factors can all have a significant effect on bearing life.

For example, the service life of bearings in one application was extended dramatically by changing how the bearings were stored before installation and use, as vibrations during storage caused lubricant failure even when the only load on the bearing was its own weight; the resulting damage is often false brinelling.

Bearing life is statistical: several samples of a given bearing will often exhibit a bell curve of service life, with a few samples showing significantly better or worse life. Bearing life varies because microscopic structure and contamination vary greatly even where macroscopically they seem identical [27].

The service life of the bearing is affected by many parameters that are not controlled by the bearing manufacturers. For example, bearing mounting, temperature, exposure to external environment, lubricant cleanliness and electrical currents through bearings etc. High frequency inverters can induce currents in a bearing, which can be suppressed by use of ferrite chokes.

2.2 Bearing life calculation

Bearings are often specified to give an "L10" life (outside the USA, it may be referred to as "B10" life.) This is the life at which ten percent of the bearings in that application can be expected to have failed due to classical fatigue failure (and not any other mode of failure like lubrication starvation, wrong mounting etc.), or, alternatively, the life at which ninety percent will still be operating. The L10 life of the bearing is theoretical life and may not represent service life of the bearing.

Normal L10 bearing life calculated by formula 2.1.

$$L10 = \frac{10^6}{60n} (\frac{C}{P})^p \tag{2.1}$$

Advanced L10 bearing life calculated by formula 2.2.

$$L10 = a_{ISO} \frac{10^6}{60n} (\frac{C}{P})^p \tag{2.2}$$

where L10-basic rating life,hours

n – shaft speed,rpm

C – basic dynamic load rating,N

P – equivalent dynamic boarding load,N

p – exponent of the life equation

aISO – advanced life factor

Bearings are also rated using *C0* (static loading) value. This is the basic load rating as a reference, and not an actual load value.

Plain bearings

For plain bearings, some materials give much longer life than others. Some of the John Harrison clocks still operate after hundreds of years because of the lignum vitae wood employed in their construction, whereas his metal clocks are seldom run due to potential wear.

Flexure bearings

Flexure bearings rely on elastic properties of material. Flexure bearings bend a piece of material repeatedly.

Some materials fail after repeated bending, even at low loads, but careful material selection and bearing design can make flexure bearing life indefinite.

Short-life bearings

Although long bearing life is often desirable, it is sometimes not necessary. Harris 2001 describes a bearing for a rocket motor oxygen pump that gave several hours life, far in excess of the several tens of minutes life needed.

Composite bearings

Depending on the customized specifications (backing material and PTFE compounds), composite bearings can operate up to 30 years without maintenance.

Oscillating bearings

For bearings which are used in oscillating applications, customized approaches to calculate L10 are used.

The working principle of the bearing is to minimize the friction between machine parts that behave in different ways such as two different speeds, opposite directions, or a rotating surface and a fixed surface.

Although can't be perceived by the eye, the roller or the balls in the bearing goes through a deformation at micron level, which occurs when their rigidity is determined based on specific speeds and specific loads. With these forces, the balls and the rollers, which normally apply linear or point pressures, apply force to a much wider surface instead of having linear or point contact , that is, they create friction by spreading over a certain area, thereby providing rotation of the balls within the bearing. All bearings must be operated with a slight force.

There is no specific rules for bearing selection, and each designer can use different bearings on the same machines. The important thing is to meet the working conditions.

For this reason, the following primary features should be considered :

– Axial and radial (vertical to the axis) load

– Operating speed

– Operating time

– Bearing life expectancy

– Lubrication type

– Selection of sealing materials

– Operating temperature

– Noise level

– The amount of vibration during operation

– Type of assembly

Most of the designers and engineers in our country are choosing bearings based on inner diameter, outer diameter and load. This leads to serious mistakes. Instead of calculating values such as design load, life expectancy and temperature, it is now possible to find these values in the catalog of each company.

Equivalent dynamic load (P)

The resultant force of radial and axial loads is the main factor that determines life expectancy of the bearing.

In bearing literature, resultant force is called. Equivalent dynamic load (P), and its formula is

$$P(N) = Fr \times \cos\beta + Fa \times \sin\beta, \quad (2.3)$$

The values of sinβ and cosβ vary based on the type and size of the bearing and these are given as the coefficients of *X* and *Y*. Thus;

$$P = X \times Fr + Y \times Fa \quad , \quad (2.4)$$

If *Fa* is below a certain value, the second term is assumed to be 0 and the formula changes to

$$P = X \times Fr, \quad (2.5)$$

Whether the value of Fa is to be taken into consideration is determined by the coefficient of "e" given in the catalog.

If Fa / Fr> e ,than formula 2.6 is used:

$$P = X \times Fr + Y \times Fa, \quad (2.6)$$

where : P-equivalent dynamic load,N

Fr-radial load,N ; Fa-axial load,N

X-radial load factor; Y-axial load factor

The calculated equivalent dynamic load (P) is the main parameter used to calculate the bearing life expectancy

Equivalent static load (P0)

The "dynamic load number (C)" used in the calculation of life expectancy is obtained from the table for the corresponding bearing in the catalog. In the tables, a "static load number (C0)" is given along with C.

The static load number (C0) is taken into account in situations when the rpm of the bearings is very low, the bearing shows slow oscillation movement, the bearing is under a load while being motionless, and most importantly when the bearing will be subjected to shock impacts. In these cases, the factor that determines the bearing performance is not the fatigue, but the permanent deformation caused by the static load [28]. This deformation causes increased noise, vibration and friction in the bearings. In order to ensure that the ball bearing operates without reaching the low performance limit, the static equivalent load P0 (N) to be used in the calculations, is calculated with the following formulas.

$$P0 = X0 \times Fr + Y0 \times Fa, \tag{2.7}$$

$$C0 = s0 \times P0, \tag{2.8}$$

$$s0 = C0/P0, \tag{2.9}$$

where $C0$-static load number is taken from the respective bearing catalog.

$s0$-static safety factor

$X0=0,6,Y0=0,5$-are provided on the relevant pages of the bearing special catalog.

The required ratio between static load number C0 and the equivalent static load P0 is provided in the s0 static safety factor table.

2.3 Bearing vibration diagnostics

A unique complex for vibration diagnostics of rolling bearings, developed in conjunction with the largest manufacturer of rolling bearings - European Bearing Corporation (EBC).

The СП-180М complex allows you to measure the vibrational characteristics of bearings at a given load and speed (figure 2.1 and 2.2).

Using the complex of vibration diagnostics of bearings СП-180М allows to identify faults and defects of bearings: defects of the outer and inner rings of the bearing, rolling elements, cage [29]. Using an additional module allows you to measure the value of the radial clearance

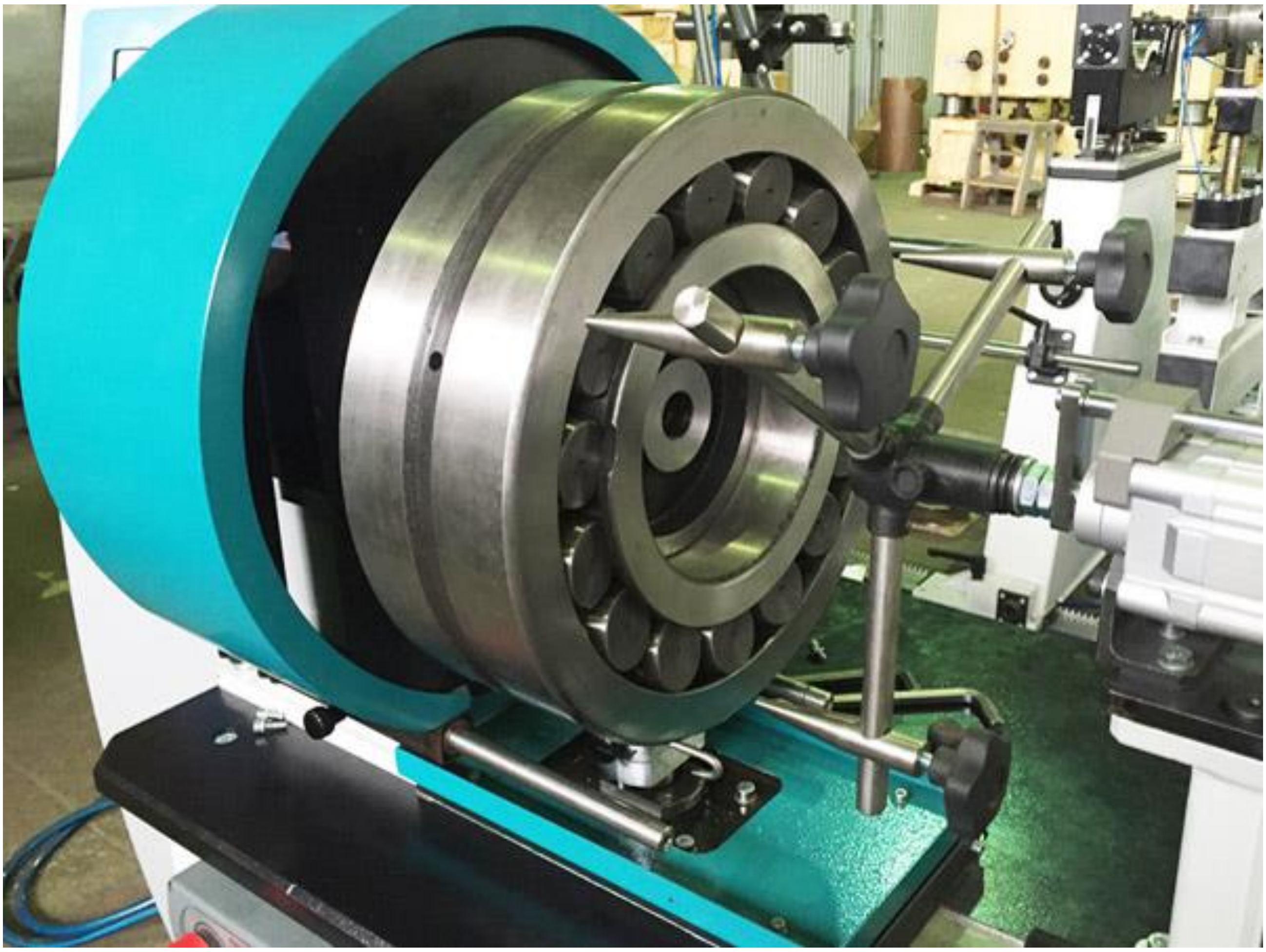


Figure 2.1 – Stand of incoming inspection of bearings СП-180М

Features :

– Automatic control of the drive rotation of the bearing.

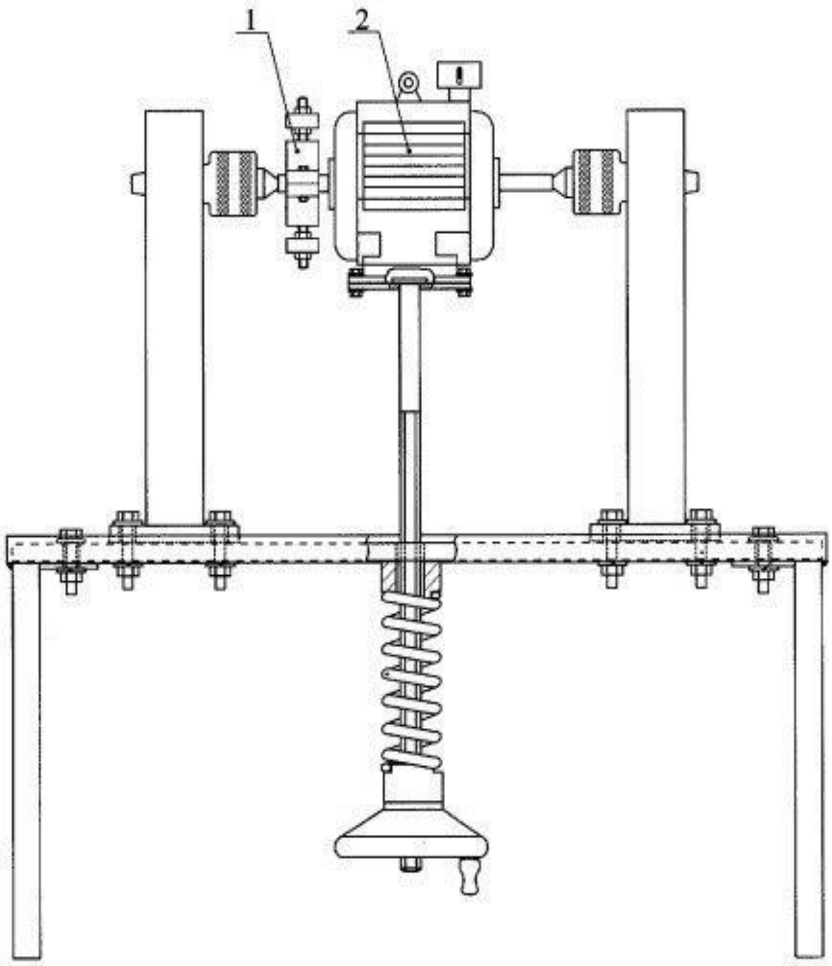
– Automatic control of the size and type of test loads.

– Measurement of vibration and obtaining a qualitative and quantitative assessment of the technical condition of the bearing.
– Bearing vibrodiagnostics mode, in which analysis functions are used: direct spectra of speed and acceleration, envelope spectra, peak factor, excess, 1/3 octave filters. Using these functions, it is possible to determine geometric errors that lead to increased vibration: waviness of bodies and raceways, high roughness of contacted rolling surfaces, separator defect, etc.
– Statistical processing of the measurement results, the formation of levels of permissible vibration in the batch of tested bearings.
– Formation of test reports of bearings, with the ability to save in text form and print.
– Bearings database with manufacturers standards. Saving measurement results in a database for archiving, analysis and protocol generation.

Figure 2.2– Stand of incoming inspection of bearings СП-180М (DIAMECH 2000)

2.4 Stand for testing of bearings for durability

The invention relates to the field of electrical engineering and can be used in industry and agriculture for bench testing of bearings of electric motors (figure 2.3). The durability test bench for electric motor bearings contains a frame with an opening for the passage of the rod of the tensioning device, racks with rotating centers fixed in them, and the tested electric motor. An eccentric is mounted on the shaft of the tested electric motor, which consists of two plates that are fastened together and have cutouts on the inside, into which the inserts are placed. On the outside, threaded rods are attached to the plates, on each of which a balancing element is strung, the position of which can be fixed. Effect: creation of an adjustable rotating radial load acting on bearings of an electric motor shaft, adaptability to testing electric motors of various sizes



1 – cam; 2 – electric motor

Figure 2.3 – General view of the durability test bench for electric motor bearings

The stand provides testing of bearings of the electric motor at constant values of the radial load .

The disadvantages of this stand are the following:

1. The stand does not allow to create a purely radial load on the bearings of the horizontal electric motor under test, therefore the compliance of bench tests with operating conditions is violated;

2. The stand is not suitable for testing electric motors of various sizes;

3. The stand does not provide smooth regulation of the load on the bearings of the tested electric motors of various sizes;

4. The stand does not allow to create the same radial load on the bearings of the tested electric motor mounted on both ends of the shaft;

5. The stand during operation has a high noise level due to the design of the tensioner.

The closest in technical essence and the achieved effect to the proposed technical solution is a stand for testing the bearings of electric motors for durability, containing a frame with an opening for the passage of the rod of the tensioning device, racks with rotating centers fixed in them, and the tested electric motor.

The objective of the present invention is to expand the functionality of the stand.

The problem is solved in the stand for testing the bearings of electric motors for durability, containing a frame with an opening for passing the rod of the tensioner, racks with rotating centers fixed in them and the tested electric motor, by installing eccentrics on the shaft of the tested electric motor to create a rotating radial load.

An eccentric mounted on the working end of the shaft allows you to create a rotating radial load and thereby expand the functionality of the bench.

The eccentric is made in the form of two symmetrical plates. On the inside of each of the plates there are semicircular cuts into which the inserts are placed.

On the outside, threaded studs are pressed into each of the plates. On the studs are strung balancing elements fixed on both sides with locknuts.

According to the information available to the authors, the set of essential features characterizing the essence of the claimed invention is not known from the prior art, which allows us to conclude that the invention meets the criterion of "novelty."

According to the authors, the essence of the claimed invention does not follow explicitly from the prior art for a specialist, since it does not reveal an effect on the obtained technical result - the creation of an adjustable rotating radial load acting on the bearings of an electric motor shaft, adaptability to testing electric motors of various sizes - a combination features that distinguish from the prototype of the claimed invention, which allows us to conclude that it meets the criterion of "inventive step" .

The set of essential features characterizing the essence of the invention, in principle, can be repeatedly used in industry and agriculture to obtain a technical result consisting in mounting eccentrics at different ends of the motor shaft, ensuring the achievement of the goal – expanding the functionality of the stand, creating an adjustable rotating radial forces on the shaft bearings of the tested electric motor, which allows us to conclude that invention, the criterion of "industrial applicability".

The invention is illustrated by drawings: figure 2.3 – General view of the stand for testing the bearings of the electric motor for durability and figure 2.4 – design of the eccentric.

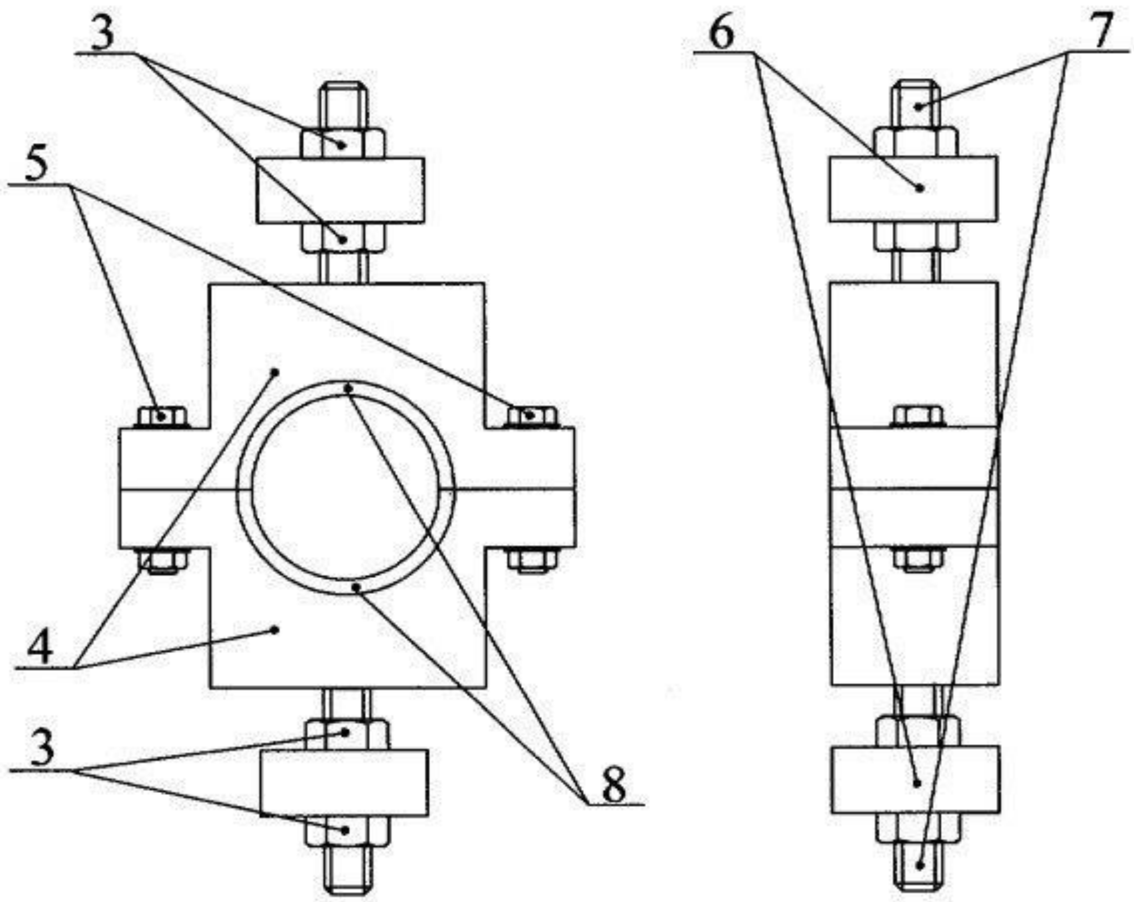
Before starting work with the stand, it is necessary to establish the required rotating radial force. Setting a given value of the rotating radial force is as follows.

The value of a given rotating radial load is determined by calculation, depending on the frequency of rotation of the shaft of the tested electric motor 2 and the distances from the balancing elements 6 to the axis of rotation.

The eccentric 1 is mounted on the shaft of the tested electric motor 2 using bolted connections 5.

The eccentric 1 consists of two plates 4, having semicircular cutouts on the inside, into which the liners are placed 8. On the outside, threaded rods 7 are pressed into each plate. A balancing element 6 is strung on each hairpin 7, fixed on both sides with locknuts 3. For testing electric motors of various powers, a set of bushings 8 is provided in accordance with the shaft diameter.

The plates 4 are mounted on the working end of the shaft of the tested electric motor 2 by bolt joints 5. By moving the balancing elements 6 along the studs 7, the necessary distance is established from the balancing elements 6 to the axis of rotation of the shaft of the tested electric motor 2. The position of the balancing elements 6 is fixed with locknuts 3.



3 – locknut; 4 – plate; 5 – bolted connection; 6 – balancing element; 7 – studs; 8 – liners

Figure 2.4 – Design of the eccentric

Installing an eccentric on the working end of the shaft of the tested electric motor allows you to simulate a rotating radial load and thereby expand the functionality of the bench.

1. A test bench for durability of electric motor bearings, comprising a bed with an opening for the passage of the tension device rod, racks with rotating centers fixed in them, and a test motor, characterized in that an eccentric is mounted on the shaft of the

test motor, which consists of two plates fastened between themselves and having cutouts on the inside, into which the inserts are placed, and on the outside, threaded rods are attached to the plates, on each of which is balanced element, the position of which can be fixed.

2. The stand according to claim 1, characterized in that the plates on the shaft of the tested electric motor are mounted using bolted connections.

3. The stand according to claim 2, characterized in that the cutouts on the inner sides of the plates have a semicircular shape.

4. The stand according to claim 3, characterized in that the studs are pressed into the base.

5. The balancing element on the pin is fixed using two control elements.

Conclusion to part 2

The bearing is essentially a planetary mechanism in which the carrier is a cage, the inner and outer rings perform the functions of the central wheels, and the satellites replace the rolling bodies.

The working principle of the bearing is to minimize the friction between machine parts that behave in different ways such as two different speeds, opposite directions, or a rotating surface and a fixed surface.

Although can't be perceived by the eye, the roller or the balls in the bearing goes through a deformation at micron level, which occurs when their rigidity is determined based on specific speeds and specific loads.

We considered a unique complex for vibration diagnostics of rolling bearings, developed in conjunction with the largest manufacturer of rolling bearings – European Bearing Corporation (EBC).

Provided a new development for the calculation of bearings on a special stand.

The disadvantage of this stand is that it does not allow simulating a rotating radial load on the working end of the shaft of the tested electric motor, which occurs in operating conditions when transmitting torque from the engine to the working machine using a mechanical coupling. This limits the capabilities of the stand and its scope.

3 DEVELOPMENT OF METHODS FOR TESTING SPHERICAL BEARINGS

3.1 Modernization of materials testing methodology for fretting corrosion

To test articulated bearing type ШН, ШМ, ШС and small size is necessary to modernize the existing method of testing materials to fretting corrosion in accordance with ГОСТ 23.211-80.

Performing research in fretting and fretting corrosion features a large variety of used techniques on the circuit load and type of contact, and in the evaluation of surface damage. Choose the method should be in accordance with the two basic requirements :

1. Imitation fretting corrosion in the laboratory should approach the maximum conditions of this type of fracture surface in real structures.
2. The method chosen should be such that you can zpivstavyty obtained results with those of other works.

By testing devices, due to the specific origin of fretting and fretting corrosion, meet the following requirements:

1) free from backlash mounting samples in clamping devices;
2) rigidity to torsion and low deformation device;
3) if vibro- movement adjustable frequency and amplitude;
4) the availability of controlled normal force to establish the necessary contact pressure;
5) the ability to supply lubricant or other medium.

Different types of contact have advantages and disadvantages. The disadvantages of plane-contact area include dissimilar conditions work wear lots of samples because their amplitude movements at this circuit is directly proportional to the distance from the axis of rotation. This shortcoming is eliminated by the choice of optimal geometry of one of the samples. In other types of contact is uneven pressure distribution in the contact area, which leads to different conditions of wear.

The choice of a flat ring contact and adjustable-contact surfaces of rotational motion due to the need to control the normal load and eliminating East regional effect.

The basis of the accepted methods of work, established a comprehensive study of qualitative parameters of friction trybopar. Scheme contact plane-plane type used at the facility, МФК - 1 (ГОСТ 23.211-80), a general view of which is shown in Figure 3.1.

Figure - 3.1 Outward of settings МФК-1 testing at fretting corrosion

The main advantages of the method are:

1) the possibility of rapid assessment of the durability of materials and coatings in terms of fretting corrosion;

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

3) simplicity of the method and appropriate equipment;

4) the possibility of stepless frequency control, normal load and amplitude mikroperemischen;

5) testing using plastic and liquid lubricants;

6) registration friction force during testing.

The method consists in the fact that moving cylindrical sample (control specimen) in contact with the real end face of the cylindrical sample at a given pressure adjustable-driven rotational movement of desired amplitude and frequency. Measured wear real sample for a specified number of cycles is determined by the value of which durability of the material.

The experimental setup is shown in Figure 3.2. Installation is as follows: 2 electric motor transmits rotary motion of the eccentric 3 with adjustable eccentricity. Speed and number of revolutions registered device 1. Eccentric rod 3 through 4, 6 scenes associated with the drive shaft 7 adjustable-rotational motion control specimen 8. The amplitude of movement control specimen 8 adjustable eccentric device 3 and 5. Fixed sample 9 is fixed in the collet 10, which centered installed on movable shaft grandmother 11. Load samples carried dynamometer 14 and loading device 15. The value of the axial load on the samples recorded by dynamometer ЗІП 02-79 3-0,2-type ДОСМ-3-0,2 (ГОСТ 2283–79) with a limit of measurement from 0.2 to 2 kN. Join forces rubbing held device 13 through the amplifier 12 with a help of tenzobeam 11. Number of test cycles controlled by the meter installed on the front of the installation.

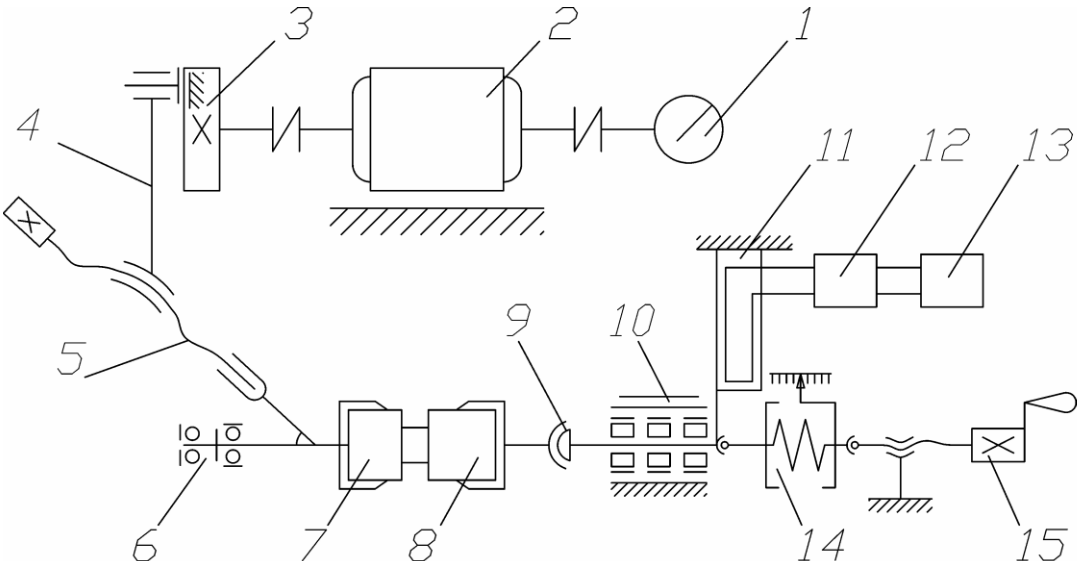
The amplitude is regulated by changing the eccentricity of the eccentric (roughly) and change the length of the horizontal arm connecting rod (exactly). Rough amplitude adjustment allows you to change its size from 10 to 1000 microns, precision - from 5 to 15 microns. The amplitude of the relative movement is defined as the difference amplitude vibrations of movable and immovable samples. Measuring the amplitude is performed directly on samples using an optical binocular microscope МБС -2 (an increase of 8 to 56 krat) using a stroboscopic effect (strobe ТСТ-100).

Installation allows testing with the following parameters:

- Load samples in the axial direction by the 200 - 5000 N;

- Swing-counter rotational movement of the sample on real sample rate of 10 - 30 Hz and amplitude of 10 - 1000 microns;

- Measuring system installation provides continuous testing in the registration number of cycles adjustable-rotational motion control specimen error of not more than 50 cycles.



1 - counter revolutions; 2 - electric; 3 - eccentric; 4 - vertical rod; 5 - pidstroyechnyy device; 6 - horizontal rod; 7 - rolling sample; 8 - stationary design; 9 - samoorentuyucha collet; 10 - moving grandmother; 11 - tenzobem; 12 - amp; 13 - registering apparatus; 14 - dynamometer; 15 - loading device.

Figure - 3.2 Scheme of МФК-1

So modernization installation МФК-1 include:

1. Change settings for eccentric increasing amplitude sufficient resources to test articulated bearing diameters of 6, 8 and 10 mm.

2. Change the unit load to increase axial loading of 500 kg.

3. Making clips to hold the specimens in the resource tests.

4. Slow sliding bearings 1 - 2 cobs per second. Achieved installing additional reducer and increase the flow of cooling the electric motor.

The main objective is making modernizuvannya installation drawings are special clips presented on fig 3.3 - 3.4.

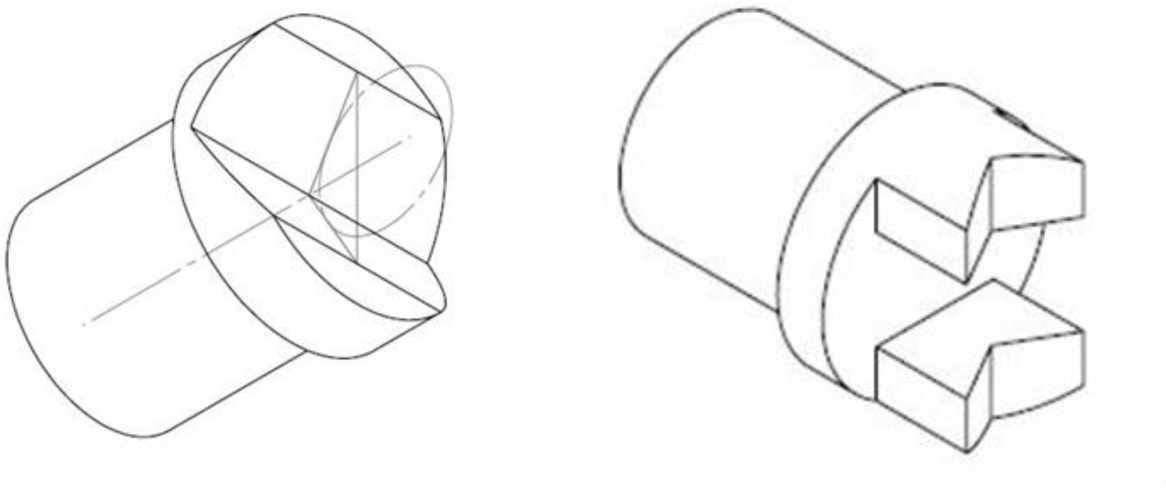


Figure - 3.3 Prisms for resource testing of spherical plain bearings on МФК

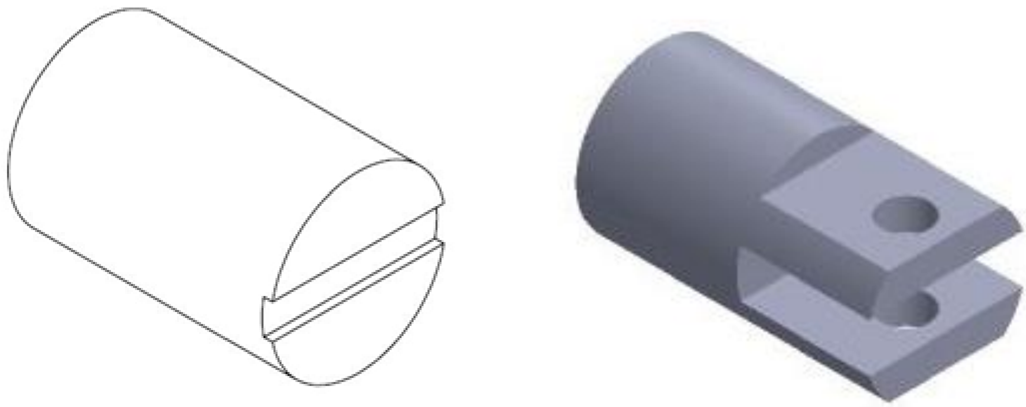


Figure - 3.4 Prisms for resource testing of spherical plain bearings on МФК

Clamps allow to reliably hold the hinge bearings in the resource test and hold them fast replacement (fig. 3.5)

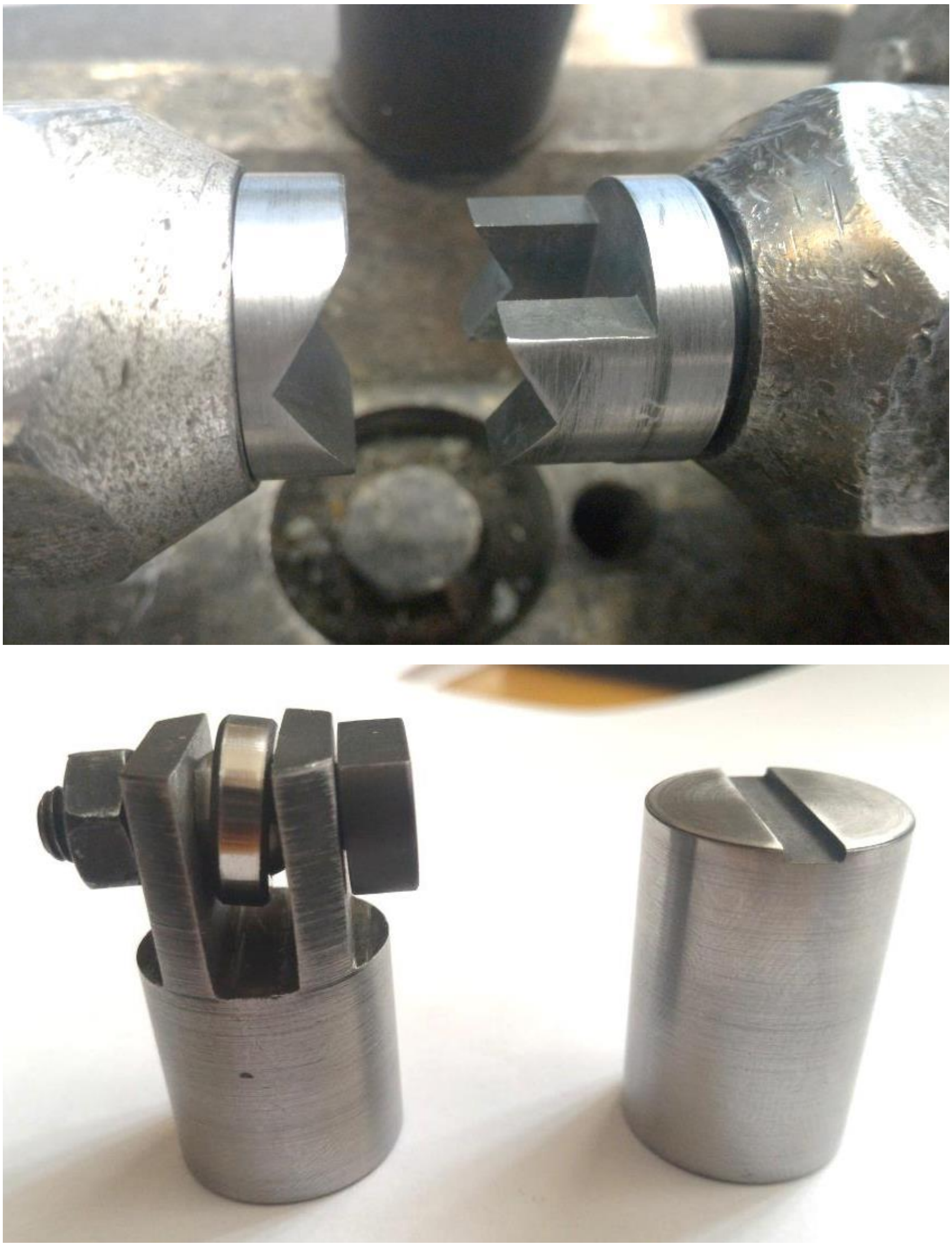


Figure - 3.5 Clips to hold the spherical plain bearings

3.2 Installation for hinge tests bearings

To test articulated bearings with a diameter of 12 to 30 mm to apply the setting that simulates the special conditions of bearings in a wide range of loads.

The experimental setup is shown in Fig. 3.6 and Figure 3.7. Installation allows you to test the hinge bearing friction in terms of reversing the radial load of up to 100 thousand N. The pressure is set and controlled by a hydraulic jack in the test resource via manometer. The angle at which shifts bearing adjusted by means of hinges and wheels, fitted to the motor and gear is 15 to 90 degrees. Speed Test is from 1 to 5 Plug in a second. The speed can be changed by changing the rotation speed of the electric motor.

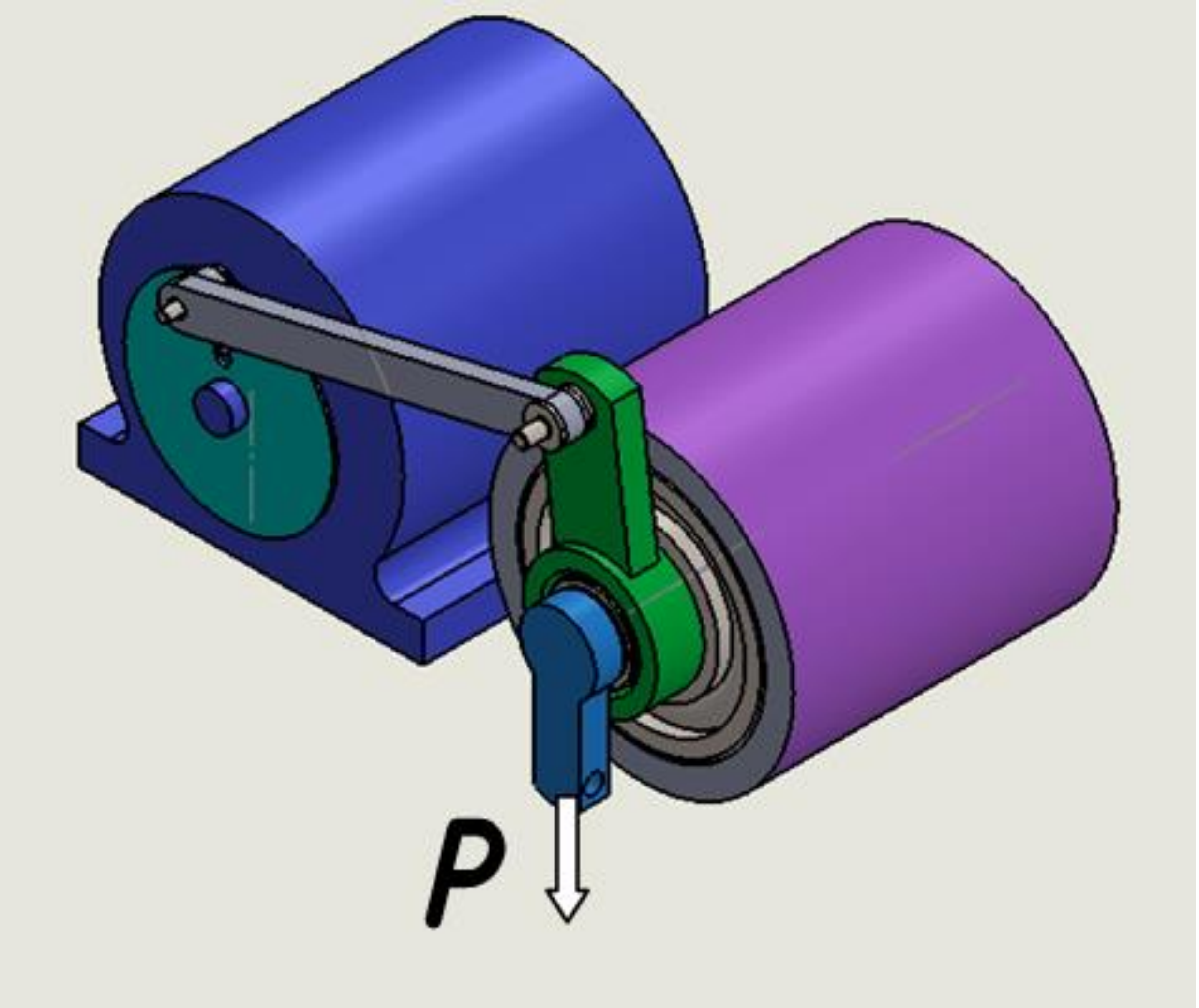


Figure - 3.6 Scheme of installation of spherical plain bearings till 20 ton

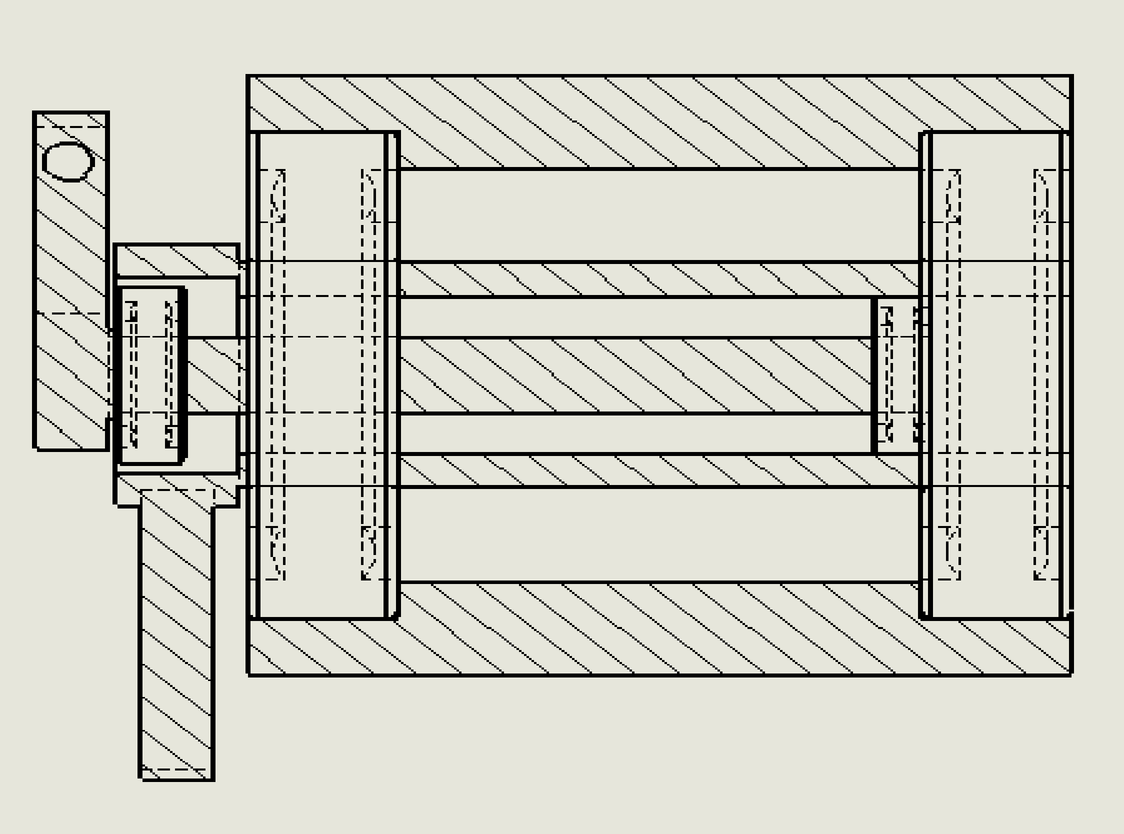


Figure - 3.7 The scheme of basic units for loading and securing the hinge bearings

The specific feature of these tests is that for every bearing size should make the transition sleeve. At high loads, we need to keep firmly articulated bearings node installation. So testing bearings with a diameter of 12 mm to 30 special transition should produce plugs for every size. Also to withstand significant loads during testing bearings diameters up to 30 mm from 20 should make the transition shaft. To test bearing 35 mm shaft should make the transition for that size.

So to test resource hinge bearings in sizes from 12 to 35 mm is necessary:

1. The engine-gearbox power of 0.5 kW and constant or variable rotations from 60 to 300 cyc / min.

2. Hydraulic jack capacity of 8 - 10 tons with manual transmission and to control and gauge the possibility of changing load.

3. Set transition sleeves each bearing size ranging from 12 mm.

4. Inner shaft for retaining the bearing unit. For sizes 12 to 17 mm.

5. Transition holding shaft for tests bearing diameter 35 mm.

6. Drive specifying the range of fluctuations in the tests.

7. Bracket for transmitting vibrations from the gearbox to the device that holds the bearings.

8. Bracket internal load bearing cage.

9. Support bracket. It is used to secure the bracket to the frame installation.

10. Bolts for connection brackets.

The engine-gearbox coaxially recommended dvuhstupenevyy motor-reducer series МЦ2С-63 and МЦ2С-80 or similar with similar characteristics. Hydraulic jack type recommended butylochnoho ДГС -10.

Tests should be conducted in the following conditions:

1. Base tests for all types of bearings defined in 100 thousand cycles. If necessary test base can be changed in the coordination of the parties.

2. Lubrication - ЭРА. (Lubricant is applied once before the trial).

3. Assessment of damage - controlled axial clearance at 100 thousand cycles. Also determined fatigue chipping contact surfaces of bearings.

4. Speed of slide 1 to 5 plug a second. (Determine the type of installation testing).

Conclusions to part 3

So, the physical dimensions, material and hardness hinge bearings controlled by the ISO 12240 та ЕТУ-100. Load, lubrication, criteria for assessing the damage and the number of test cycles determined by the requirements of СТП651.02.061-92 та ГОСТ 3635-78.

Test resource hinge bearings up to 10 mm using the modernized plant for testing at fretting corrosion in accordance with ГОСТ 23.211-80.

Test bearings in sizes from 12 to 35 mm should use the setting that allows testing at loads up to 10 thousand N.

4 LABOUR PRECAUTION

4.1 Introduction to part 4

The use of such equipment is associated with a number of harmful factors, such as radiation from displays, noise from engineering equipment, high levels of electromagnetic radiation, etc.

Work on the manufacture of bearings is carried out in specialized workshops and factories equipped with machine tools, machine tool and computerized laboratory equipment [40].

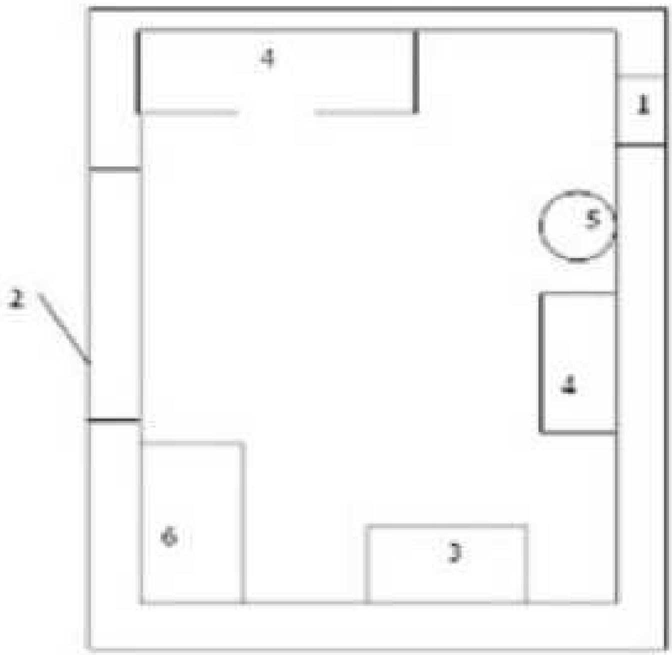
Rules for ensuring labor protection are mandatory for all modern enterprises, regardless of the type of activity and scale of the organization. Labor protection is a system of socio–economic, legal, organizational, technical, rehabilitation, preventive and sanitary–hygienic measures aimed at ensuring the safety of health and life of employees while they are at the workplace.

The presence of an effective OSH management system is a prerequisite for the full functioning of any company, since it allows for risk management in this area.

4.2 Analysis of working conditions

Work on the analysis of orders and the correction of the transportation of articulated bearings should be performed in specialized laboratories or computing centers equipped with electronic computers (computers) with specialized software and computerized laboratory equipment [41]. The use of such equipment is associated with the effects of several harmful factors, such as radiation from displays, noise from laboratory equipment, high levels of electromagnetic radiation, etc.

Let us analyze the main harmful factors that arise when testing and adjusting files in a laboratory (when working on a personal electronic computer) and also when working with machines and machines figure 4.1)



1 – entrance; 2 – window; 3 – grinding machine; 4 – workbench; 5 – host computer; 6 –drilling machine

Figure 4.1 – Scheme of the working room of the engineer

The production area and equipment are schematically shown here. List the purpose of all the above designated equipment:

– workbench: used to cut metal parts of the required size;

– grinding machine: the machine has a grinding disc as a tool; it cleans the surface of the bearing parts from the oxide film according to the program;

– machine for drilling and drawing outline drawing: the machine has one tool for performing these 2 operations;

– host computer: controls all the machines, issues information to the information monitor, and is also used by the engineer to perform all operations with an order.

4.3 List of harmful and dangerous production factors

At the workplace of the engineer, during the performance of the work there are harmful and dangerous production factors, which cause a negative impact on both the employee and the quality of work.

Noise

The noise of the sound range leads to a decrease in attention and an increase in errors when performing various types of work. Noise slows down the response of the person to the signals coming from the technical devices. Noise depresses the central nervous system (CNS), causes changes in the rate of respiration and pulse, promotes metabolic disorders, the occurrence of cardiovascular diseases, gastric ulcers, hypertension. Exposure to high levels (more than 140 dB) may result in rupture of the eardrums, contusion, and even higher (more than 160 dB) death.

Maximum permissible noise levels in workplaces are set taking into account the severity and intensity of work activities (according to ДСН 3.3.6.037–99 « Sanitary standards for industrial noise, ultrasound and infrasound» [42]. For the main most typical types of work and jobs are presented in Table 4.1.

Table 4.1 – Acceptable sound pressure levels, sound levels and equivalent sound levels.

Type of work activity, workplace	Sound pressure levels, dB, in octave bands with geometric mean frequencies, Hz									Sound levels, equivalent sound levels, dBA
	31,5	63	125	250	500	1000	2000	4000	8000	
Scientific activity, designing and designing. Jobs of design bureaus, designers	86	71	61	54	49	45	42	40	38	50

The noise level of a modern PC is 35… 50 dBA. Consider the noise from one computer used to perform design tasks at 45 dBA.

Additional noise sources are street noise (45 dBA) and air conditioning noise – 26… 36 dBA.

We conclude that the noise level is within the remote control. Therefore, the workplace of a structural engineer can be attributed to the harmful class of working conditions 2.

Microclimate effect

Optimal microclimatic conditions are established according to ДСН and rules «Hygienic classification of labor by indicators of harmfulness and danger of factors of production environment, severity and intensity of work process» [43]. They provide a general and local feeling of thermal comfort with minimal stress on the mechanisms of thermoregulation, do not cause deviations in health, create prerequisites for high levels of performance and are preferred in the workplace.

With prolonged operation of computers and their peripheral equipment in the workplace, heat is released. Overheating of the environment adversely affects the person.

The relative humidity, which is included in the concept of effective temperature, also has a significant effect on humans. For example, very high relative humidity causes the body to overheat, and too low causes a dry sensation of the mucous membranes of the upper respiratory tract. The optimum values of relative humidity are in the range of 40 ... 60.

The air velocity should not exceed 0.1 m / s at a temperature of 21..25 °C in the cold and warm season and relative humidity of 40..60%.

In order to maintain acceptable microclimate parameters, the room must be equipped with a heating and air conditioning system. District heating systems are used for space heating. The temperature on the surface of the heating appliances must not exceed 95 °C to eliminate dust burning.

The temperature, humidity, air velocity at the engineer's workplace must be as shown in Table 4.2.

Table 4.2 – Temperature, humidity, air velocity at the engineer's workplace.

Period of the year	Category of works	Air temperature, °C	Relative humidity,%	Air velocity, m/s
Cold	Ia	22–24	60–40	0,1
	Ib	21–23	60–40	0,1
Warm	Ia	23–25	60–40	0,1
	Ib	22–24	60–40	0,1

The categories of work are distinguished on the basis of the intensity of energy consumption of the organism in kcal / h (W).

Category Ia includes works with an intensity of energy consumption up to 120 kcal / h (up to 139 W), produced by sitting and accompanied by insignificant physical stress (a number of professions in the enterprises of precision instrumentation and mechanical engineering, hourly, garment industries, in the sphere of management, etc. .).

Category Ib includes work with an intensity of energy consumption 121 – 150 kcal / h (140 – 174 W), made sitting, standing or associated with walking and accompanied by some physical stress (a number of professions in the printing industry, communication enterprises, controllers, masters in various types of production, etc.).

All rooms must have natural mechanical or mixed ventilation. Air conditioning devices are required. Air conditioning provides:

– air purification from dust and harmful fumes and gases;
– small excess pressure to prevent contaminated air from entering;
– automatic maintenance of temperature and relative humidity.

Thus, maintaining the temperature and relative humidity of the air within the appropriate limits through a system of centralized heating, ventilation and air conditioning allow to provide a production microclimate corresponding to the permissible class of working conditions 2.

Light environment

With any type of lighting, it is necessary to monitor the uniformity of illumination of the workplace. Otherwise, in case of uneven illumination, the transfer of gaze from a more illuminated area to a less illuminated one, or vice versa, will cause the user to narrow and dilate the pupil. This leads to eye muscle tension and general fatigue according to ДБН Б.2.5.56–2018 [44].

Indoor lighting is mixed (natural and artificial). Artificial lighting should be carried out in the form of a combined lighting system (general and local lighting of the workplace) using fluorescent light sources. The amount of illumination during artificial lighting with fluorescent lamps should be in a horizontal plane not lower than 300 lux for a general lighting system and not lower than 750 lux for a combined lighting system .

Natural lighting should be provided through light openings oriented mainly to the north and northeast and provide NLC of not less than 1.2% in areas with stable snow cover, and not less than 1.5% in the rest of the territory. All working rooms should have a sufficient amount of natural light, the equipment is placed perpendicular to the window, light should fall on the operator on the left side.

For interior decoration of the interior of the room must be used diffusely reflective materials, with a reflection coefficient for the ceiling – 0.7 – 0.8; for walls 0.5 – 0.6; for the floor 0.3–0.5.

Artificial lighting in the premises of the PC should be carried out by a system of uniform lighting. In cases of predominant work with documents, the use of a combined lighting system is allowed. Illumination on the table surface should be 300–500 lux. Local lighting should not create glare on the surface and increase the brightness of the screen by more than 300 lux.

Direct brilliance should be limited, while the brightness of luminous surfaces (windows, lamps, etc.) in the field of view should be no more than 200 cd / m2. There are also restrictions on the reflected brilliance, while the brightness of the glare on the PC screen should not exceed 200 cd / sq.m. The uneven distribution of brightness is limited, while the ratio of brightness between the working surfaces should not exceed 3: 1–5: 1, and between the working surfaces and the surfaces of the wall of the equipment 10: 1.

As light sources under artificial lighting, mainly fluorescent lamps should be used. It is allowed to use incandescent lamps in local lighting fixtures.

Working rows and walls must be evenly lit, without glare, it is desirable to arrange the rows of fixtures parallel to the wall with light openings. With this arrangement, 1–2 rows of lighting devices fall into the field of view and are viewed along the length. With the transverse arrangement of rows of lighting devices, a lot of transverse stripes fall into the field of view, which, due to the alternation of light and shadow, excite and irritate the eye.

When illuminated with fluorescent lamps, measures must be taken to reduce the pulsation of the luminous flux. The ripple coefficient should not exceed 5%. The following methods are used for this:

– switching on adjacent luminaires for different phases of the alternating current network alternately;

- inclusion of part of the lamps according to the advanced current circuit;
- inclusion of lamps in multi–tube lamps for different phases of the network;
- lamp power with alternating current of increased frequency (from generators 400 Hz).

Conclusion: in the design department premises mixed lighting should be implemented.

The correct arrangement of the artificial lighting system reduces the burden on the employee’s eyes, the class of working conditions is acceptable.

Electrical Safety

Electrical installations, which include almost all computer equipment, pose a great potential danger to a person, since during operation or carrying out preventive maintenance, a person may touch live parts. Specific danger of electrical installations: current–carrying conductors, cases of computer racks and other equipment that have become energized as a result of damage (breakdown) of the insulation do not give any signals that warn a person of danger. The reaction of a person to electric current occurs only when the latter flows through the human body. Extremely important to prevent electrical injuries is the proper organization of maintenance of existing electrical installations, repair, installation and preventive maintenance. Depending on the category of premises, certain measures must be taken to ensure sufficient electrical safety during the operation and repair of electrical equipment.

When performing work on the adjustment of individual units, blocks in electrical installations up to 1000 V, certain technical and organizational measures must be applied, such as: fences located near the workplace and other live parts that may be touched accidentally; work in dielectric gloves or standing on a dielectric rug; use of the tool with insulating handles; in the absence of such a tool, dielectric gloves should be used. Work of this kind must be performed by at least two workers.

The following requirements are imposed to consumers and maintenance personnel of electrical installations: persons under the age of 18 cannot be allowed to work in electrical installations; persons should not have injuries and diseases that interfere with production work; After appropriate theoretical and practical training, persons must pass a knowledge test and have a certificate of access to work in electrical installations.

In computer centers (CC), discharge currents of static electricity most often occur when you touch any of the elements of a computer. Such discharges do not pose a danger to humans, but in addition to discomfort, they can lead to computer failure. To reduce the magnitude of the emerging charges of static electricity in the CC, the coating of technological floors should be made of a single–layer polyvinyl chloride antistatic linoleum. Another method of protection is the neutralization of a charge of static electricity by ionized gas. The general measures of protection against static electricity in the CC include general and local air humidification.

Ventilation of industrial premises: rules for the organization of air exchange

The main work performed by the ventilation of industrial premises is the removal of used air and pumping out fresh. With its help, in the shops and offices of the enterprise create a comfortable air environment that meets regulatory requirements according to ДБН В.2.5–67 Heating, ventilation, air conditioning [45] and ДБН Д.2.6–3–2000 Ventilation and air conditioning systems [46].

It is difficult to overestimate the role of an effective ventilation system. After all, only in conditions of clean air, normal temperature and humidity conditions can one increase labor productivity. To understand how to organize sufficient air exchange in a building, you need to understand the types and features of the operation of various ventilation systems [47].

All existing ventilation systems are grouped by 4 signs:

1. According to the method of moving air, ventilation is called: natural, mechanical or artificial, combined when both options are present at the same time.

2. In the direction of air flow, ventilation systems are divided into supply, exhaust or supply and exhaust.

3. At the place of action, ventilation systems are combined into 3 groups: general exchange, local, combined.

4. By designation, the operating and emergency systems are allocated.

While the processes that occur during natural ventilation depend on the heat and wind pressure and are practically not subject to man, forced air exchange is possible only with his active participation

4.4 Fire protection

Fires in the workplace pose a special danger, as they are associated with large material losses (according to Code of Civil Protection of Ukraine) [48]. A characteristic feature of the CC is the small area of the premises. As you know, a fire can occur during the interaction of combustible substances, oxidation and ignition sources. In the premises of the CC there are all three main factors necessary for the occurrence of a fire.

Combustible components at the CC are: building materials for acoustic and aesthetic decoration of rooms, partitions, doors, floors, cable insulation, etc.

Fire protection is a set of organizational and technical measures aimed at ensuring the safety of people, preventing a fire, limiting its spread, as well as creating the conditions for successful fire fighting.

The ignition sources in the CC can be electronic circuits from computers, devices used for maintenance, power supply devices, air conditioning, where, as a result of various violations, overheated elements, electric sparks and arcs can form that can ignite combustible materials.

In modern computers, a very high density of electronic circuit elements. In the immediate vicinity of each other are connecting wires, cables. When electric current flows through them, a significant amount of heat is released. In this case, melting of the insulation is possible. For the removal of excess heat from the computer are ventilation and air conditioning systems. With continuous operation, these systems pose an additional fire hazard.

One of the most important tasks of fire protection is to protect the premises from damage and ensure their sufficient strength under conditions of high temperatures during a fire (figure 4.2).

During construction, as a rule, brick, reinforced concrete, glass, metal and other non–combustible materials are used. The use of wood should be limited, and if used, it must be impregnated with flame retardants.

Fire extinguishing agents designed to localize small fires include fire barrels, internal fire water pipes, fire extinguishers, dry sand, etc.

In production facilities, carbon dioxide fire extinguishers are mainly used, the advantage of which is high fire extinguishing efficiency, the safety of electronic equipment, and the dielectric properties of carbon dioxide, which makes it possible to use these fire extinguishers even when it is not possible to disconnect the electrical system immediately.

The effectiveness of the use of AFA systems is determined by the correct choice of type of detectors and their installation locations. When choosing fire detectors, it is necessary to take into account the specific conditions of their operation: the features of the room and the air, the presence of fire materials, the nature of the possible combustion, the specifics of the process, etc.

Unexpected explosions and fires in the workplace are frequently caused by risk factors such as faulty gas lines, poor pipefitting, improperly stored combustible materials or open flames. These incidents cause damage to the respiratory system, varying degrees of burns and potential disfigurement.

Explosions and fires in the workplace can be extremely dangerous and you should take the necessary steps to ensure maximum fire safety.

In the premises at the beginning of a fire, various plastic, insulating materials and paper products burn a significant amount of smoke and little heat. The CC objects must be equipped with stationary automatic fire extinguishing installations.

Figure 4.2 – Fire protection system

4.5 Air exchange calculation

If harmful substances are not emitted as a result of production activities, the amount of air required for ventilation is calculated by the formula:

$$L = N \times Ln, \quad (4.1)$$

where: *N*–the number of people usually in the room,

Ln – is the volume of air needed for 1 person, measured in m^3 / h. Normally, it is from 20 to 60 m^3/ h.

Using a parameter such as air exchange rate, the calculation is performed according to the formula:

$$L = n \times S \times H, \quad (4.2)$$

where: *n* – is the air exchange rate in the room (for the production room $n = 2$),

S– is the area of the room in m^2,

H –is its height in m.

Example of calculation

The calculation of the supply ventilation of industrial premises should be carried out according to aggregated indicators that express the flow rate of incoming air per unit volume of the room, per 1 person or 1 source of pollution.

The standards set their own standards for various industries. The formula is as follows:

$$L = Vk \quad (4.3)$$

where: *L*– is the supply air volume in m3 / h,

V–is the room volume in m3,

k–is the air exchange rate.

For a room with an area of $100\ m^3$ and a height of *3* meters for a *3*–fold air change you will need:

$$100 \times 3 \times 3 = 900[m^3\ /\ hour]$$

The calculation of exhaust ventilation of industrial premises is carried out after determining the required volumes of supply mass.

Conclusion to part 4

Health and safety is one of the oldest engineering concerns. Sanitation engineering and public health drastically improved the quality of life amongst ancient peoples, through the construction of aqueducts and sewage drainage systems. Working with machinery can greatly simplify certain tasks, but also leaves room for dangerous workplace accidents. With the Industrial Revolution, machinery became much larger and more complex, and the need for safety became a much more prominent concern. Topics in this category deal with the concern for human safety in and out the workplace and the general well–being and healthiness of the population.

In this part, issues such as calculation of air in the production room, types, classifications of air ventilation are considered and drew attention to fire safety at the workplace

It is very important to comply with all safety rules in the workplace in order to avoid negative consequences.

Only when the most comfortable conditions are achieved, does the coefficient of the employees' working capacity and the quantity of production increase

The human factor in the workplace plays an important role, that's why safety rules are created, adhering to which we protect ourselves and others.

5 ENVIRONMENTAL PROTECTION

5.1 Reduce $C0_2$ emissions from International aviation

The transportation sector is a significant contributor to worldwide CO_2 emissions, accounting for approximately 14 per cent of greenhouse gas (GHG) emissions.8. While international aviation is comparatively a small contributor at 1.3 per cent of all anthropogenic emissions, aviation activities are expected to grow, and the sector recognizes the importance of this projected growth being made environmentally sustainable [49].

These CO_2 emissions are produced by aircraft when in flight and while parked at the gate in between flights. Objectives associated with reducing CO_2 emissions during flight are primarily focused on advancing aircraft technology, improving operational procedures, and developing sustainable aviation fuels as an additive to and potential long-term replacement for existing jet fuels. Aircraft parked at the gate typically power on-board electrical systems and cabin conditioning by running an auxiliary power unit (APU) fired by jet fuel. These CO_2 emissions can be reduced through electrification of aircraft power when on the ground and by developing clean renewable sources of electricity to provide the power. While clean electric gate power can contribute to reducing CO_2 emissions from aircraft operating international flights, it can also decarbonize domestic aircraft gate operations and thus generate co-benefits.

Clean power generation can also be scaled to not only offset gate power, but other electricity loads in the terminal and at the airport as well. Diesel-powered ground support equipment (GSE), such as tugs and baggage handlers, can also be converted to electric power in a similar manner as the gate retrofit. Energy efficiency audits and upgrades can further reduce the airport’s demand for fossil fuel power.

Each ICAO Member State is invited to develop a State Action Plan on CO_2 emissions reduction activities for international aviation, which establishes a CO_2 emissions baseline and identifies emissions reduction measures for future implementation [50]. In developing the Action Plan, Member States can better understand international aviation's share of CO_2 emissions, enhance cooperation among all aviation stakeholders, identify relevant mitigation strategies, streamline policies, enhance stakeholder support, and promote capacity building.

Improve local air quality

Environmental policies to address international aviation CO_2 emissions will have important benefits for mitigating climate change. In addition, the implementation of such policies could also improve the local air quality at and around the airport.

This consideration needs to remain a key component of the airport's environmental policy objectives. ICAO provides guidance and best practices to Member States on issues associated with air quality through Doc 9889, Airport Air Quality Manual. Reconfiguring airport flight corridors to reduce aircraft travel distance and time will improve the overall air quality and reduce noise impacts from arriving and departing aircraft [51]. Electrifying aircraft parked at the gate can also reduce aircraft local emissions occurring on-site and, when combined with a clean energy solution, can also eliminate emission sources more broadly, which may otherwise have been supplied by a fossil fuel power plant. Conversion of fossil fuel powered GSE to an electric source will also eliminate on-site emissions and could represent an environmentally sustainable solution when the electric power is supplied by a renewable energy source.

As part of the development and implementation of State Action Plans, many States plan to implement measures that will also improve local air quality. These measures can support the development of a strong relationship with local communities and allow for further traffic growth, while minimizing environmental impacts.

A key component of a successful aviation environmental policy is the ability to build relevant national capacity. Civil aviation authorities have the primary objective of issuing a set of regulations to allow for the safe, secure and environmentally sustainable growth of the national and international aviation sector. Such regulations apply to all operational stakeholders, aircraft operators, airports [52]. They require multi-disciplinary skills, one of which being in the area of need is in environmental protection.

Capacity building is often necessary to integrate the specific expertise of the aviation industry and the diverse environmental issues that are encountered in international civil aviation. Once an investment has been made to provide this expertise, it can be advanced through training and through broader information transfer [53].

As more civil aviation authorities develop environmental expertise and expand skills in the area of CO_2 emissions reduction, the State, in cooperation with all operational stakeholders will be able to develop and implement CO_2 emissions reduction plans and achieve its environmental goals.

5.2 Airport pollution during aircraft maintenance and emergency situations

A transition from conventional aviation fuels to sustainable aviation fuels (SAF) represents a significant opportunity to reduce emissions from the global aviation sector.

The focus of the aviation industry is on the development of “drop-in” fuels, i.e. fuels that do not require any changes to aircraft or fuelling infrastructure, however the commercial scale implementation of such a measure still requires a considerable amount of coordination between national governments, aircraft manufacturers, fuel developers, airlines, and others [54].

An illustration of a possible process of growing/collecting and processing feedstock, transporting products, and delivering a fuel for aircraft (figure 5.1).

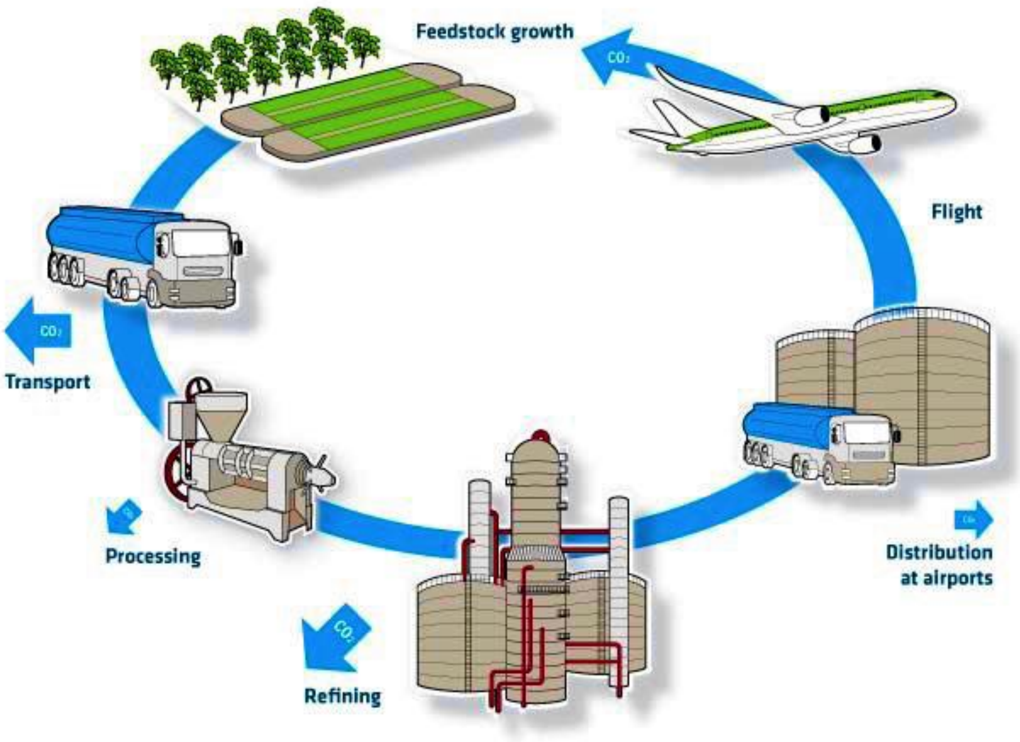


Figure 5.1 – The development process for growing feedstock and creating SAF

Pursuant to Assembly Resolution A39- 2, ICAO has taken a leadership role in facilitating discussions and supporting interim measures [55]. At the second ICAO Conference on Aviation Alternative Fuels (CAAF/2) in October 2017, ICAO Member States agreed on the ICAO Vision on Aviation Alternative Fuels which will help to ensure that a significant proportion of conventional aviation fuels are substituted with SAF by 2050. ICAO [56].

Member States recognize that the sustainability of aviation alternative fuels is of essential importance to the efforts of international civil aviation to reduce its CO_2 emissions.

In order for an aviation alternative fuel to be considered an SAF by ICAO, the fuel must meet sustainability criteria, which are currently under consideration by ICAO [57].

Member States ICAO tracks live alternative fuel flights on its website through the Global Framework for Aviation Alternative Fuels (GFAAF) [58].

By November 2017, it reported, inter alia, the following commercial flights:

• United Airlines and KLM flights departing from Los Angeles International Airport

• Lufthansa, SAS, and KLM / KLC flights departing from Oslo Airport

• SAS, KLM, and BRA flights departing from Stockholm Arlanda Airport

• All departures from Bergen Airport

At that time, alternative fuels had also been delivered to Stockholm Bromma Airport, Åre Östersund Airport, Göteborg Landvetter Airport, Karlstad Airport, Halmstad Airport, Brisbane Airport, and Chicago O'Hare International Airport. ICAO also reports on the progress being made to advance alternative fuels, including over 100,000 commercial flights using such fuels from a variety of feedstocks, and the announcement of a number of long-term offtake agreements for purchasing alternative fuels. Oslo International Airport, Los Angeles International Airport, Arlanda International Airport, and Bergen Airport have commercial flights refuelling with alternative fuel on a regular basis and have developed as alternative fuel hubs [59].

Member States ICAO are engaged in the development of SAF to different degrees, with many seeing the potential economic opportunity of using different sources of feedstocks more suitable to their specific circumstances, and developing fuel to serve regional demand.. ICAO will be publishing additional technical guidance on feasibility studies of sustainable aviation fuels to support Member States with assessing the opportunities [60].

5.3 Operational improvements

More efficient operations on the ground and in the air can reduce aircraft fuel consumption and limit CO_2 emissions from international aviation. Modifications of movements on the ground may be influenced by the need for infrastructure improvements and updating operating procedures.

En-route changes seek to limit the distance flown by aircraft to reduce associated fuel burn. Figure 5.2 shows the concept of continuous descent approach (CDA) as an example of one activity to improve flight route efficiency.

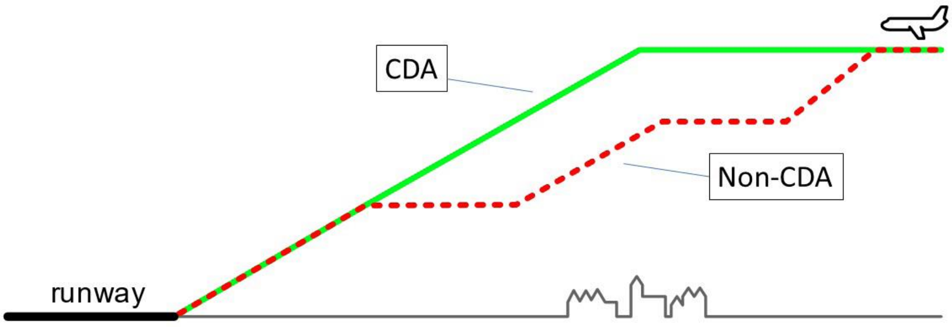


Figure 5.2 – Continuous Descent Approach and potential benefits

Guidance on operational improvements is detailed in ICAO Doc 10013, Operational Opportunities to Reduce Fuel Burn and Emissions [61]. ICAO has also developed guidance on improved operational procedures in the Global Air Navigation Plan (GANP). The GANP presents a series of essential air traffic management (ATM) concepts for implementation on a regional basis to improve efficiency and air transport capacity, while also limiting environmental impacts. The GANP also includes the Aviation System Block Updates (ASBUs) strategy, which focuses on technologies, procedures, and operational concepts available to increase future air traffic capacity, preserve safety, and minimize per passenger environmental impacts. ICAO, is working with the operational community to assess the potential environmental benefits of the ASBUs [62]. As with aircraft technology and standards, Member States are participating through ICAO, to develop policy to be carried out by States and the industry. As ICAO approves new actions, Member States adopt policies for aircraft operations at airports and look to work with civil aviation authorities to implement operational measures [63]. Some operational improvements at airports will have a direct benefit to international aviation emissions reductions while others, though still important considerations for the civil aviation authority's overall national environmental programmes, will not.

Specific measures that will contribute to international aviation emission reductions include gate electrification improvements to reduce or eliminate emissions from the APU on international flights, and airfield improvements that make movements of aircraft operating international flights more efficient on the ground [64]. Gate electrification equipment, such as a ground power unit (GPU) frequency converter, represents a significant emission reduction opportunity, which allows aircraft to disengage use of the APU while at the gate and obtain electricity from the terminal. When coupled with a solar power facility, the installation demonstrates the solar at-gate emission reduction Clean Development Mechanism (CDM) small-scale methodology [65].

In order to keep the aircraft's internal temperature comfortable, this retrofit also requires the installation of an electrically-powered pre-conditioned air unit (PCA). The systems associated with retrofitting the gate for electric power are shown in Figure 5.3

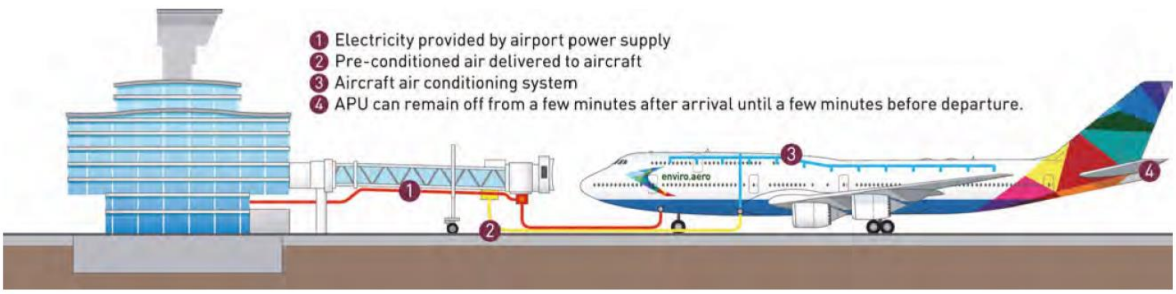


Figure 5.3 – Gate electrification equipment

Airfield enhancements that can improve aircraft movements on the ground and reduce CO_2 emissions include the construction of additional taxiways and runways to provide direct terminal access and reduce congestion.

Another promising technological improvement known as "electric taxiing" would involve electrically charged equipment to move aircraft, without the use of jet fuel, from the landing point to the terminal gate.

Conclusion to part 5

To implement, manage, and maintain environmental initiatives associated with the reduction of international aviation carbon emissions, States may need to develop or adjust existing organizational programmes. This section reviews some of the regulatory frameworks applicable to international aviation and climate change that may be considered by Member States as they develop expertise and establish a structure to coordinate with other jurisdictions to act on international aviation emissions reductions.

Civil aviation authorities should consider the emission reduction opportunities associated with infrastructure improvement as part of their long-term airport planning. They may also want to track and support energy legislation that could benefit the airport’s use of renewable energy. In addition, there may be opportunities to identify climate financing for such projects and potentially attract private sector investment for certain aspects of the programmes, such as solar power facility development.

There are a number of other measures that can be taken to reduce or eliminate emissions from GSE and airport off-road vehicle use through conversion to biofuels, electricity or other alternative fuels. While these measures should be important considerations in developing the State’s environmental protection goals, these emissions reductions are not covered by ICAO’s global aspirational goals for international aviation, as they relate to emissions from domestic sectors. However, these measures deliver environmental co-benefits from ICAO’s standpoint.

GENERAL CONCLUSION

1. An hinge bearing is a product that is part of a support or abutment that supports a shaft, axis or other movable structure with a given stiffness. That is why their use in the aviation industry is very relevant.

2. In the process, they perform very important functions, which leads to their wear. Accordingly, the development of test methods for various loads is required.

3. The methods of testing the articulated bearings for durability and load are analyzed. In the process of analysis, it was found that there are many methods for testing durability, but these methods are in accordance with the specified requirements and do not include the specific operating conditions of the spherical bearings

4. Improved installation for research on fretting corrosion in the installation for research of hinge bearings for wear resistance up to 10 mm

5. An installation has been developed for testing hinge bearings from 12 to 35 mm, which allows loading spherical bearings with radial loads of up to 10 tons.

6. The analysis and calculation for lighting and air conditioning of the workplace of an engineer who takes part in tests of hinge bearings was analyzed and harmful factors for the environment were considered.

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