Ministry of Education and Science of Ukraine
National Aviation University

Lab Works

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7/8.07010301 «Технології робіт та технологічне обладнання аеропортів»
(шифр та назва)

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Laboratory work #1

Aim of the work – to get acquainted with the method of determination and calculation of surface hardness parameters.

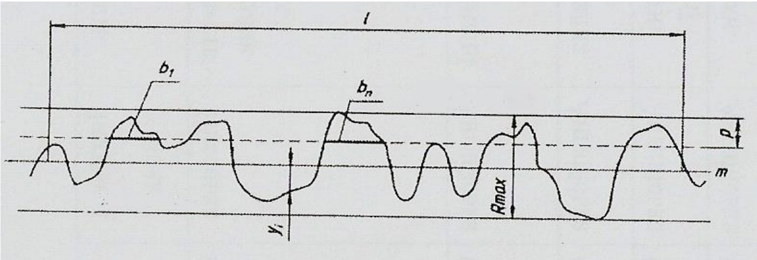
Content and the order of work procedure

1. With the help of data calculate parameters of surface hardness
2. To plot the graph
3. According to the table 2 determine class of hardness of a contact surface
4. To make analyses. And to make a report

Fundamentals and calculation formulas

Real surface that limits the detail unlike the nominal – geometrically correct and smooth – have the complex surface, which is characterized by micro and macrogeometry . Hardness – is the characteristic of microhardness of the real surface of the detail. Terminology, determination and value of hardness parameters of a surface are determined by ГОСТ2789-73 and ГОСТ 25147-82.

Hardness of a surface – is like a set of surface defects with the relatively small steps on the base length (2-800 mkm) and height (0,003-400 mkm). There are two different types of surface hardness stable and output.



Main parameters of hardness

L - Base length

m – Mean line of profile

R_{max} – Biggest height of the profile defects

Y_1 – Deflection of the line from the line m

P – Level of the profile intersecting

B_u – Length of the segment in the intersecting on the level P

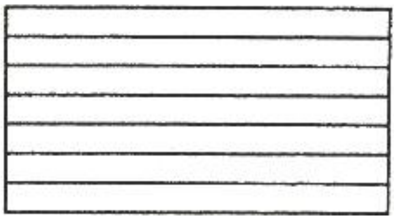
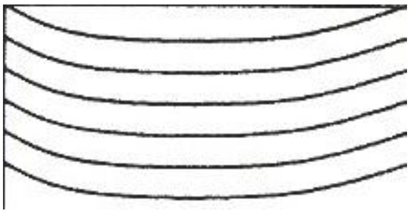
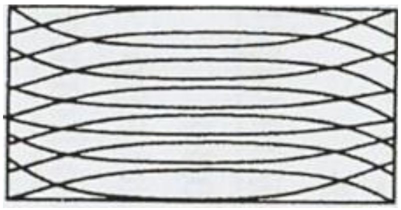
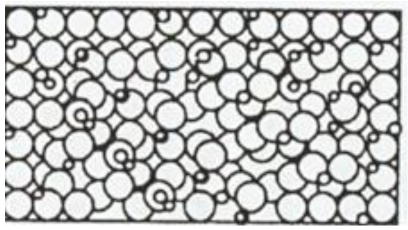
R_a – Mean profile deflection

$$R_a = \frac{1}{n}\sum_{i=1}^{n} y_i ;$$

R_z – Height of the profile defects according to ten points

$$R_z = \frac{1}{5}\left(\sum_{i=1}^{5} y_{виступів} + \sum_{i=1}^{5} y_{впадин}\right).$$

Technical surfaces are characterized by a specific processing of each type of surface.

direction of the deflections	**Schematic representation of a structure**	**Types of processing**
Parallel		Whetting, cylindrical milling, shaping
Arc		Face whetting
Intersecting arc		Face milling, grinding
Without definite direction		Electroerosion, sandblasting and shot blasting processing
Discursive line		Polishing, honing, superfinishing processing

Class and categories of surface hardness and their marking according to ГОСТ 2789-59	Parameter of hardness according to ГОСТ 2789-59		Base length L, mm
	Mean inclination of a profile R_a	Height of profile defects according to ten points R_z	
	Parameter, mkm	Parameter, mkm	
V1	----------	320 – 160	0,8
V2		160 – 80	
V3		80 – 40	----------
V4		40 – 20	2,5
V5		20 - 10	
V6a	2,5 - 2,0	----------	----------
V6б	2,0 - 1,6		
V6в	1,6 - 1,25		
V7a	1,25 - 1,00	----------	
V7б	1,00 - 0,80		
V7в	0,80 - 0,63		
V8a	0,63 - 0,50	----------	
V8б	0,50 - 0,40		
V8в	0,40 - 0,32		
V9a	0,32 - 0,25	----------	0,25
V9б	0,25 – 0,20		
V9в	0,20 - 0,16		
V10a	0,160 - 0,125	----------	
V10б	0,125 – 0,100		----------
V10в	0,100 – 0,080		
V11a	0,080 – 0,063	----------	
V11б	0,063 – 0,050		
V11в	0,050 – 0,040		
V12a	0,040 – 0,032	----------	
V12б	0,032 – 0,025		
V12в	0,025 – 0,020		
V13a	----------	0,100 – 0,080	0,08
V13б		0,080 – 0,063	
V13в		0,063 – 0,050	
V14a	----------	0,050 – 0,040	
V14б		0,040 – 0,032	
V14в		0,032 – 0,025	

In accordance to conditions of surface work the parameter of hardness is appointed during designing of machine details. Also there is a something common between marginal deviations of size and hardness.

1. Hardness of surface according to ГОСТ 2.309-73 is denoted on the graph like sign V. Above this V we can denote numerical value in mkm of the one chosen hardness parameter.
2. Numerical value of hardness limits only the biggest value according to parameters R_a and R_z. If it needed to limit also the smallest value of the hardness, that we denote it with the help of such signs $\overset{2.5}{\underset{\vee}{1,25}}$ and $R_z\overset{320}{\underset{\vee}{160}}$
3. Surfaces with processing without removing of chips is denoted like $\overset{0}{\vee}$, with the processing and removing of chips ∇.
4. Methods of syrface processing is pointed just in case, when the are like a one hole, that garanty quality of the product.

Stylus method of surface roughness measurement

Profilometer is the device intended for the surface irregularities measurement. The surface roughness is usually used as special index for the estimation of surface irregularities. Typical profilometer has a scale with the help of which the magnitude of surface roughness index is determined.

In technics profilometers are usually used for determination of product surface roughness with cross-section as a straight line in the measurement plane in laboratories, work units of machine instrument engineering factories and other plants as well as in field conditions.

Surface roughness parameters measurement is carried out according to the mean line system as directed by nomenclature and range of values specified by ГОСТ 2789-73.

Measurement procedure. The detail is installed and oriented on the device table in such a way that inclination angle of investigated surface with respect to the movement path was negligible. For this reason measuring transducer trial passes with the evaluation of result according to the device scale without turning in the recording instrument is carried out. Base line is chosen according to assigned roughness parameters if its value isn't standardized.

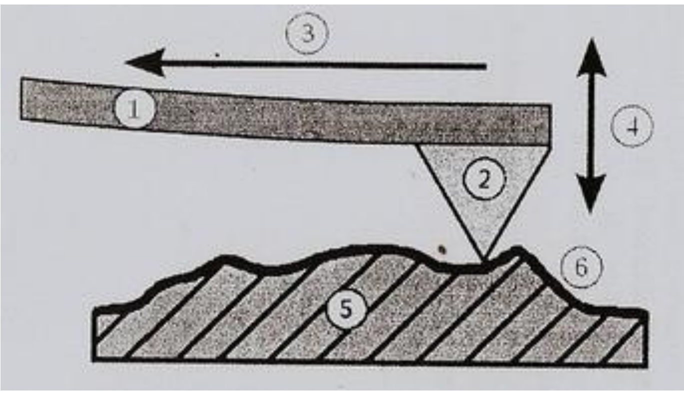


Fig. 1.2 Scheme of measurement realization using profilometer

Console (1) (Fig. 1.2) holds stylus (2) that moves horizontally in direction (3) over the object surface (5). Stylus movement repeats basic profile irregularities and moves console in vertical direction. Vertical position (4) is recorded as measured surface profile (6) (black line).

After detail installation on the table and choice of basic length roughness parameters are measured and profilograms are made. Measurements are carried out on several segments to obtain sufficient image about controlled surface. Locations and number of tracks are determined according to the surface dimensions and configuration as well as obtained measurements results distribution. Direction of measurement (if not specified) must provide showing of maximum surface roughness parameters values. In case if there are explicit regular machining marks on the detail surface, then measurement tracks must be directed perpendicularly to them.

Initial data and task

Determine roughness class of contact surface using the profilogram. Profilogram recorded while tracking one of the controlled segments may be used for the determination of basic parameters values.

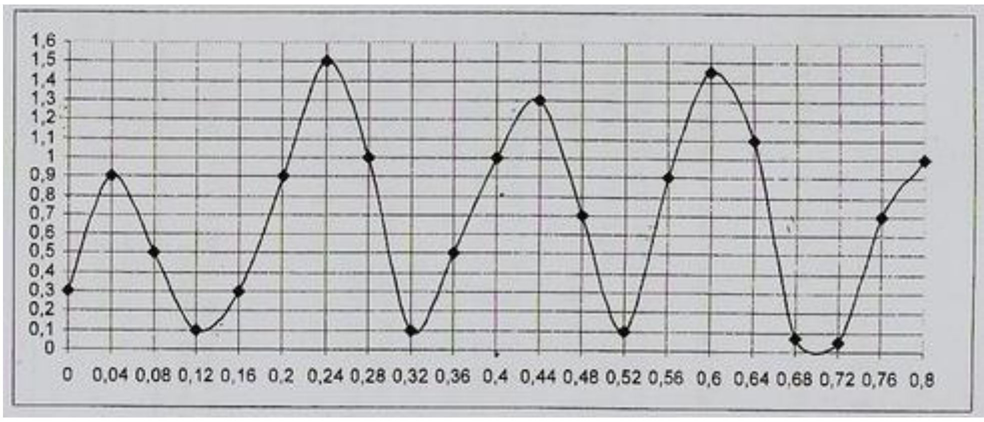


Fig. 1.3 Surface profilogram

Mean line *m* is drawn on the profilogram as a line dividing area separated from above and below by profilogram lines from the straight line on the basic length on two equal parts. The position of mean line is determined by mean-value method. For this reason basic length 0.8 mm is divided into 20 segments (n) with step equal to 0.04 mm. Mean line is constructed through 2 points with such coordinates:

$$x_1' = \frac{n}{4} \qquad x_2' = n - x_1$$

Ordinates of the mean line are determined in the next way: the profile ordinates $y_1, y_2, \ldots y_{20}$ on 20 chosen segments (n) of horizontal line drawn parallel to the profile under the profile deepest cavity. Mean line coordinates are:

$$y_1' = \frac{\sum_1^{10} y_i}{10} \qquad y_2' = \frac{\sum_{11}^{20} y_i}{10}$$

Equidistant to this line we construct lines of cavities and concavities. The distance between these lines taking into account scale of vertical increment determines maximum height of profile irregularities R_{max}.

Determine mean absolute error of profile R_a:

$$R_a = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_1' + y_2'}{2} - y_i\right|$$

Questions for self-checking:

1) What does the term “surface roughness” mean?
2) Name the mechanisms of initial surface roughness changes during beginning of operational life.
3) What does the term “equilibrium or exploitation” surface roughness mean?
4) How many surface roughness classes are there according to ГОСТ 2789-59?
5) What kind of surface structure is created after the superfinishing detail processing?

Laboratory Work № 2

Techniques for determination of the metal's surface layers' microhardness

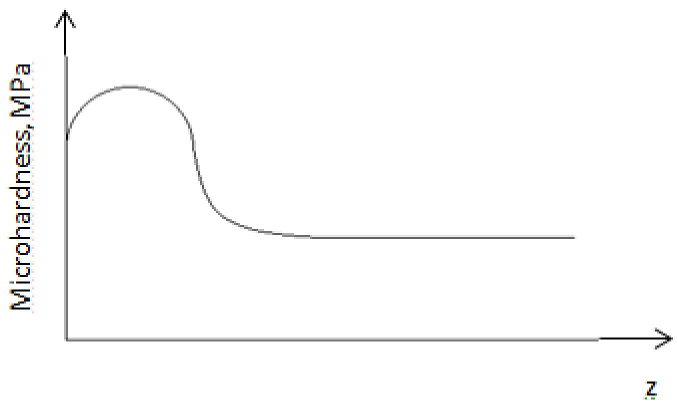
<u>Purpose of laboratory work:</u> to determine influence degree of additives composition and additives in mineral oils on the kinetics changes in metal's upper and near-surface layer layers' microhardness.

<u>Content and the order of work procedure:</u>

1. According to the results of investigation make corresponding calculations and plot the diagrams.
2. Make analysis of the work. Write a conclusion.

<u>Main Theoretical Information and Calculation Formulae</u>

External friction of rigid body is realized according to conditions when the strength of adhesive bonds is less than the cohesive strength of the surface layers of contact pairs. That's why mechanical qualities of material with the depth increase while alienating from the surface on some distance, reaching maximum value, and then gradually decrease to values, typical to the main material (pic. 3.1).



Pic. 3.1 Change in microhardness with the increase of depth

This change of mechanical qualities of the near-surface layer of rigid bodies is called *the rules of positive gradient of mechanical qualities with changing of depth.* According to this rule external friction is realized only in cases when on the surface of the rigid body are located layers with lower hardness, than on the near-surface layer of the main material.

Analysis of tension in the areas of actual contact suggests that the thickness of the deformed surface layers of at the external friction in the presence of elastic deformations in the contact does not exceed 3 … 25 mkm. In contact with the predominance of plastic deformation component the thickness of layers being deformed by friction is 17 … 80 mkm.

Internal friction of solid bodies is realized under conditions when the strength of adhesive bonds exceeds cohesive force interactionof one of the contact surfaces. During this process, shift occurs in the volume of surface layers; constant deformation in material in the direction of sliding is observed.

Structure of the surface layers. During friction or mechanical processing surface layer of rigid body sustain of intense deformation, subjected to thermal impulsive actions and are saturated with the elements counter body and the surrounding environment. This leads to a change in their structure and causes the heterogeneity (anisotropic) in depth (fig. 3.2).

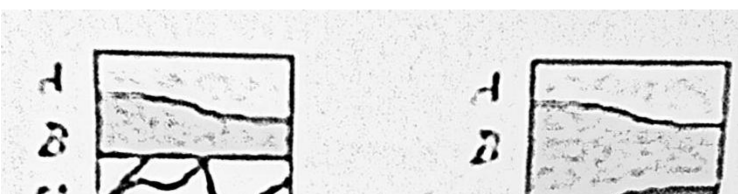


Fig. 3.2.Structure of the surface layers of steel specimen after friction (a) and grinding (б).

During friction boundary layer A (h ≈ 0,3 nm) consists of adsorbed gas molecules, moisture, lubricating materials, that can be removed from the surface if heated in vacuum.

Layer B (h≈ 0,2-8 nm) - oxide films, formed by the interaction of metal with oxygen. It also includes products tribochemical reactions, strongly deformed particles of metal. It is characterized by high concentration of pores and microcracks.

Layer C (h ≈ 5000 nm) consists of strongly deformed crystals that are affected by temperature and mechanical load.

Layer D is the structure of the original metal. The thickness of each of these layers depends on the mode of loading and type of lubrication in tribotechnical contact.

During grinding between layers B and C may appear a layer thickness of which is 5 nm, which consists of small structural units, which are difficult to identify, as most of them do not have a completed crystal lattice. This layer is called layer Beylbi.

In the presence in the lubricant surfactant species (поверхностно-активные в-ва) appear Rehbinder’s effects.

External Rehbinder’s effect. Elementary structural components of rigid body (atoms, molecules) are located in the middle volume, interact with the surrounding particles in all directions. Resulting of these forces is close to zero, which corresponds to minimum potential energy. Surface solid particles due to uncompensated bonds are characterized by the extra energy that causes their interaction with molecules of the environment or with atoms (molecules) counterbody.

During the adsorption of surfactant species free energy of solid body decreases. This decreases the resistance of the surface layer of solid plastic deformation, plastic facilitated the shift in grain yield and dislocation to the surface. The top layer of metal may have a lower microhardness than lower ones, rich layers of dislocations, as well as a lower limit of yield stress and coefficient of strengthening. Deformed in the presence of surface substance layer of metal is characterized by a fine granular structure. This phenomenon is adsorption plasticizing of solids under the action of surfactant species is called an Rehbinder’s effect. Thickness of the plasticized layer is approximately 0.1 microns. Unlike chemical surface modification, Rehbinder’s effect occurs when the simultaneous action of the environment and mechanical stress, and when removing surfactant species adsorption plastification of surface does not shown.

Internal Rehbinder's effect (adsorption-dissociative) - a phenomenon adsorption reduction of strength (of brittle fracture at low stress up to spontaneous dispersion). Implemented by diffusion active components of lubricant to the tops of newly formed cracks, when the active centers of the molecules reach the area, its size is two sizes smaller molecules, the latter divided it. This pressure on the wall at the top of the crack reaches 10MPa, which makes destruction crystal lattice of the metal in these areas and initiate further development of cracks. Under these conditions, reduced resistance to material fatigue fracture.

Methods of determining the microhardness of surface layers of metal. The main instrument for research materials on the microhardness, which is used in modern laboratories, a variety of purposes - a domestic instrument PMT-3 (fig.3.3), the latter model is developed MM Khrushchev and ES Berkovich.

PMT-3 device and other domestic models commonly used for research materials on indentation under load of 2 (5) to 200g. As dented tool (indentor) they used diamond pyramid with square base and the angle at the top between the opposite sides 136^0. In the study measured the length of the dent diagonal and count the number of hardness, as a share of dividing the applied load on the surface of the resulting dent.

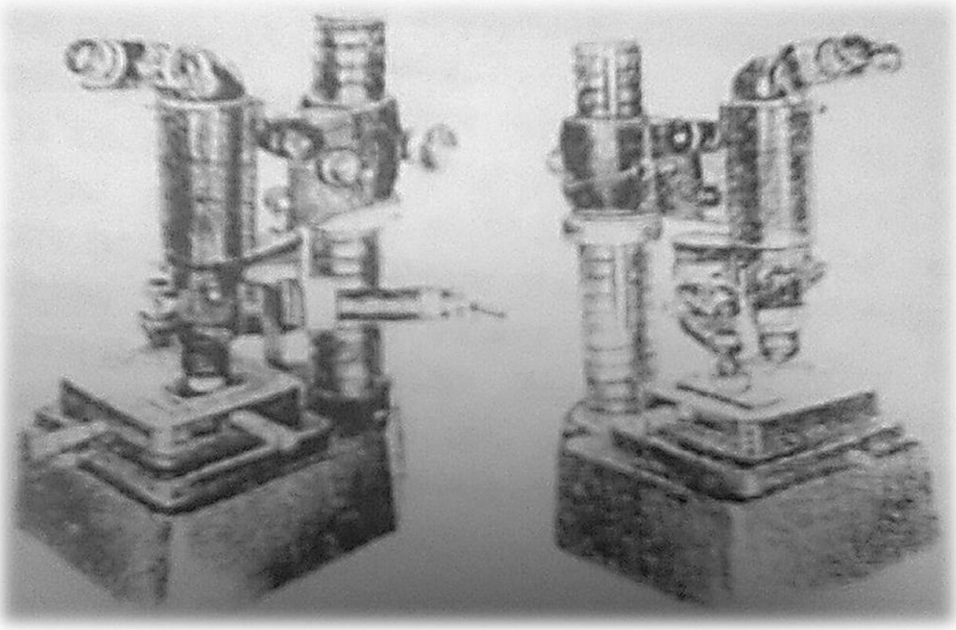


Fig. 3.3. External view of the device PMT - 3

In the study of microhardness numerical value of the outcome measure is the portion of dividing the load *P* (kg) on the side of a dent *F* (mm) the assumption that the angles in dent are the same as in the pyramid itself:

$$H_\mu = \frac{P}{F} = \frac{2P\sin\frac{\alpha}{2}}{d^2} = \frac{1{,}854P}{d^2}$$

where α - angle at the top of the diamond pyramid (136° or 2.47 rad).

If *P* is expressed in grams and *d* - diagonal impression in micrometer, then the formula for calculating microhardness takes the form:

$$H_\mu = \frac{1854 \cdot P}{d^2}$$

<u>**The problem and the original data.**</u>

According to the results of surface layers microhardness measuring (Table 3.1) and surface layers microhardness of steel 45 (tabl.3.2) plot changes in metal microhardness depth (according to Table 3.1) and change this option when working out, depending on the number of cycles of developments (Table. 3.2). Identify patterns of change in microhardness in surface lubrication by mineral oil I - 40 and its composition with oleic acid (surfactant), fullerene C60 (nanodispersed additive), RVS (ceramic-metal additive).

<u>**Questions for self-control:**</u>

1. What is the difference between external and internal friction?
2. Describe the basic rule of external friction in the contact.
3. Under what conditions is shown externality Rehbinder's effect?
4. What is cohesion and adhesion forces of interaction?
5. What are the main types of surface layers of metal that are formed during friction.

Change in microhardness of the surface layers Table 3.1

Depth, *mkm*	*0,5*	*1*	*1,5*	*2*	*2,5*	*3*	*3,5*	*4*	*4,5*	*5*	*5,5*	*6*	*6,5*	*7*	*7,5*	*8*
Oil 1-40																
Diagonal of the dent , mm	*17*	*16*	*16,3*	*16,3*	*16,4*	*16,4*	*16,5*	*16,6*	*16,7*	*16,8*	*16,9*	*17,4*	*20,2*	*23,4*	*24,7*	*24,9*
Microhardness, *kG/mm2*																
Oil 1-40 +1%oleic acid																
Diagonal of the dent , mm	*24,65*	*24*	*23,7*	*23,9*	*24,45*	*24,55*	*24,65*	*24,6*	*24,55*	*24,6*	*24,65*	*24,7*	*24,75*	*24,8*	*24,9*	*24,9*
Microhardness, *kG/mm2*																
***Oil 1-40*+fullerene C_{60}**																
Diagonal of the dent , mm	*16,5*	*15,3*	*15*	*15,3*	*18*	*22*	*24*	*24,5*	*24,7*	*24,75*	*24,9*	*24,85*	*24,9*	*24,85*	*24,9*	*24,9*
Microhardness, *kG/mm2*																

Lab number 3

Methods for determining the wear of machine parts

The purpose is to familiarize with the basic laws of the wear and wearing by artificial bases method.

Content and order of performance:

1 To perform calculations and construct the following diagrams: the wear of steel hardness material (experiments 1 and 3), the bulk temperature lubricant (experiments 5 and 6), the life of the oil (experiments 5 and 7), load (Experiments 9 and 7) and roughness of contact surfaces (experiments 9 and 10).

2. To make analysis.

Theoretical information

Wear is the process of the material separation from the surface of solid body as a result of friction and (or) an increase in permanent deformation that is accompanied by a gradual change in size of the body.

Wearing is the change in size and form of the solid body as a result of wear.

Absolute wear is the wear expressed in the units of length, volume or weight.

Linear wear (Δh) is the wear determined by the change in size along the normal to the surface of friction.

Volumetric wear (ΔV) is the wear determined by the volume change.

Weigh wear (Δm) is the wear determined by the weight change.

Local wear is the linear wear on a separate area of friction surface.

Quantitative characteristics of the wear are the intensity and the speed of deterioration.

The intensity of the wear (I) is the ratio of absolute wear (or a tested sample) to the distance of friction (L).

Linear wear intensity is the worn layer thickness dh per unit path of friction:

$$I_h = \Delta h / L. \qquad (2.1)$$

Quantity I_h is dimensionless, in most cases the intensity of the wear of real body is $I_h = 10^{-3} - 10^{-13}$

Weight intensity of the wear is the weight of a substance removed from the surface of the worn body per unit of road friction:

$$I_m = \Delta m / L. \qquad (2.2)$$

Volumetric wear intensity is the volume of the worn material per unit path of friction:

$$I_v = \Delta V / L. \qquad (2.3)$$

Determining the intensity of the wear is reasonable to attribute the absolute wear not to the wear of rubbing parts but to the other measurer that is common for all units and units of this machine. For example, the quantity of kilometers of the path can be taken as a measuring device for cars and the number of hectares of plowing can be used for tractors.

Wear rate (i) is the ratio of absolute wear (or a tested sample) to the time within which the trial took place. There are linear (i_h), volume (i_v) and weight (i_m) rate of the wear:

$$I_h = \Delta h / \Delta t; \quad i_v = \Delta V / \Delta t; \quad i_m = \Delta m / \Delta t.$$

Durability (ε) is the property of details, material or conjugated parts to resist wear in certain operating conditions or experiments. Wear resistance of friction pairs is defined as the value converted to the intensity of the wear therefore the durability of real friction units can take values from 10^3 to 10^{13}.

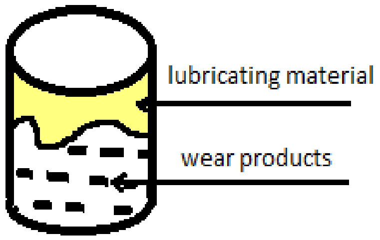
All methods for determining wearing are divided into two groups: periodic measurements of parts that form a connection and indirectly by testing the machine without stopping.

The methods for determining the periodic measurement of wear parts are determined by :

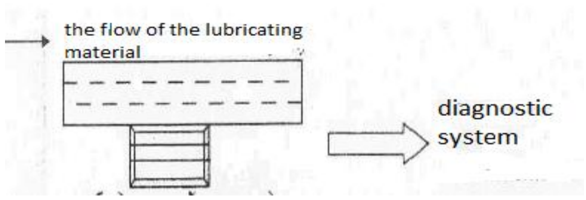
- Micrometric measurements or the method of micro measuring. More often it is used for large absolute values of the wear parts. It is based on the measuring of the parts before and after the wear test. The accuracy of the measurement is usually 0.01 ... 0.001 mm. As the means for assessing wearing by the method of micro measurement the following devices are used: end length measuring devices, micrometers, caliper’s indicator, beam clamps, lever-mechanical devices, lever-optical instruments, tools and universal microscopes;
- The loss of weight is the method usually used to determine the wear of small parts weighing them before and after the wear. The accuracy of this method depends on the accuracy of the scales within (0.05 ... 5) Ч 10^{-6} h. The loss of the weight is not recommended to be measured in cases when the size of a detail changes not only due to the separation of metal particles from it, but also through plastic deformation, as well as in determining the wear parts made of porous material impregnated with oil. As the means of measuring devices different kinds of measurement scales are used: instrumental ПР-500, analytical ВА-200 АДВ-200m, technical, desktop, closed ВНЗ-3 and others;
- Method of artificial bases is the calculation of the distance from the friction surface

to the bottom one of an excavation artificially performed on this surface and the bottom. The axis of the impression is perpendicular to the surface of friction and linear wear of the surface is determined by the direction of this axis. Methods of making impressions (usually diamond or Carbide tool) can vary:

- The content of wear products in used oil (Fig. 2.1). Analysis of the lubricating medium is very important as it contains environmental products wear, oxidation and chemical reaction. This analysis is rather important in the systems with lubricant circulation as diagnostic sensors can be placed in areas where the localized wear products from designated units of friction are used;



Sediments (Ferography) | Nondestructive methods (Optical photometry) | Destructive methods (Emission spectroscopy)



Installed Device (Acoustic Sensor)

2.1 General scheme of analysis of lubricating material

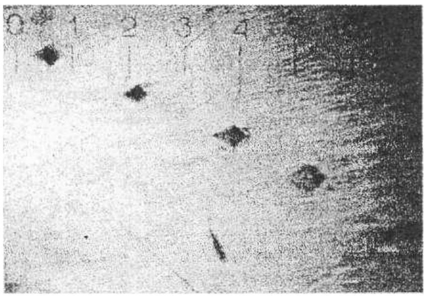
- Using radioactive isotopes, when the studied sample is injected radioactive isotope of antimony, tungsten or cobalt. When a sample is washed wear lubricants, which makes products wear with radioactive isotopes. Passing through the particle counter to measureradioactivity lubricant that increases as wear, isotope, accu mulate in the oil, makes it possible to conclude wear. This method allows to study the wear mechanisms of several parts or machines same time. Significant drawback - the complexity of sample preparation, and use special equipment to measure radiation.

Tasks and initial data

To determine the magnitude of the linear depreciation method of artificial bases and calculate the wear of contact surfaces for ten experiments.

Investigation of the wear of steel and steel 40Х-ШХ15 was conducted at the facility for СМЦ-2 in a slip (samples: movie - block) using the "start-stop" when lubrication transmission oils with different initial temperature lubricant.

Dents on the surface were left by the means of an instrument ПМТ-3 with a diamond indenter, which is a tetrahedral diamond pyramid with an angle at the top of 136^0 (Fig. 2.2).



2.2 Dents of the pyramid while determining linear wear.

Depth of the pyramid dent with an angle α = 136 ° is calculated by the formula:

$$h=d/7.$$

The value of the linear wear of the steel surface is defined as the difference between the depths of the dent before depreciation and after this process:

$$\Delta h=h_1-h_2=(d_1-d_2)/7,$$

Where Δh – line of depreciation;
h_1 - the depth of the dent before the experiment;
h_2 - depth of the dent after the experiment;
d_1-length of the diagonal square pyramid dent before the experiment;
d_2 - diagonal length of the dent after the experiment;

Experiment 1
Load – 50N
Material type – steel 0.4C + Cr
Lubricant – Titan 80w-90 (commodity)
Temperature without heating

Shoe/Block	1	2	3	4
Before experiment, micron	23	24	25	24
After experiment, micron	12	12	22	19
Difference				
ΣDifference/4				
Wear				

Roller	1	2	3	4
Before experiment, micron	25	24	23	24
After experiment, micron	16	5	15	18
Difference				
ΣDifference/4				
Wear				

Experiment 2
Load – 50N
Material type – steel 0.4C + Cr
Lubricant – Titan 80w-90 (commodity)
Temperature – 90^0C

Shoe/Block	1	2	3	4
Before experiment, micron	24	25	25	23
After experiment, micron	14	17	12	13
Difference				
ΣDifference/4				
Wear				

Roller	1	2	3	4
Before experiment, micron	23	23	24	25
After experiment, micron	6	0	23	11
Difference				
ΣDifference/4				
Wear				

Experiment 3
Load – 50N
Material type – steel ШХ-15
Lubricant – Titan 80w-90 (commodity)
Temperature – without heating

Shoe/Block	1	2	3	4
Before experiment, micron	20	21	19	20
After experiment, micron	10	19	18	18
Difference				
ΣDifference/4				
Wear				

Roller	1	2	3	4
Before experiment, micron	20	21	19	20
After experiment, micron	17	19	17	17
Difference				
ΣDifference/4				
Wear				

Experiment 4
Load– 50N
Material type – steel ШХ-15
Lubricant – Titan 80w-90 (commodity)
Temperature - 90^0C

Shoe/Block	1	2	3	4
Before experiment, micron	20	20	21	20
After experiment, micron	3	16	14	10
Difference				
ΣDifference/4				
Wear				

Roller	1	2	3	4
Before experiment, micron	19	19	19	20
After experiment, micron	18	17	18	17
Difference				
ΣDifference/4				
Wear				

Experiment 5.
Load- 50N
Material type – steel 0.4C + Cr

Lubricants - TAD-17i (commodity)

Temperature - without heating

Shoe/Block	1	2	3	4
Before experiment, micron	23	24	25	24
After experiment, micron	7	10	10	11
Difference				
ΣDifference/4				
Wear				

Roller	1	2	3	4
Before experiment, micron	25	24	25	25
After experiment, micron	19	21	18	10
Difference				
ΣDifference/4				
Wear				

Experiment 6.
Load- 50N
Material type - steel 0.4C + Cr
Lubricants - TAD-17i (commodity)
Temperature - 90 ° C

Shoe/Block	1	2	3	4
Before the experiment, micron	25	24	23	23
After the experiment, micron	5	8	8	6
difference				
Σ Difference / 4				
wear				

Roller	1	2	3	4
Before the experiment, micron	24	25	24	23
After the experiment, micron	20	21	19	17
difference				
Σ Difference / 4				
wear				

Experiment 7.
Load- 50N
Material type - steel 0.4C + Cr, Ra = 0.3 microns
Lubricants - TAD-17i (mileage 25 thousand km)
Temperature - without heating

Shoe/Block	1	2	3	4
Before the experiment, micron	25	24	23	24
After the experiment, micron	5	3	3	3
difference				
Σ Difference / 4				
wear				

Roller	1	2	3	4
Before the experiment, micron	23	25	24	24
After the experiment, micron	12	17	13	14
difference				
Σ Difference / 4				
wear				

Experiment 8.
Load - 50N
Material type - steel 0.4C + Cr
Lubricants - TAD-17i (heading)
Temperature - 90 ° C

Shoe/Block	1	2	3	4
Before the experiment, micron	25	25	24	23
After the experiment, micron	-	1	-	1
difference				
Σ Difference / 4				
wear				

Roller	1	2	3	4
Before the experiment, micron	23	24	25	25
After the experiment, micron	17	10	23	20
difference				
Σ Difference / 4				
wear				

Experiment 9.

Load - 40N

Material type - steel 0.4C + Cr, Ra = 0.3 microns

Lubricants - TAD-17i (mileage 25 thousand km)

Temperature - without heating

Shoe/Block	1	2	3	4
Before the experiment, micron	25	24	23	24
After the experiment, micron	10	9	10	11
difference				
Σ Difference / 4				
wear				

Roller	1	2	3	4
Before the experiment, micron	23	25	24	24
After the experiment, micron	18	22	20	21
difference				
Σ Difference / 4				
wear				

Experiment 10.
Load - 40N
Material type - steel 0.4C + Cr, Ra = 1.0 microns
Lubricants - TAD-17I (mileage 25 thousand km)
Temperature - without heating

Shoe/Block	1	2	3	4
Before the experiment, micron	25	24	23	24
After the experiment, micron	6	7	4	3
difference				
Σ Difference / 4				
wear				

Roller	1	2	3	4
Before the experiment, micron	23	25	24	24
After the experiment, micron	10	15	16	15
difference				
Σ Difference / 4				
wear				

Questions:
1. What is the meaning of the term "demolition" and "wear" of the contact surfaces?
2. What methods of wear measuring are used without stopping the machine?

3. What are the methods for determination of the periodic measurement of the wear parts?

4. How changes the wear of contact surfaces with load increasing?

5. How changes the wear of friction pairs with increasing hardness of the material?

6. Build the diagrams: wear vs hardness of material;
wear vs temperature of lubricant;
wear vs surface roughness.

7. Which of this factors have a grate influence on the wear?

Laboratory work №4

Indirect measurements of density of solid bodies

The aim: followingtheexample of solid bodies density measurement to familiarize withthetechnique and the senseof indirect measurementsandtoestimatetheresult of measurement and an its error.

Indirect measurementisthe measurement ofrequired physical value on the basis of results of direct measurements of other physical magnitudes functionally connected with the required value. The measurement ofdensity(compactness) of a solid body consists in direct measurements of the weight of a body, its geometrical dimensions and calculation the ratio of the weight to volume according to the formula:

$$\rho = m/V. \qquad (1)$$

In this laboratory work indirect measurement of density of a material (substance) of solid bodies of three different forms is made. Theyare:

wooden rectangular prism

direct circular cylinder from textolyte

steel ball.

The density of the material of each of the named bodies is defined according to the following formulas:

forprism: $\rho = m/(lbh),$ (2)

for cylinder: $\rho = 4m/(\pi d^2 l),$ (3)

for sphere: $\rho = 6m/(\pi d^3),$ (4)

where ρ–density of the material [kg/m^3]

m- weight of the corresponding body[kg]

l,b,h - length, width and prism height[m]

d,l - diameter of the cylinder and sphere and length of the cylinder[m]

At an assumption that all three bodies have the correct form, don't contain emptiness and the material is homogeneous, the error of indirect measurement of density will develop from the errors of direct measurements of the weightand sizesof the bodies. On the basis of the linearization method the error of measurement of the required size (density) is connected with the errors of measurement of the sizes measured by direct measurements in following ways:

a) absolute limiting (absolute probable) following the formula:

$$\Delta\rho_{\max} = \sum_1^m \frac{\partial\rho}{\partial Q_i}\Delta Q_i = \sum_1^m b_i \Delta Q_i = \sum_1^m \Delta\rho_{\max j}\ , \qquad (5)$$

where $\Delta\rho_{\max}$– absolute limiting error of measurement of density[kg/m^3]

$\frac{\partial\rho}{\partial Q_i}$ –partial derivative of density on i-th size of direct measurements;

Q_i - absolute limiting error of measurement of i-th size of direct measurements,[kg] or [m];

m –number of sizes of direct measurements;

b_i – coefficient of influence of an absolute error of measurement of i-th size on an absolute error of measurement of density;

Δρ max, i – absolute partial error of measurement of the density brought by an absolute error of measurement of i-th sizes of direct measurements;

b) relative limiting according to the formula:

$$\delta\rho_{\max} = \frac{\Delta\rho_{\max}}{\rho}100 = \sum_1^m \frac{\partial\rho}{\partial Q_i}\frac{\Delta Q_i}{\rho}100 = \quad = \sum_1^m \frac{\partial\rho}{\partial Q_i}\frac{Q_i}{\rho}\frac{\Delta Q_i}{Q_i}100 = \sum_1^m B_i\,\delta Q_i = \sum_1^m \delta\rho_{max,i}, \quad (6)$$

where dρ max – relative limiting error of measurement of density, [%];

ρ – measured value of density,[kg/m3];

B_i – factor of influence of the relative error of measurement of i-th sizes on the relative error of measurement of density;

dQ_i – relative limiting error of measurement of i-th size of direct measurements, %;

$d\rho_{max,\,i} = B_i dQ_i$– relativepartial error brought by a relative error of measurement of i-th size,[%]

c) absolute most probable following the formula:

$$\Delta\rho = \sqrt{\sum_1^m \left(\frac{\partial\rho}{\partial Q_i}\Delta Q_i\right)^2} = \sqrt{\sum_1^m (b_i \Delta Q_i)^2} = \sqrt{\sum_1^m \Delta\rho_{\max,i}^{\ 2}}\ ; \qquad (7)$$

d) relativemost probable following the formula:

$$\delta\rho = \sqrt{\sum_1^m \left(\frac{\partial\rho}{\partial Q_i}\frac{\Delta Q_i}{\rho}100\right)^2} = \sqrt{\sum_1^m (B_i \delta Q_i)^2} = \sqrt{\sum_1^m \delta\rho_{\max,i}^{\ 2}}\ . \quad (8)$$

One of the most important conditions to be fulfilled isproviding of precise direct measurements ieapproximate equality of the partial errors defined by the errors of valuesmeasurement, subjected to direct measurements as the part of an error of measurement of the required value (density). In the case of absence specified exactly equal an error of the measurement of required value, especially the most probable will be defined entirely by the greatest error of measurement of any of values measured directly while smaller errors of the measurement of other values will negligible small and the efforts spent for providingthese small errors will be vain and irrational.

3. Equipment

3.1 Bench-type scales РН-6Ц13У, limits of weighing from 40 g to 6 kg,division value 10 g, class of accuracy average (an absolute admitted error ±10).

3.2 Trammels ШЦ-II, limits of measurement 0 – 250 mm, division value of displayed device 0,05 mm, an absolute admitted error ±0,08 mm in the range of lengths from 1 to 50 mm, ±0,09 mm in the range of lengths from 50 mm to 80 mm and ±0,1 mm in the range of lengths over 80 mm.

3.3 Examples of solid bodies: straight right-angled prism from a tree (pine), straight circle cylinder from ebonite, steel sphere.

4.The order of the experiment procedure

4.1 To measure the geometrical sizes of samples with the help of trammels, measuring mean sections of samples. Fill the table 1 with the measured results.

4.2 To measure mass of samples by weighing on scales, to make count ofindications to produce step-type behavior to half of price of the scale division. Before weighing to check the position of the scales(it should be horizontal position and indications should be equal to zero in the absence of a load on the weighing area; in case of non-observance of these requirements to result scales in an appropriate stateby regulation of supports and rotation of the handle of a regulator. To fill the table 1 with the received results of measurements.

Table 1

Material and the shape of the sample	Geometrical size of the sample, m		Volume of the sample V,m^3	Mass of the sample m, kg	Density of the material ρ, kg/m^3
Wood, prism	Length *l*	$220,2*10^{-3}$		$410*10^{-3}$	
	Width *b*	$71,1*10^{-3}$			
	Height *h*	$49,9*10^{-3}$			
Ebonite, cylinder	Diameter *d*	$20*10^{-3}$		$80*10^{-3}$	
	Length *l*	$188,2*10^{-3}$			
Steel, sphere	Diameter *d*	$55,7*10^{-3}$		$720*10^{-3}$	

4.3 It is recommended to write down the results of measurements of the geometrical sizes and results of calculations of volume and density with 10 multiplier in an appropriate power.

5. Handling of the results of experiment

5.1 To calculate the volume of each sample and density of a material according to the formulas (1) – (4); to approximate thevalues of volumes and density to four significant digits and fill the table 1.

5.2 As absolute sample errors of direct measurements of the geometrical sizes and mass to accept absolute admitted errors of the applied measuring apparatuses according to part 3. To define relative errors of all values measured directly; Fill table 2 with received errors.

5.3 On the basis of formulas (5) – (8) make formulas for calculation of all types of errors, including partial error , indirect measurement of density for all materials (samples), to formulas (6) and (8) substitute instead of received values of density the expression for density of the appropriate sample according to formulas (2) – (4).

5.4 According to the received formulas to calculate appropriate errors of measurements of density of each material (sample) and fill the table 2 with the data with approximation to fourth significant digit.

5.5 To approximate calculated data (errors of measurement of density and earlier calculated values of density according to metrological rules) and fill the tables 1 and 2 accordingly, to put down the values of density with thelimits of the most probable absolute error on type $\rho \pm \Delta\rho$.

Table 2

Material and the shape of the sample	**Measured value**	Error of direct measurements		Partial (Limiting) Error		Error of measurement of density			
						absolute, kg/m^3		relative %	
		absolute kg/m^3	relative %	absolute kg/m^3	relative %	limiting	most probable	limiting	most probable
Wood, prism	length *l*	±0,1*10^{-3}	±0,05	-0,24	-0,05				
	width *b*	±0,09*10^{-3}	±0,13	-0,66	-0,13				
	height *h*	±0,08*10^{-3}	±0,16	-0,84	-0,16				
	mass *m*	±0,01	±2,44	12,8	2,44				
Ebonite, cylinder	diameter *d*	±0,08*10^{-3}	±0,4	-0,22	-0,79				
	length *l*	±0,1*10^{-3}	±0,05	-6,47	-0,05				
	mass *m*	±0,01	±8,2	16,9	8,2				
Steel, sphere	diameter *d*	±0,1*10^{-3}	±0,54	-42,88	-1,63				
	mass *m*	±0,01	±1,39	110,58	1,39				

5.6 To compare received results of measurement of density of the investigated materials with the data of directories and to make a conclusion on reliability of carrying out indirect measurements.

6. Control questions:

1. What is direct and indirect measurement; in what cases can we use indirect measurements?
2. In what manner dependences (equation of connection) between the required size measured indirectly and the size measured directly are established? Give 2-3 examples of indirect measurements of physical sizes, except density.

3. What are the requirements for samples of solid bodies for indirect measurement of their density? What can be the consequencesof non-observance of these requirements?
4.What does the error of indirect measurements consist of? Whether a methodical error can take place at indirect measurements and what is thepossible reason (use the example of measurement of density of solid bodies)?
5. What is the requirement of exactly equal direct measurements with reference to indirect measurements? How much does this requirement correspond to the direct measurements?
6.What is the expediency and legitimacy of usage for an estimation of accuracy of indirect

measurements the most probable error received by square-law summation of errors of direct measurements?
7.Whether transition from indirect measurements of any sizes to their direct measurementis it expedient and under what conditions is possible? Give2-3 examples of such transition.

Laboratory work № 5

Processing of the results of averaged measuring with repeated observations

The aim of the work: To get acquainted with the methods of processing of the results of averaged measuring with repeated observations. To learn how to determine the presence of arguments' errors correlation and to calculate the measuring result error.

Theoretical information

The processing of the results of averaged measuring with repeated observations is carried out in accordance with МИ 2083-90 «ГСОЕИ. Измерения косвенные. Определение результатов измерений и оценивание их погрешностей».

It's known that during averaged measuring the unknown quantity of physical value Y is found due to the results of measuring of arguments $\chi_1,\chi_2 \ldots\ldots\ldots \chi_m$, which are connected with unknown quantity by an equation:

$$Y=f\,(\chi_1,\chi_2 \ldots\ldots\ldots \chi_m).$$

The function f has to be known from theoretical data or determined by an experiment, neglecting error.

Arguments on which the unknown quantity depends are taken as constant physical values; known fixed errors of measuring results are excluded, and uncovered fixed errors are evenly distributed within given borders ±Θ.

The methods of processing are established for estimation of averaged measurand and result errors:

- At linear dependence and absence of correlation between errors of arguments' measuring.
- At non-linear dependence and absence of correlation between errors of arguments' measuring.
- For correlative errors of arguments' measuring at presence of a series of separate values of measured arguments.

1. During processing the results of observations of arguments ($\chi_{1,1} \ldots \chi_{1,n}$),($\chi_{2,1} \ldots \chi_{2,n}$) … ($\chi_{m,1} \ldots \chi_{m,n}$) due to which the result of measurement Y is calculated at *nonlinear* dependence and *absence* of correlation between errors of measurements of arguments it is necessary:

1.1. To extract known fixed and serious errors from the results of arguments' observations.

1.2. To calculate average value from readjusted results of arguments' observations, taking into account as result of measurements of argument $\bar{x}_i$.

1.3. To calculate mean square deviation of argument $x_i - S(x_i)$ observations.

1.4. To calculate the value of mean square deviation of argument' $S(\bar{x}_i)$ result.

1.5. To calculate the result of measurement $\tilde{Y} = f(\bar{x}_i, \ldots, \bar{x}_m)$.

1.6. To calculate mean square deviation of indirect measurement result error $S(\tilde{Y}) = \sqrt{\sum_{i=1}^{m} b_i^2 \cdot S^2(\bar{x}_i)}$, where $b_i = \frac{\partial f}{\partial x_i}$.

1.7. To calculate confidence limits of random error resulted from indirect measurement $\varepsilon(P) = t \cdot S(\tilde{Y})$, where t - Student's coefficient, and corresponds to confidence probability $P = 1 - q$ and amount of freedom degrees f_{ef}, calculated by the formula:

$$f_{ef} = \left(\left[\sum_{i=1}^{m} b_i^2 S^2(\bar{x}_i)\right]^2 - 2\left[\sum_{i=1}^{m} \frac{b_i^4 \cdot S^4(\bar{x}_i)}{(n_i+1)}\right]\right) / \sum_{i=1}^{m} \frac{b_i^4 \cdot S^4(\bar{x}_i)}{(n_i+1)},$$

where n_i - amount of measurements during determination of argument x_i.

1.8. To calculate the limits non-excluded systematical error (non-excluded excesses of systematical error) θ_d.

$\theta_d = \theta(P) = 1{,}1 \cdot \sqrt{\sum_{i=1}^{m} b_i^2 \cdot \theta_i^2}$, $P = 0{,}95$.

1.9. To calculate confidence limits measurement result error Δy. If $\theta(P)/S(\tilde{Y}) > 8$, than $\Delta y = \theta(P)$, if $\theta(P)/S(\tilde{Y}) < 0{,}8$, than: if $0{,}8 < \theta(P)/S(\tilde{Y}) < 8$, $\Delta P = K(\varepsilon(P) + \theta(P))$, where K – coefficient depending from confidence probability and from relation $\theta(P)/S(\tilde{Y})$. The value of K depending upon relation $\theta(P)/S(\tilde{Y})$ for probabilities $P = 0{,}95$ $P = 0{,}99$ (table 18).

The value of K

$\theta(P)/S(\tilde{Y})$	0,5	0,75	1	2	3	4	5	6	7	8
K(for $P = 0{,}95$)	0,81	0,77	0,74	0,71	0,73	0,76	0,78	0,79	0,80	0.81
K(for $P = 0{,}99$)	0,87	0,85	0,82	0,80	0,81	0,82	0,83	0,83	0,84	0,85

2. While processing the series arguments of observations' results with *non-linear* dependence and *presence* of correlation between errors of arguments' measurements, it is necessary to do the following:

2.1. To calculate the correlation coefficient between arguments X_i and X_j

$$r(X_i, X_j) = \frac{D(X_i, X_j)}{\sqrt{s(X_i) \cdot s(X_j)}}, \quad D(X_i, X_j) = \frac{1}{n-1} \sum_{k-1}^{n} (x_{i,k} - \bar{x}_i)(x_{j,k} - \bar{x}_j),$$

$s(X)$ - the value of mean square deviation of an argument (see in 1.3.)

2.2.To estimate the significance of correlation between errors of arguments X_i and X_j using Student's t-criteria :

if $t = \left| \frac{r(X_i, X_j)\sqrt{(n-2)}}{\sqrt{1 - r(X_i, X_j)^2}} \right| < t_\propto(\upsilon)$,correlation is insignificant, so the presence of correlation may not be calculated , $t_\propto(\upsilon)$ - is the boundary value of Student statistic (table 10), at $\nu = n - 2$ degree of freedom and α level of significance , n - number of observations of each of the values X_i and X_j

2.3. If correlation coefficient is significant method of contraction is used.

2.3.1. Calculate the value of measured magnitude Y_i , $i = 1; m$, for each group of argument observations $(x_{1,1}; x_{2,1} \dots x_{m,1})$, $(x_{1,n}; x_{2,n} \dots x_{m,n})$.

2.3.2. To calculate the result of measurement

$\tilde{Y} = \frac{1}{n} \sum_{i=1}^{n} Y_i$;

2.3.3. To calculate mean square deviation of measurement

$S(\tilde{Y}) = \sqrt{\sum_{i=1}^{n} \frac{(Y_i - \tilde{Y})^2}{m(m-1)}}$.

2.3.4. Then perform the calculations according to procedure (see in 1.7-1.9)

The order of work performance

1. To measure resistance $n = 10$ of different resistors with the help of multimeters using the voltmeter - ammeter method. To write down obtained series of observations.

2. To calculate the result of measurements and confidence limits of error Δy according to formulas in 1.1-1.9 taking into account the quality of (НСП non-excluded systematical error)components we use the boundary of maximum allowable error of multimeters on chosen range of observations and conductor resisnance .

3. To estimate the presence of correlation between errors of arguments.

4. To calculate the value of observations and confidence limits of error Δy according to formulas 2.1-2.7

Test questions

1. How does the result of average measuring with repeated observations determined?

2. How are fixed and random errors considered while determining the result of measurement ?

3. What is the meaning of test of significance of error correlation of observations?

4. What is the method of contraction?

Laboratory Work #6

Methods of Preprocessing of Direct Measurement Results with Multiple Observations

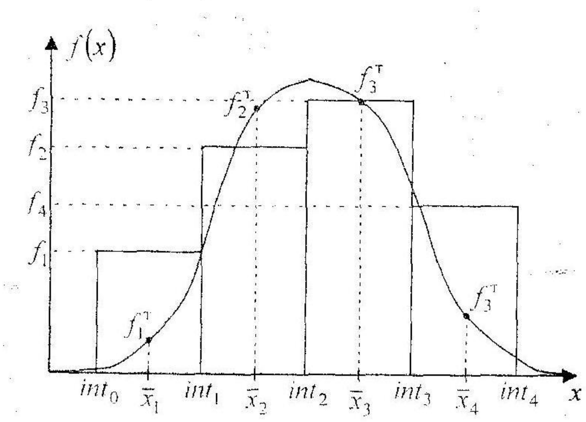
Aim of the work: to get acquainted with methods of preprocessing of direct measurement results with multiple observations. Learn how to determine the law of random inaccuracy component distribution and find the result with enormous error.

Theoretical Data

Processing of direct measurement results with multiple observations is held according to ДСТУ ГОСТ 8.207:2006. The form of observation results distribution law is evaluated by the agreement criteria. During the evaluation by means of distribution histogram the Pierson's criteria χ^2 is used.

Histogram construction algorithm:

1. Find minimal x_{min} and maximal x_{max} values.
2. Experimental data are divided into ℓ intervals. Number of intervals is determined as $\ell=[\sqrt{n}]$, at n<100, where [] is an integer part.
3. Determine the width of histogram integrals $\boldsymbol{h=(x_{max}-x_{min})/\ell}$.
4. Determine integral boundaries $\boldsymbol{int_1=x_{min}+i*h,\ i=0...\ell}$.
5. Calculate empirical frequencies $\widehat{m}_j$ - number of integer values, which are included in ***j***-th interval ($int_{j-1}\le x_k<int_j$, $k=1...n,\ j=1...\ell$).
6. Calculate histogram marks $\boldsymbol{f_j=\widehat{m}_j/(n*h)}$, if any value of f_j=0, then it is necessary to decrease number of intervals ℓ, or to join them.
7. Construct the histogram, form of which determines the distribution type (pic.13).



Pic.13 Histogram

Pierson's criteria χ²:
1. Determine average values of *j-x* histogram integrals $\bar{x}_j=(int_j+int_{j-1})/2$, where $int_{j-1}(int_j)$ – values of interval boundaries.
2. Calculate parameters for chosen tightness function *f (x)* by means of the investigated sample.
3. Determine appropriate theoretical values of $\boldsymbol{f_j^T=f(\bar{x}_j)}$ by means of the chosen tightness function *f (x)*.
4. Calculate theoretical frequencies $\boldsymbol{m_j^T=f_j^T*n*h}$.
5. Calculate statistics of χ_p^2: $\chi_p^2=\sum_{j=1}^{l}(\overline{m}_j-m_j^T)^2/m_j^T$.

If $\chi_p^2<\chi_\alpha^2(v)$ hypothesis of the distribution law is accepted.
Values0 of $\chi_\alpha^2(v)$ are found in tables (table 15), value of v=ℓ-k-1, k – number of parameters of the chosen distribution law.

Table 15

Pierson's coefficient $\chi_\alpha^2(v)$

ν	α			ν	α			ν	α		
	0,1	**0,05**	**0,01**		**0,1**	**0,05**	**0,01**		**0,1**	**0,05**	**0,01**
1	2,71	3,84	6,64	8	13,4	15,5	20,1	15	22,3	25	30,6
2	4,61	5,99	9,21	9	14,7	16,9	21,7	16	23,5	26,3	32,0
3	6,25	7,81	11,3	10	16,0	18,3	23,2	17	24,8	27,6	33,4
4	7,78	9,49	13,3	11	17,3	19,7	24,7	18	26,0	28,9	34,8
5	9,24	11,1	15,1	12	18,5	21,0	26,2	19	27,2	30,1	36,2
6	10,6	12,6	16,8	13	19,8	22,4	27,7	20	28,4	31,4	37,6
7	12,0	14,1	18,5	14	21,1	23,7	29,1				

Determination of results with excessive errors

In case of low result accuracy requirements, we can operate the simplest criteria: “3σ” (Wright’s), Romanowski’s and Dickson’s

The application of “3σ” (**Wright’s**) criterion is the following:

1) If one ”suspicious” result x' from the row of observations x_i, $i=\overline{1,n}$ is checked**,** then the ”suspicious” result x' is removed from the row x_i, $i=\overline{1,n}$ and the average x and mean square $\hat{\sigma}_x$ are calculated.

   If the condition $|x'-\bar{x}| > 3\hat{\sigma}_x$ is carried out, then x' is said to have a rough error.

2) If the whole row of results x_i, $=\overline{1,n}$ is checked:
   For a row of results x_i, $=\overline{1,n}$, population mean $\bar{x}$ and mean square $\hat{\sigma}_x$ are determined. All the observations results, which satisfy the condition $|x'-\bar{x}| > 3\hat{\sigma}_x$, are said to have rough errors. In case of uniform division such conclusion satisfies the condition $|x'-\bar{x}| > \sqrt{3\hat{\sigma}x}$, for the triangular - $|x'-\bar{x}| > \sqrt{6\hat{\sigma}x}$
   Romanowski’s criterion.
   The result x_i from the row of observations has a rough error, if

$$t = \frac{x'-\bar{x}}{s(x)} > t_\alpha',$$

where $s(x)$- assessment of standard deviation of results (sampling), calculated without taking into account the suspicious result;

$\bar{x}$- the average value of sampling;

t_α'- modified Student’s coefficient (table 16), which is chosen regarding the sampling amount n and significance level α.

Dickson’s criterion

The measurement results are ordered incrementally:

$x_1 < x_2 < ... < x_n$.

The result x_n has a rough error if

$$K_D = \frac{(x_n - x_{n-1})}{(x_n - x_1)} > z_\alpha$$

Where z_α – coefficient, value of which is chosen regarding the sampling amount n and significance level α (table 17). For intermediate values of n during z_α determination, linear interpolation is used.

Table 16

Modified Student's coefficient t_{α}'

n	α		n	α		n	α		n	α	
	0,05	0,01		0,05	0,01		0,05	0,01		0,05	0,01
2	15,561	77,964	10	2,372	3,409	18	2,168	2,997	26	2,099	2,840
3	4,969	11,460	11	2,327	3,310	19	2,156	2,953	27	2,094	2,830
4	3,558	6,530	12	2,291	3,233	20	2,145	2,932	28	2,088	2,820
5	3,041	5,044	13	2,261	3,170	21	2,135	2,912	29	2,083	2,810
6	2,770	4,355	14	2,236	3,118	22	2,127	2,895	30	2,079	2,802
7	2,616	3,963	15	2,215	3,075	23	2,119	2,880	40	2,048	2,742
8	2,508	3,711	16	2,197	3,038	24	2,112	2,865	60	2,018	2,683
9	2,431	3,536	17	2,181	3,006	25	2,105	2,852	120	1,988	2,628

Table 17

z_{α} coefficient value

n	α				n	α			
	0,10	0,05	0,02	0,01		0,10	0,05	0,02	0,01
4	0,68	0,76	0,85	0,89	16	0,28	0,33	0,39	0,43
6	0,48	0,56	0,64	0,70	18	0,26	0,31	0,37	0,41
8	0,40	0,47	0,54	0,59	20	0,26	0,30	0,36	0,39
10	0,35	0,41	0,48	0,53	30	0,22	0,26	0,31	0,34
14	0,29	0,35	0,40	0,45					

Work procedure

1. Build a histogram displaying the observations of LW#6.
2. Determine the result distribution law by the criterion χ^2. Use the uniform, triangular and Gaussian laws.
3. Check the series of observations for excessive error presence by all the mentioned criteria.

Control questions

1. Explain the reason of determination of random inaccuracy distribution law.
2. What is the histogram construction algorithm?
3. How can be determined the theoretical distribution law?
4. How the correctness of histogram construction can be checked?

Uncertainty
погрешность; недостоверность; неопределённость; неточность
uncertainty in calibration — погрешность поверки или градуировки;
uncertainty in measurement — погрешность измерения;
uncertainty on a result — погрешность результата
- absolute uncertainty
- clock uncertainty
- combined uncertainty
- component uncertainty
- delay uncertainty
- documented uncertainty
- experimental uncertainty
- fractional uncertainty
- individual uncertainty
- instrumental uncertainty
- overall uncertainty
- phase uncertainty
- random uncertainty
- root-sum-square uncertainty
- statistical uncertainty
- synchronization uncertainty
- systematic uncertainty
- time uncertainty
- total uncertainty