Yu. PER

ECONOMIC METROLOGY

Part II

Labor process – a social "molecule"

$$T_q = \frac{\sum_{i=1}^{n} C_{pi_i} \cdot C_{ii_i} \cdot t_i}{Q}$$

Ministry of Science and Higher Education of the Russian Federation
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Institute of Economics and Management

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Labor process – a social "molecule"

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The book outlines the philosophical foundations and methodology associated with the transfer of International Metrological System of Measurements to socio-economic processes and, in particular, to single labor processes.

The book will be useful to undergraduate students and postgraduate students in the study of courses in natural sciences, labor economics and ergonomics and all those who deal with problems of socio-economic dimensions.

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Contents

Preface

We use the term “economic metrology” to describe the results of our research for several decades. Such science does not exist in our society so far. However it is strongly required by many researchers and some of them were personally involved in its development (A. G. Granberg, A. E. Kogut).

As it is well known, the word *metrology* [Greek metron – measure + + logos – notion, study] denotes the study of measures, various systems of measures and weights, ways of determining their images. An applied branch of science has been formed on the grounds of the achievements of natural, engineering and social sciences, and its research object covers the measurement of physical units, methods and means required for their integrity and accuracy. Theoretical, applied and legislative branches have emerged in the frameworks of metrology.

Economy [Greek oikonomike, which literally means “art of housekeeping”] is an aggregate of production relations of certain social structure. As claimed by C. R. McConnell and S. L. Brue – the authors of popular textbook “Economics”: “Economics deals with the issues of management and efficient utilization of limited resources to ensure the maximum satisfaction of human material needs. Consequently, the combination of two words (“metrology” and “economy”) into one notion suggests a new research and practical course of social life related to **measurements** in national economy management.

Metrology had passed a long and difficult way of development in different countries until the international system of units was formed. Trade and later industrial development caused difficulties driven by diversification, inaccuracy and randomness of units. Scientific achievements made it possible to put forward the idea of referring the length unit and other values to permanent natural phenomena; in much the same way as it had been done before when opting for time units. It allowed to ensure the recoverability of units and gave a chance to test the viability of measures due to re-measurements. The development of metric system of measurements (which was originally thought of as a system without national features and the one that could be adopted internationally) facilitated the handling of the problem associated with the abolishment of units’ diversification.

France is regarded as the motherland of metrology. After the French Revolution (1789-95) the Constitutional Assembly decreed the requirement for common measures and weights following the report by Talleyrand.

The notion of the system of units was further widened by the German mathematician C. Gauss. In 1832 he proposed a method for forming combined units for a wider range of values, for magnetic quantities, in particular. In 1851 W. Weber extended the system of units proposed by C. Gauss to electrical quantities. Before 1919, at the suggestion of French metrologists, International Bureau of Weights and Measures worked out the system of units based on such units as meter-kilogram-second (MKS), the one which was recommended as international. However, World War I cut this work short. It was only after World War II when the unification of units was focused at again as an issue of international concern.

In 1948 IX General Conference on Weights and Measures considered the proposal of International Union of Pure and Applied Physics related to the establishment of international practical system of units. Moreover, the French Government introduced the project on the international unification of units. In October 1960 XI General Conference on Weights and Measures eventually adopted the new system named "International System of Units" (SI). The adoption of International System of Units was the significant progress thereby making it possible to switch to the universal system of units, i.e. the system that covers all types of measurements.

X General Conference on Weights and Measures accepted the following resolution: to adopt at the international stage the range of basic units of the practical system of units:

a unit of length – *meter*,
a unit of mass – *kilogram*,
a unit of time – *second*,
a unit of thermodynamic temperature – *degree Kelvin*,
a unit of amount of substance – *mole*,
a unit of luminous intensity – *candela*,
and later some extra units were adopted:
a unit of plane angle – *radian*,
a unit of solid angle – *steradian*.

Relying on seven basic units, the metrology develops a large system of derived units applied in different scientific fields and in practice in such sections as:

I. Space and time.
II. Periodic and relative phenomena.
III. Mechanics.
IV. Heat.
V. Electricity and magnetism.
VI. Light and relative electromagnetic radiation.
VII. Acoustics.
VIII. Physical chemistry and molecular physics.
IX. Ionizing radiation.

However, the metric system is not a closed one, it keeps on developing occupying sections of economy and sociology which have not been subjected so far to its measurement processes. The openness of metrological system is of crucial importance in terms of integration of economy and metrology into economic metrology. We believe that **qualimetry** as a science of quantification is a liaison between economy and metrology.

In our studies we use the fact that the basic metric units are not "God given" but taken by a man (mankind) himself and then reified quantitatively for himself in the surrounding natural phenomena. So far, let us emphasize our statement without any proof that a meter is a step of a standard human body; a kilogram is a liter (dm^3) of water required for a standard human body for the daily basic metabolism; a second is one cycle of contraction of the heart muscle of a standard human body in the state of complete rest (basal metabolic state).

If these allegations are true, Protagoras, who is credited with the thesis that "man is the measure of all things", was also right. Still the life of a person can be treated with a wide variety of aspects: biological, economic, social, etc. "In the real world there are only three types of "products": substance, energy and information" [50]. A living organism can give substance to the external environment as a result of metabolism based on the law of conservation and transformation of mass of substances. A living organism generates energy continuously, and muscular energy is very important for animals because it provides them with food and preserves their life. The most valuable is managing the impact on the environment, which a person deliberately performs generating necessary information for this purpose.

We consider all the phenomena of nature and society as manifestations of the three basic laws:

substance: law of transformation and conservation of mass of substances;

energy: law of transformation and conservation of energy;

information: law of transformation and accumulation of information.

Every single conversion process is the unity and simultaneity of manifestation of previously mentioned laws.

The comparison of basic units with the manifestations of the mentioned fundamental laws claims that the metric system should be supplemented by the **information measurement** units in terms of basic units and by the whole system of economic and social units through it in terms of the sections of derived units. It is discussed in this book.

Human relations in a society are enmeshed by money "octopus". "Money bewitches people. Because of money, people suffer and **work** for them. They come up with the most ingenious ways to get it and the cleverest ways to spend it". People are trying to understand the nature of money and turn to economic sciences with the help of which it appears that money is a multifunctional measuring instrument of social relations and, in particular, a means of circulation, a measure of value, a store of value, a means of payment.

In social phenomena and processes there has been a concept and actual functioning of money for thousands of years. "No one dares to, and shall not doubt, – says a faithful disciple of lawyers, Philippe of Valois in a decree of 1346, “only we and our royal majesty have the right of ... coinage, supplying money and any instructions regarding the coin, the right to let the money in circulation, and at the price we want and consider for the good”.

The publisher of the world famous guide Hutte in 1936 informed that the value expressed in rubles comes from the fact that 1 ruble is an equivalent to 0,774234 grams of pure gold. But then he warned that in many countries (e.g., England, USA, Sweden, and others) the previously existed exchange of treasury and bank notes for gold had been closed, and therefore their value was subject to significant fluctuations, and the tables relevant for more or less long period of time cannot be made in respect of such currencies. “The rate exchange value of these currencies, – concludes the publisher, – has to be found out from the newspapers”. And so the gold standard disappeared from the world stage after the Great Depression of 1929-32. And, as the authors of the famous textbook “Economics” contend: “On August 15, 1971 President R. Nixon suspended the convertibility of US dollar into gold”. Commission for Gold, set up by R. Reagan in 1981, did not recommend to return to the gold standard.

At the beginning of “perestroika”, when the country – the Soviet Union, still convulsively thrived, a number of international organizations represented by the Fart Fund decided to hold an international contest for the best project of Soviet ruble conversion among stable international currencies. As it was clear from the results, quite a large number of experts (more than 600 bids) took part in the contest. We were also among the contest participants and had our own proposals to change the monetary system based on labor measures. After considering the contest results, 5 prizes were awarded, but we got only a diploma. The prizes were given out, and probably materialized by the winners for their personal purposes. However, it was sad that the very object of conversion – Soviet ruble – disappeared from the world stage. Did the organizers expect such an outcome of the contest?

The successors of Soviet ruble became a “big brother”– Russian ruble with biceps bird of prey and fourteen CIS “sovereign independent younger brothers” of minted birds, animals and personalities. Was the situation in Earth noosphere improved after that? Modern circumstances and an endless series of tensions in the world create more and more pessimistic people.

Not so long ago (in 1993) Margaret Kennedy published a brochure entitled “Money without interest and inflation. How to create a medium of exchange useful for everybody?” She appeals to readers with a call to participate in changing the global monetary system. But how can the broad mass of people manifest itself in such a confusing system, which is the percentage current monetary system? She writes: “If we accept the existence of public institutions, which by their nature are directed against these objectives, the social justice, environmental survival and social freedom are under threat”.

A practical suggestion by the author carries some shade of hypotheses, but they excite the mind, force everybody to leave his/her own little world, the vicious circle of “compound interest” on investment and look at the problem from the standpoint of the whole humanity based on the interests of the entire noosphere of Earth, as Academician V. I. Vernadsky would say.

The historical fact described by M. Kennedy sounds very obliging. We will give it in full. In the Weimar Republic (1924-1933) after the hyperinflation of 1923, in 1924 Reichsmark was introduced, which meant a return to the gold standard. After “Black Friday” in 1929 and the economic crisis which started after that, Reichsbank was forced to return a part of its gold reserve taken in credit in the United States. As after that the circulation money supply could not be secured by gold in the required amount any more, Schacht, being at that time President of Reichsbank, began to reduce gradually the amount of money in circulation. The ensuing shortage of money led to higher interest rates, which was followed by the decrease in investment business, bankruptcy of companies, rising unemployment, and there appeared a good breeding ground for radicalism that eventually brought Hitler to power. Thus, the monetary policy became a prerequisite for the victory of Nazis.

Silvio Gesell foresaw such course of events. Already in 1918, shortly after the end of World War I when everyone was talking about peace and numerous organizations advocating peace were appearing, he wrote to the publisher of Berlin newspaper “Zeitung am Mittag” the following letter: “In spite of the fact that the nations give sacred oath to condemn war at all times, despite the call of millions: “No war!”, in spite of all hopes for the better future, I have to say: **If the current monetary system saves the percentage economy, I will dare to claim today that within 25 years we will face a new, even more destructive war** (emphasized by Yu. Per). I see the course of events very clearly. The current level of technology will allow the economy to reach the highest efficiency very rapidly. Despite the severe damage during the war, there will be a rapid formation of capital and when it is in plentiful supply, the interest will be reduced. Then money will be withdrawn from circulation. It will lead to the reduction in industrial production, the streets will be full of the army of the unemployed... The discontented masses of people will reveal wild, revolutionary insights, poisonous sprouts of supernationalism will appear. No country will be able to understand the other, and it will result only in a war”.

The greatest obstacle to the monetary system transformation is the fact that very few understand the problem, and even fewer know that there is a solution (but they do not want to realize it).

Deep inflation processes in transition economy clearly and tangibly demonstrate the instability of the whole monetary system and further urgent necessity to differentiate the functions of money and their units. First of all, the money currently seeks another unit distinguished from the ruble (the kopeck has already gone) as **a measure of cost.**

Some legal acts and norms (decrees, regulations, directives, decisions) appeared as a result of inflation and issued by administrative organs of various hierarchical levels during the past years amuse thinking people and impress interested ones. For example, a trolleybus passenger is imposed "a punishment" for a possible "crime": "The fine of 0,1 of the minimum wage for a free ride". If there is one-tenth of the minimum wage, there must be the whole unit – 1 minimum wage. But what measure is it? What social phenomena can and should it measure?

The minimum payment for the work performed (minimum wage) is set by the state bodies in the respective terms of money (rubles, dollars, marks, etc.). However, the very concept of value is something objective, physiologically vital activity of the phenomenon. Viewed in this way, the introduction of a new official means of payment of fines and other services in the form of the minimum wage is very symptomatic. At present (March, 1996) one minimum wage is 76,000 rubles a month, in the very recent past it was 39,000 rubles a month. Thus, the minimum wage is a kind of constant measure of living conditions and it constantly changes its ruble equivalent. If we convert a monthly minimum wage into a daily minimum wage, we will get:

76,000:30=2,533 rubles per day;

2,533:24=105,56 rubles per hour;

105,56:60=1,76 rubles per minute.

Surprisingly, but this value is the same as that from the standpoint of modern labor physiology, a person with a healthy body and able to work requires minimum amount of nutritional substances (about 1,8 kcal/min) for metabolism. Thus, a fixed minimum wage reflected a physiological minimum of energy consumption in the human body during the transition from "no work" (basic metabolism) to "work" (to suitable behavior of an unemployed about getting a minimum wage). Moreover, the minimum wage acts as the measure of labor product set according to their ability to replenish physiological energy losses in a human body.

Perhaps, this fact is a kind of confirmation of Karl Marx's predictions that "only on the world market money fully acts as a commodity, the natural form of which is the social form of human labor in abstracto. The process of its existence becomes adequate to its concept" [28, P.378, footnote 89].

Much is said about social justice in the period of structural adjustment. None of the modem politicians will fail to say that he is committed to the principle of fairness. However, as soon as it becomes necessary to solve problems related to justice more specifically, there are serious difficulties in the theoretical study and practical implementation of justice.

When you ask the question: "Why did the Soviet Union fail to build socialism?" Instead of a clear answer another question comes up: "Was justice put right in the Soviet Union?" Justice in itself means the relationship between people with the "right to know", i.e. on the basis of law. According to the Marxist theory it is known that "by its very nature the right can be exercised only in the application of an equal measure" and generalizes the meaning of the law-governed state that "the right of manufacturers is **proportional** to the labor they produce, ... the equality means that measurement is made by equal measure – labor, ... but for labor to serve as a measure it must be determined by duration or intensity, otherwise it would cease to be a measure" [26, P.48].

Thus, we face a major problem – the definition of labor measure, measurement of its quantity and quality. Without solving this basic problem the meaning of law-governed state is lost, the slogan "To each according to his work" hangs in the air, justice, no matter how much we speak about it, remains a wishful thinking. But where is the key to solving the problem? It is in the same Marxist logic of **labor measure**, which can be legally implemented on the basis of metrology research of physical and informative and psychological manifestations of human labor processes. Our further research is dedicated to this problem. The essence of this research is described in our earlier works and, in particular, in the journal "The Economist", 1991, No 3.

Politicians, economists and lawyers are trying to see justice in the quantitative monetary manipulations, both with respect to the individual and between different parts of the state and between different states. But we have already seen from the history the consequences of resolving the issues of justice on the basis of theory and practice of mercantilism. Fair social relations can be based on **the system of measures** of economic metrology where the central position is occupied by **the labor measure, measure of consumption, measure of fair distribution and exchange.** However, there is such a comprehensive notion as **cost**, which is interpreted differently by researchers in economics. We proceed from the following definition: "Cost is the relation of production costs to utility" [26]. In our economic metrology studies the important place is given to the utility measurement on the basis of qualimetric measures of products and measures of living and past labor. Through them we come to the cost measure and quantification of **monetary measure** of cost.

To prove our points of view on the stated problems of economic measures we needed to do multi-disciplinary research of a wide range of physical, technical, chemical, biological, labor, qualimetric, economic and social measurement procedures in public life. We intend to present our views in the following consequence.

Part I. Philosophy of everyday life.

Part II. Human society as a cybernetic system.

Part III. Labor process.

Part IV. Labor qualimetry.

Part V. Product qualimetry.

Part VI. Production qualimetry.

Part VII. Cost economy.
Part VIII. Entrepreneurial qualimetry.
Part IX. Economic metrology.
Part X. Social qualimetry.

•••

And now about the features of our work. It is mainly in the form of compilation. In Part 1 the author got the following results of research [39]:

– representation of the life development stages on Earth in the form of stepped functions of nooevolutional process;

– general concept of economic metrology;

– suggesting the idea of distribution of metrology principles onto economic and social values;

– development of qualimetry principles as the binding system of physical, technical, chemical and biological measurement units with the system of economic and social measures;

– formulation of the law of information transformation and accumulation;

– analysis of the formation principles of information concept as the reflected complexity;

– proposal for introducing the notion of "information quantum" into scientific use based on the own interpretation of "the second remarkable limit";

– substantiation of the quantitative measure of complexity.

The proposed book "Labor process – a social "molecule" is the revised edition of the author of the book "Labor process. Engineering and economic search for labor measure" (1974). Most of the aspects, as we believe, have not outdated and even have become more urgent for today's situation in economic life of the society. The most essential aspects in this part are:

– suggesting the idea of initial element of labor economics – single labor process;

– representation of the labor process as a cybernetic system;

– quantitative expression of the labor process in the form of mathematical model of information and energy manifestation of the labor subject;

– introduction of the notion "Q-factor of labor process functioning at the workplace" into scientific terminology;

– substantiation of the quantitate criteria and method of calculating the costs of live labor in work-hours applying the indexes of hardness, complexity, intellectual intensity and duration of the labor process;

– development of the optimized model of the workplace functioning in the form of qualimetric equation of the workplace;

– formulation of own definitions of labor economics as a science, economic category and socio-practical activity;

– and the most important – substantiation of the quantitative measure of labor.

The work compilation nature is in the fact that in order to substantiate the proposed ideas we use works of scientists and publicists to the extent necessary for us “to construct the architectural structure”. So, we use the letters of Russian, Greek and Latin alphabets, words – from the Russian language dictionary and dictionary of foreign words, formulas – from reference-books in mathematics and physics, we borrowed individual “mind-bricks”, “mind-blocks”, “mind-panels” from different authors, often without making changes in their style – only for them to serve well in the structure we called “Economic metrology”. Many thanks to everybody whose thoughts and words have served as decent “building material”.

Philosophy of everyday life. Extract

Before reading part II “Labor process –a social molecule”, we propose the extract from part I “Philosophy of everyday life [39] as Chapter 1, in particular, the contents of the entire book and concluding chapter 9.

Thus, in part I the following issues are considered.

Chapter 1.What is life? General theory of life. Material-energy and information unity of life. Mathematical summary.

Chapter 2. Substance. Aggregate states. Radioactive substances. Bioinert substance. Substance structure. Physical and mathematical summary.

Chapter 3. Forces in nature. Motion generates a force. Movement measurability. Long-range forces. Forces of electromagnetic field. Forces of charged bodies. Magnetic forces. Physical and mathematical summary.

Chapter 4. Energy conversion. Energy. Conversion process. Physical and mathematical summary. First law of thermodynamics. Entropy. Electric energy. Mass and energy ratio.

Chapter 5. Conversion and accumulation of information. What is idea? Monad, entelechy. W. Leibniz’s monadology. A. Renyi about information. Three approaches of A. N. Kolmogorov to the notion “amount of information”. C. Shannon’s bandwagon. D. Felker and M. Volkenstein on the interrelation of energy and information. A. Wilson and M. Wilson on measures of information quantity. Measure of uncertainty. Measures of structural complexity. Measures of metric information. Three aspects of information. General law of information conversion and accumulation. Mathematical summary. Efficiency and redundancy.

Chapter 6. Problems of measuring complexity. Philosophy of complexity. Complexity and related notions. On criteria of complexity. Features of complex and highly organized systems. Measurement unit of complexity. Variety of sense organs. Mathematical summary.

Chapter 7. Information as reflected complexity. Notion of system. Interpretation of the second remarkable limit. Quantum of information. Unit of complexity. Biophysical representation of information and complexity. Mathematical interpretation. From theory of desirability functions.

Chapter 8. Evolution of life. Hypothesis of origin: Kant, Copernicus, Ptolemy. Origin and chemical evolution of Earth. Living substance. Scheme of stepped evolutionary processes on Earth.

Chapter 9. Noosphere – sphere of labor. New geological force. Noosphere as the sphere of labor. Homo sapiens faber. Stepped nooevolutional process. Summary. Kingdom of labor processes.

Chapter 1
Noosphere – sphere of labor

"Man, as he is observed in nature, like all living organisms, like every living substance is a certain function of the biosphere in its particular space-time" [53] .

Man, like all living things, is not self-sufficient natural object, independent of the environment. The continuity of a living organism with the environment is undoubtful for a modern naturalist. A biogeochemist takes it and tries to accurately and perhaps deeply understand, express and establish this functional dependence. Every living organism in the biosphere, a natural object, is a living natural body. A living substance of the biosphere is the totality of living organisms.

A living substance, as well as the entire biosphere, has its special organization and can be regarded as a naturally expressed function of the biosphere. There is a continuous exchange of material and energy between the inert lifeless (inorganic) part of Earth, between its inert natural bodies and living substances inhabiting it, which is materially expressed in the motion of atoms induced by the living substance. This exchange in the course of time is expressed by the equilibrium naturally changing, continuously striving for stability. It penetrates into the entire biosphere, and this biogenic current of atoms largely creates it. Thus, the biosphere is inseparably linked throughout the whole geologic time with the living substance inhabiting it.

1.1. New geological force

In the course of geological time we observe the process of continuous expansion of the biosphere boundaries – its population with a living substance. The biosphere organization – organization of a living substance – should be regarded as the equilibrium in single cycles and, at the same time, as the development process in the course of geological time.

The evolutionary process of living substances continuously spans the entire biosphere throughout the whole geological time, so that the evolution process – change – is transferred to the natural bioinert and biogenic bodies, playing the major role in the biosphere, to soils, to surface and underground waters (seas, lakes, rivers, etc.), to coals, bitumen, limestone, organore, etc. The evolution of types passes into the biosphere evolution. At the same time, the evolutionary process obtains a particular geological significance due to the fact that it created **a new geological force – the scientific thought of social mankind.**

We are just going through its clear entry into the geological history of the planet. In the last millenniums, there was an intensive growth of influence of one species of living substance – civilized mankind – on the biosphere change. Under the influence of humanity and scientific thought the biosphere transits to a new state – **the noosphere**.

Humanity is encompassing the entire planet in a natural movement that lasted with the ever-increasing pace for several billion years or so, is distinguishing itself, is being separated from the other living organisms as a new unprecedented **geological force**. At a rate, comparable with the reproduction, expressed by the geometric progression over time, the ever-growing set of new for the biosphere inert natural bodies and new large natural phenomena is created in it.

Before our eyes, the biosphere is rapidly changing. And there can hardly be any doubt that its restructuring by scientific thought through the organized human labor, manifested in this way, is not an accidental phenomenon, which depends on a human will, but it is a spontaneous **natural process**, whose roots lie deeply and were prepared by the evolutionary process, which lasted for hundreds of millions of years.

Man must understand how only the scientific rather than philosophical or religious concept of the world will possess it, that it is not a random, independent of the environment freely acting natural phenomenon. It is the inevitable manifestation of the large natural process, naturally having lasted for at least two billion years.

Currently, under the influence of the surrounding horrors of life, along with an unprecedented blossom of scientific thought, we have to hear about the approach of barbarism, collapse of civilization, self-destruction of humanity. These sentiments and judgments seem to me the result of insufficient penetration into the environment. The scientific thought has not entered our life yet; philosophical and religious skills, not satisfying the realities of today's knowledge, are still persisting. The scientific knowledge, which manifests itself as a geological force creating the noosphere, cannot lead to the results contrary to the geological process whose creation it is. This is not an accidental phenomenon – its roots are very deep. This process is connected with the creation of human brain [51].

1.2. Noosphere as the sphere of labor

The main impact of human thoughts as a geological factor is revealed in its scientific manifestation: it mainly constructs and directs the technical work of the mankind. Man as a constituent element of humanity thought scientifically and changed the biosphere with labor, adapted it to himself and created conditions for the manifestation of biogeochemical energy of propagation inherent by him. The population of the entire planet was completed by the beginning of XX century. We can assume that by the first quarter of the century it became the fact and it strengthens more and more every year. It was only possible due to the sharp changes in the living conditions associated with the new ideology, with the sharp changes in the tasks of state life, with the growth of scientific methods and instruments.

After many hundreds of thousands of years the coverage of the entire biosphere surface was completed by the single social species of the animal kingdom – man. There is no corner in the world inaccessible to him. There are no limits for his propagation. By his life, scientific thought and state-organized technique guided by it, man creates the new biogenic force in the biosphere, directing his propagation and creating favorable conditions for the population of the biosphere parts, into which his life had not penetrated yet, and even those places where there was no life before.

Humanity is one whole, and although mainly it is realized, the unity is manifested in the forms of life, which in fact deepen and strengthen it imperceptibly to humans, spontaneously, as a result of the unconscious appetence to it. The life of humanity, with all its diversity, has become indivisible, united. The event happened in the remote corner anywhere, of any continent or ocean is reflected and has consequences – large and small – in a number of other places, everywhere on Earth surface. The telegraph, telephone, radio, TV, planes, satellites have covered the entire globe. Communications are becoming simpler and faster. Every year their organization is increasing, is growing rapidly.

The scientific thought reached such depths of the matter structure that mankind learned to create artificial chemical elements, to artificially initiate and accelerate radioactivity. Now it is possible to conduct organic synthesis, create new strains of bacteria, species of plants and biological organisms. Moreover, mankind started to create artificial human organs and their transplantation.

It is clearly seen that this is the beginning of spontaneous movement, natural phenomenon that cannot be stopped by contingencies of human history. Here for the first time, perhaps, the relationship of historical processes with fossil history of the emergence of Homo sapiens is so evidently revealed. This process of the total population of the biosphere by man is conditioned by the course of history of scientific thought, it is inseparably connected with the rate of relations, with the successes in the mobile machinery, with the possibility of instant transmission of thought, its simultaneous discussion everywhere on the planet.

The fight against this major historical trend causes ideological opponents to actually obey it. State formations, which do not ideologically recognize the equality and unity of all people try, not ashamed of the means, to stop their spontaneous manifestation, but there is little doubt that these utopian aspirations cannot be securely realized. This will inevitably redound with the course of time, sooner or later, since the creation of the noosphere from the biosphere is a natural phenomenon, deeper and more powerful in its base than human history. It requires the existence of mankind as a whole. This is its inevitable prerequisite. This is a new stage in the history of the planet, which does not allow using, for comparison, without amendments, its historical past. For this stage creates substantially new in the history of Earth, and not only in the history of mankind.

Man first really realized that he is an inhabitant of the planet, and he can and must think and act in the new aspect, not only in the aspect of an individual, family or genus, states or their alliances, but also in the planetary aspect.

He, like all living things, can think and act in the planetary aspect only in the field of life – **in the biosphere**, in particular earth shell, with which it is inseparably naturally linked and from which he cannot escape. His existence is its function. He carries it with him everywhere. And he is inevitably, naturally, constantly changing it.

A man capable of labor is the creation of nature and society. And through labor the humanity creates and transforms Earth. **Noosphere, the sphere of mind, is by its very nature the sphere of labor.** But the sphere of labor is not self-sufficient, the area of people interaction cut off from the natural dependence. Here, the carrier of labor capability himself – Homo sapiens – is the result of the evolutionary process on Earth. Mankind becomes a geological force called upon by the very evolution to be the power of mind and with its transformative activity to continue the evolution of Earth in the direction of saving the biosphere from the destruction of ever-increasing excess of energy coming from Sun and Universe.

Humanity is called upon by the development history to become the keeper of its habitation. The evolution of Earth itself, the evolution of processes of substance and energy conversion in inorganic and organic world led to such a state that a biological organism appeared, which does not only convert substance and energy, but also creates something different from substance and energy – **ideas**, which are called information in the modern language.

1.3. Homo sapiens faber

The centuries-old dispute between idealists and materialists still remains unsolved in philosophy. Still there are discussions on the primacy of matter or spirit. At the same time, the controversial question on the essence and measure of labor is still disputable. The difference of a human in the biological fauna consists primarily in the fact that he is able to work – to put forward an idea and implement it in his activities by creating new things and processes compared to natural bodies and phenomena. **Man converts and accumulates information.** This is its fundamental difference from all congeners in the animal kingdom. But a human can become the transmitter and accumulator of information only in human society in the process of social labor. Man capable of labor, performing the labor **becomes a person**. One of the groups of persons (Homo sapiens faber) is the people of science whose labor is a high form of informational process.

The creator of the informational field of knowledge of the noosphere, a philosopher and naturalist V. I. Vernadsky uncommonly and clearly reflected the essence of scientific labor both by the books (information) left for his generation and by his actual life as a scientist. “Slow, hard, accurate, quantitative account – **first of all, the measurement** (emphasis is added by us) – and by no less accurate scientific description of the surrounding, the science and natural science, in particular, are moving forward. Millions, a gillion of facts are covered by convenient techniques newly created for this. And only with deepening and accounting so processed countless empirical material – with maximum precision and subtlety of accounting and description – the science can move forward.

Only occasionally, in the epochs of scientific thought blossom, there are revealed the new opportunities of such coverage of scientific facts, countless phenomena of nature and conversion of them into the instrument of penetration into the unknown – new fields of facts are opened. For a scientist it is clear that it is impossible to embrace the boundless, to express the nature of our reality and ourselves with words and notions. We can brightly feel the boundless only working on concrete facts. While working on scientific facts, actively entering the nature in its individual empirical areas, by this action the scientist is experiencing the reality of the world so fully and deeply that a person cannot do it in other forms of his consciousness. This is the largest and deepest – and complete – what is available for Homo sapiens faber by his existence spontaneously connected with the biosphere whose integral part he is.

Studying steadily the infinite nature, bottomless reality, embracing countless facts and going into them during the long life, a scientist, brighter than anyone, can realize the impossibility of explaining it in simple and clear verbal images. This feeling is senseless for a thinker, staying away from the empirical establishment of facts, from their collection and comparison. This inability is linked with the fact that a man, Homo sapiens faber, is only the transient stage in the evolution of forms of a living substance, in which inseparably and spontaneously he himself and potentially new future manifestation of life, which will replace him – a future not Homo sapiens – are revealed” [4].

1.4. Stepped nooevolutionary process.
Summary

“Over the last dozen – two dozen thousand years the geochemical impact of humanity that captured green living substance by agriculture, became unusually intense and varied. We see the amazing growth rate of the geochemical work of humanity. We see a still greater influence of consciousness and collective mind of man on geochemical processes. Man introduced a new form of impact of a living substance on the atom exchange between the living substance and inert matter into the world structure. Previously organisms affected the history only of those atoms, which were necessary for their growth, propagation, nutrition, breathing. Man extended this range, affecting the elements needed for engineering and for the creation of civilized life forms. Man acts here not as Homo sapiens, he acts as Homo sapiens faber (man of sense, producing, creating)" [4].

All that was said, can be represented as a block diagram of the evolutionary process on Earth (Fig. 1).

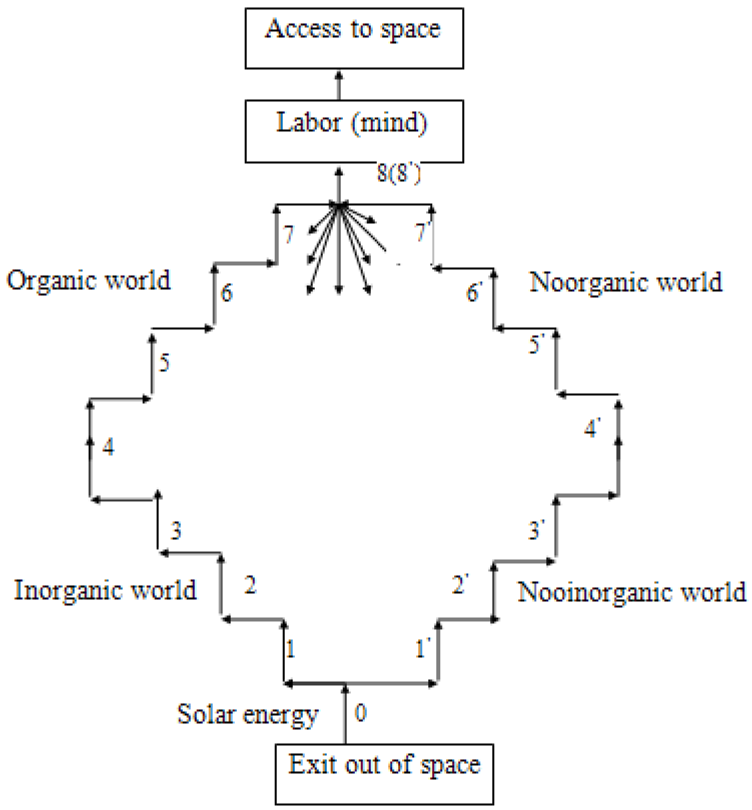


Fig. 1. Scheme of stepped nooevolutional process on Earth

Inorganic world
1. Gaseous natural substances.
2. Liquid natural substances.
3. Solid natural substances.
4. Radioactive natural substances.

Organic world
5. Microorganic world.
6. Vegetational organic world.
7. Animal natural world.
8. Humanity.

Nooinorganic world

1'. Gaseous artificial substances.
2'. Liquid artificial substances.
3'. Solid artificial substances.
4'. Radioactive artificial substances.

Noorganic world

5'. Artificial microorganisms.
6'. Artificial vegetation-like.
7'. Artificial animal-like.
8'. Noorobots.

We divide all forms of the evolutionary process into two kinds:
- Natural processes;
- Noologic (rational-human) processes.

In any individually considered process and in the totality of the processes the substance, energy and information conversion proceed simultaneously.

Evolutionary processes are depicted in the diagram in the form of stepped graphs $\uparrow\!\!\longrightarrow$. This image is taken by us for the schematic representation of the law of transition of quantitative changes (accumulation) into a new qualitative state. The horizontal arrow (→) – quantitative change inside the given state of substance, and the vertical arrow (↑) – jump from the given state into the new state, change of quality.

The substance is converted in the processes, transiting from one state into another, it retains its mass after the conversion.

The energy in the processes is converted from one form into another, and the total amount of energies before and after the processes is preserved.

The information is generated by the processes of substance and energy conversion, testifies the forms and number of conversions and is accumulated in the corresponding forms on the carriers.

The inorganic world is the totality of inorganic compounds formed by chemical processes of solar energy interaction with the substance of Earth, but not possessing the property of life.

The inorganic world is available on Earth in three aggregation states: gaseous, liquid and solid. Substance density (ρ) is the main quantitative characteristic of the aggregation states

$$\rho = \frac{M}{V} \;,$$

i.e. the ratio of the substance mass (M) to its volume (V).

The transition state from inorganic to organic is the radioactive state, i.e. the state when the given substance has an excess of internal energy and it can radiate it into the environment.

Now the notion of radioactivity as the ability of some atomic nuclei to transform into other nuclei with the emission of particles has already become common. The alpha decay, beta decay, spontaneous division of nuclei accompanied by gamma radiation are the examples of radioactive transformations. We distinguish the natural radioactivity, i.e. the radioactivity of isotopes that exist in nature, and artificial – the radioactivity of isotopes produced in nuclear reactions. One becquerel (Bq) called after the French scientist A. Becquerel is accepted as the quantitative measure of radioactivity. 1 Bq equals the activity of nuclide (atomic nucleus) in the radioactive source, in which one act of decay takes place in one second. In addition, the radio emission activity is expressed by the specific radioactivity through the ratio of radioactivity (Bq) to the mass of radioactive material (*m*), i.e.:

$$\mathrm{Bq}_m = \frac{\mathrm{Bq}}{m}.$$

The organic world is a set of organic substances formed from the inorganic ones as a result of chemical processes of Sun interaction with the substance and energy of Earth, having the property of life.

The organic world is represented by microorganisms, plants, animals. In this series of the substance, energy and information conversion, there is a quantitative characteristic associated with the biological productivity (β) and release of free energy during photosynthesis (*hv*) that can be expressed by the formula:

$$\beta = \frac{B}{t},$$

where B – biological mass of the producer during the life cycle; t – duration of the life cycle in time.

1.5. Kingdom of labor processes

The kingdom of humanity is especially distinguished in the organic world. Mankind, as well as everything living and lifeless on Earth, converts substance and energy, but differs in the specific ability to accumulate information, i.e. special practicability of actions. This ability forms the kingdom of special processes – **labor processes**. The ability of mankind to convert the substance of Earth, referred to the total of its biomass, can serve as the quantitative characteristic here, i.e.

$$\gamma = \frac{W}{B_h},$$

where W – mass of Earth substance converted by human labor; B_h – biomass of humanity; γ – productivity of humanity.

In addition to Earth substance, the mankind converts the energy of nature, thus increasing the value of its geological force, consequently:

$$\varepsilon = \frac{E}{T},$$

where E – energy of nature converted as a result of human labor; T – amount of labor committed by humanity during the considered period of geological time.

Each generation of mankind starts its labor activity based on the information (knowledge) of the previous generation, and thus, humanity deals with the objective law of nature – **law of information accumulation**. It follows that

$$J_1 < J_2 < J_3 ... < J_k \quad \text{and} \quad e = \frac{J_k}{T} \rightarrow \max,$$

where J_k – information accumulated by mankind as a result of labor activity to the period "k".

The foregoing is an additional confirmation of the provisions made by V.I. Vernadsky that mankind on Earth manifests itself as progressive geological force and this force is manifested in the form of constantly evolving labor activity related to the conversion of natural substances and organisms, conversion of natural energy and accumulation of information. Following V.I. Vernadsky, we call this process the nooevolutional process, or otherwise – evolution of mind.

The pointed out arguments are expressed on the scheme of nooevolutional stepped process on Earth (Fig. 1) as follows: solar energy (gravitational and electromagnetic) affects substances of Earth and interacts with its resistance energy (gravitational and electromagnetic).

Due to the energy of Sun the constant changes in the aggregation state of inorganic substances take place, the accumulation of excessive energy is manifested in the substance radioactivity. The exposure to radioactivity of substances of Earth and Sun gives rise to the organic life and constant progressive chain of changes in the state of organic variety and acquisition of information in the human manifestation of labor power.

Mankind, manifesting itself as a geological force of reason, creates artificial technological processes of substance conversion. Artificial substances are formed and constantly accumulated as new forms of inorganic world also in three aggregation states and by the content satisfying human needs. We call this world of substances – nooinorganic (reasonably inorganic) world of substances.

Human activity tends to create the reasonable (nooorganic) world of organisms, becoming helpers of humanity in the process of evolution and, therefore, increasing its geological force of substance and energy converter. Modern development of society already allows creating powerful machines converting substance and energy, producing artificial radioactive substances and implementing the processes emitting them, creating new microorganisms, plants and something like animal world and initiating the bold human dream – to fly in the outer space.

Thus, the energy of Sun converted on Earth into the form of inorganic and organic substances and energy and substance converters reaches its climax – creation of man as a substance and energy converter and information converter and accumulator. Man becomes a powerful geological force capable to continue a variety of natural processes of conversion (inorganic and organic world) in the form of artificial (rational) conversion processes (nooinorganic and nooorganic world). This latter process of the manifestation of geological forces of man is still only at the beginning of its formation, only at the initial stage of the powerful manifestation of its converting force. The future development and salvation of Earth from its spontaneous destruction is in the "hands" of human society. Hence is man's need for the knowledge of laws and regularities of his own manifestation in the variety of Sun and Earth energy converters.

Mankind is inevitably forced under the pressure of excessively accumulated energy of Sun on Earth to create such substance and energy converters that would seize and send the excessive energy of Sun out of Earth and its electromagnetic field. **Man is the savior of Earth from its destruction by the excessive energy of Sun!** The global thoughts of humanity are directed at solving this top priority.

When the creation of nooinorganic and nooorganic variety of substance and energy converters is completed by humanity (Fig. 1, the right side of the diagram), only then the necessary part of Sun energy follows the natural series of conversions reaching the maintaining of the physiological existence of man, and the excessive part of Sun energy will be perceived by artificial (nooinorganic and nooorganic) converters and sent into the outer space in accordance with the balance of substance and energy needed to preserve Earth.

Thus, we have the magnificent geological force of mankind – productive force of labor activity of society.

"Therefore, the labor as a creator of values in use, as useful labor, is the condition of human existence, eternal, natural necessity independent of all social forms: without it, the substance exchange between man and nature would be impossible, i.e. the human life itself would not be possible" [28, P.53].

Chapter 2
Primary element of labor economics

2.1. Starting point

The starting point of labor economy is “labor in its historically determined social form, and its subject is the social organization of this labor” [21, P.3]. In the socialized humanity with the existing historically determined social form of labor organization, “the individual labor is no longer a roundabout way, but it directly exists as an integral part of aggregate labor” [29]. Consequently, a deeper study of labor processes in the context of directly social character of their manifestation is one of scientific problems of modern labor economics

The study of labor processes, regardless of the specific social form of their manifestation, involves many scientific areas, where the most significant are the design and organization of technological processes, labor standardization, labor protection and safety techniques, labor physiology, labor psychology, scientific labor organization, ergonomics, praxeology, etc. Thus, a significant number of scientific disciplines are being developed in the direction of more detailed study of various aspects of labor processes.

However, there is the question: What science should study labor processes generally, i.e., “labor in general”? In the course of the development of Scientific Organization of Labor (SOL) at the junction of engineering sciences, physiology, psychology, labor hygiene, technical standardization, technical aesthetics, a special discipline called ergonomics emerged. The complex character of this science is manifested in the desire of complete recognition of human and technical factors when considering the efficiency of the system: “human-machine-production environment”. Ergonomics in its development is aimed at finding the ways of comprehensive (systemic) approach to describing the regularities manifested in various labor processes. Nevertheless, this science is just an integral part of labor economics since it is developing its starting point – labor “regardless of any definite social form” [27, P.184].

In the majority of works devoted to the issues of SOL, starting from the Taylor times to its Soviet renaissance, the authors’ desire to attribute themselves and their researches to the field of labor economics is not felt. On the other hand, scientists who form the scientific areas of labor economics clearly strive to dissociate themselves from SOL, ergonomics, praxeology, technical rationing and quickly make them independent scientific disciplines. If we proceed from the subject of labor– social organization of labor under the conditions of directly-social character of individual labor processes manifestation, then a completely natural assertion arises that labor rating, SOL, ergonomics, praxeology are the branches of labor economics. No other science, except the labor economics, can give the basic methodological principles emanating from the laws of social development to the indicated areas. On the other hand, the labor economics by itself, without the development of its specified constituent parts, becomes insubstantial, impractical, uncritical, devoid of the natural foundations of its starting point – study of labor process.

We attempted to generalize the achievements of various sciences in the study of labor processes, in this connection, for a number of years, have investigated the following problems on the basis of natural-science and evolutionary principles.

2.2. Basis of social labor organization

1. What is the basis of social labor organization under the conditions of directly-social manifestation character of individual labor processes? The study of manufacturing practice led to the assertion that the basis for social labor organization in the context of socialized humanity, especially at the present stage of business development in international scale, is the labor rating.

The application of cybernetics principles and general theory of systems to considering the problem of interrelation of productive forces and production relations made it possible to reveal the place and role of social rationing in the system of production relations more clearly. When studying this issue, we decided to introduce Q-factor of production relations – the concept unusual for economic theory and labor economics. At his time academician S.G. Strumilin wrote: “Generally speaking, theoretically, the rate of economic growth is entirely determined by two indicators: the growth rate of productive forces and coefficient of their use” [47].

Guided by the law of correspondence of production relations to the development level of productive forces, once revealed by K. Marx, we show the correctness of the assertion that the higher the Q-factor of production relations and, consequently, the social labor organization and its basis – social rating, the higher the utilization coefficient of productive forces.

2.3. Elementary form of labor

2. What is the elementary form of social labor organization under the conditions of modern production method? In the course of studying this question on the basis of the labor division doctrine, we introduced the concept of single labor process. The entire system of social labor organization consists of the labor organization totality in the elementary cells of social production– single labor processes, whose practical realization we find in the form of technological operations. In turn, the generalization of the forms of specific technological operations made it possible to present the abstract structure of a single labor process, to describe it in terms of cybernetics (the labor process is the highest form of the cybernetic system manifestation) and to give quantitative criteria for the classification of labor processes. The analysis of various technological operations on the basis of the block diagram of individual labor processes proposed by us, clearly demonstrated the constituent elements of the labor process, allowed us to trace the dynamics of their development, revealed the essential differences and unity of the concepts “physical labor” and “mental labor”. In considering this issue, in our opinion, an attempt, extremely important for the labor economics, was made to analytically describe the labor process in terms of mathematics and to give the study of labor processes a more precise and analytical character in the form of mathematical model.

Modeling of labor processes is not a new phenomenon, because the science of design and technology in its essence represents the actual process of modeling individual labor processes, taken separately or in their totality, representing the production process. If the design drawing is the model of an object or labor tool, then the technological process is the model of a labor process. Therefore, designers, technologists and rate setters are constantly engaged in compiling algorithms for performing a particular job, i.e., describing the labor algorithms that must be actually tested in practice, must be really accomplished. This approach to labor processes as objects of social science is based on precise methods of technology, design (the latter are labor processes in themselves), mathematics, physiology, labor psychology, the activity in which is also presented as the manifestation of living labor.

Algorithmic (mathematical) description of the starting point of labor economics – labor process – is the beginning that must transform the labor economics into the mathematically precise science, which gives the access to technology, mathematics and, consequently, a wide class of computers to the arsenal of its scientific methods. There was a definite reason that K. Marx noted that “Technology reveals an active attitude of man to the nature, the direct process of his life production, and, at the same time, of his social conditions of life and spiritual ideas resulting from them. Actually, every history of religion abstracted from this material basis is uncritical” [28, P.378, footnote 89].

2.4. Labor costs

3. What are the costs of living labor? Can they be expressed quantitatively without resorting to monetary calculation? For the mathematical expression of the working time amount, we thoroughly examined the definition given by K. Marx: “As the quantitative being of motion is time, so the quantitative existence of labor is working time. The difference in the duration of labor by itself is the only difference inherent in it. As labor time, labor gets its scale in the natural measures of time, hours, days, weeks, etc. Working time is a living being of indifference to its form, content, individuality; it is a living quantitative being of labor and, at the same time, an immanent measure of this being" [34, P.16]. In the study of this issue, the above definition enabled us to consider that, for the same duration, labor processes of different quality have different amounts of living being, i.e., different amounts of working time. This approach led us to the need of determining the quantitative measure of working time – work-hour, whose essence is expressed mathematically in the form of the functional dependence of working time on labor costs in the physiological sense, on the specific form of the expedient activity and duration of the living being of labor.

Based on the generalization of achievements in the labor physiology, a quantitative measure is introduced in the form of coefficient of physical labor intensity (hardness coefficient). The application of modern achievements in engineering psychology, information theory, cybernetic law of necessary diversity and law of experience accumulation (investigated and substantiated by the English scientist, one of the founders of cybernetics – W.R. Ashby) made it possible to introduce a quantitative measure – coefficient of intellectual labor intensity (hardness coefficient).

Thus, we came to the scientific conclusion on the measure of the living labor costs and unit of its measurement – work-hour. **One work-hour** is the cost of living labor in the labor process, which has the coefficient of physical intensity (hardness coefficient) equaling one, the coefficient of intellectual intensity (complexity coefficient) equaling one, lasting for one hour. The product of the coefficients of hardness, complexity and duration of labor expresses the working time amount, or, that is the same, the amount of labor expressed in work-hours. The product of the coefficients of hardness and complexity expresses the intensity of the labor process, i.e., the intensity of the "living being of labor".

The expression of labor intensity through the product of the coefficients of hardness and complexity of labor, according to the sources available to us, was proposed by V.F. Maier, Doctor of Economics [35]. However, it does not provide practically acceptable and theoretically grounded methods for the quantitative expression of these coefficients. We have developed the methods for quantifying the physical and intellectual labor intensity, practically tested in the production of a number of machine-building enterprises.

The rating system of works by hardness and labor complexity is considered from the positions of the introduced labor unit and its constituent elements. The study establishes a very important fact of the practical manifestation of energy transformation law, law of transformation and accumulation of information in actual labor processes, which also confirms the thesis that "labor, for it to serve a measure, has to be determined by duration or intensity, otherwise it would cease to be a measure" [29].

2.5. Reduction of labor

4. What is the relationship between the concepts of "measurement of labor" and "reduction of labor"?

A lengthy discussion on the problem of the so-called reduction of labor is well-known in political and labor economics. In our study we come to the conclusion that if a unit of measure is found, i.e., scientifically substantiated, as well as the measure of labor and its quantitatively expressed unit, then the reduction of labor disappears as a problem, since the measured labor no longer requires reduction. The public system of labor rating is actually transformed into the active system for measuring the costs of living labor, or, that is the same, into the system of quantitative expression of working time, and all practice becomes scientifically substantiated practice of labor reduction. It is well known that K. Marx, considering the capitalist production method, wrote: "Comparatively complex labor means simple labor that was only raised to power or, rather, multiplied, since a smaller amount of complex labor equals greater amount of the simple one. The experience shows that such reduction of complex labor to the simple one is constantly done. The goods can be the product of the most complex labor, but its value makes it equal to the product of the simple labor and, therefore, represents only a certain amount of simple labor. Various proportions, in which different kinds of labor are reduced to simple labor as the unit of their measurement, are established by the social process behind the manufacturers' backs and, therefore, seem to be the latest established custom" [26].

2.6. Strength and result of labor

5. What is the essence of economic categories–the productive force and labor productivity – as applicable to a single labor process? Here we proceed from the definition: "The productive force of labor is determined by various circumstances, by the way, the average degree of the worker's art, level of science development and degree of its technological application, public combination of the production process, size and efficiency of the production means, natural conditions" [27, P.48]. The detailed study of this definition based on the structural labor process scheme developed by us and its mathematical description led us to the conclusion that the productive force of labor is the definition related to the characterization of labor processes in the sense of their possibility, productivity in potency. The quantitative criteria of the productive force can be found in the criteria of the factors determining them, namely:

- degree of the worker's art (labor subject);
- level of science development;

- degree of technological application of science;
- public combination of the production process;
- size of the production means;
- effectiveness of the production means.

In the complex of our researches in economic metrology, each of the factors is considered separately, the methodological basics for quantitative measurement of the constituent elements separately and level of the labor productive force in general are proposed based on industrial practice. The methods are brought to mathematical formulas. The academician S.G. Strumilin in his work "Problems of labor economics" [48] details the essence of the difference between the productive force of labor and labor productivity, examines different points of view on this issue among the economists of the USSR during the first five-year plans. Sharing, to a great extent, the opinion of S.G. Strumilin, to consider the generality and difference of these categories, we resort to the mathematical expression of two interrelated concepts: dependent and independent variables. In mathematics it is known that their interrelation is expressed by a function in the form of formula $y=f(x)$, where x – independent variable (argument); y –dependent variable (function). By resorting to reasoning by analogy and investigating single labor processes on the basis of previously stated provisions, we introduce functional dependence $P_r=f(P_p)$, according to which the productivity of labor is the function of the productive force of labor. Labor productivity is a category characterizing the result of labor processes (labor fruitfulness), and the productive force of labor is a category related to the characterization of labor processes that have not taken place yet, showing their ability to have a certain level of productivity. This approach does not contradict, but, on the contrary, confirms the definition that "the very change in the productive force, which increases the fruitfulness of labor, and, consequently, the mass of consumer values delivered to it, reduces, as we see, the total value of this increased mass, once it reduces the amount of working time necessary for its production, and vice versa" [28, P.53].

2.7. Labor input as a concept

6. What is the essence of the concept "labor input" and is it a category related to labor economics? The modern practice of organizing industrial production (especially machine-building) at all levels of national economy cannot do without the concepts of "labor input of products", "labor input of work" and quantitative indicators corresponding to them. Moreover, according to GOST 14.201-73 and 14.202-73 (National Standard) when calculating the design of products for manufacturability, the labor input of product manufacturing is the main technical and economic criterion of their design perfection. This indicates the economic importance of the concept "labor input”. However, political economics, and following – labor economics, only “casually” mention the product labor input. Some researchers openly disapprove the indicator of labor input as an economic concept and refer it to indicators that characterize the technology of product manufacturing.

We are conducting the study of the significance, scale and practicality of the indicator of labor input for carrying out technical and economic calculations in program-target forecasting. At the same time, one-sidedness of the labor input indicator applied in practice, which reflects only the duration of labor processes (total of unit time) related to the production of certain products is considered; the content characteristics of labor costs – physical and intellectual intensity – remain uninvolved.

We assert that the concept “labor” with its indicators (duration, hardness, complexity) refers to the “living being of labor”. The concept “labor input” is a characteristic of the labor product. Labor costs quantify the costs of living labor in general, and the labor input of the product shows how much labor was spent (socially necessary working time) in the production of one unit of the product of labor. Also, the conventionality of the distinction between the concepts is considered here: “living labor”, “past work”.

Considering the essence of categories, we proceed from the premise that “this is an essential, typical in all variety of content” [31, P. 55]. Economic categories are “theoretical expressions, abstractions of production social relations” [33, P.133]; “economic categories are only the essence of abstraction of these actual relations and are truths only insofar as these relations exist” [32, P.406]. The study of labor input as a technical and economic indicator of production from the standpoint of the definitions of the category cited leads us to the conclusion that labor input, characterizing the manufacturing technology, becomes the main category of labor economics. The significance of this category will grow more and more as the socialization of mankind increases, replacing the role and significance of the category “value”. The categories “labor input” and “labor costs” reflect the actual manifestation of the economic law formulated by Marx as follows: “Assuming the existence of collective production, the definition of time naturally remains important. The less time is required for society to produce wheat, cattle and etc., the more time it gains for another production, material or spiritual ... Therefore, the saving of time, as well as the systematic distribution of working time for different branches of production, remain the first economic law based on collective production. This becomes a law even to a much higher degree” [30, P.114].

2.8. The first law of labor economics

7. What specific factors of labor organization the first economic law objectively operates through – the law of working timesaving? What is the *mechanism of manifesting this law in the primary stage of production – at the workplace?* The answers to the questions posed are formulated based on a critical examination of the definitions of labor and workplace organization.

The labor organization is treated separately as a science, as a public practical activity of people and as an economic category.

The workplace is understood in the form of an elementary part of the production space, in which single labor processes are carried out in accordance with the target function of production. A stage-by-stage study of the material-energy, psychophysiological, social-information factors that form the workplace led to the development of its information model.

The model of the workplace is expressed in the form of mathematical analytic interdependence of various factors, which makes it possible to trace the law of labor saving (working time), law of labor productivity growth, law of production efficiency and quality of work at real workplaces.

Further, based on the law of labor saving, the mathematical equation of the workplace is derived, which is called the qualimetric equation of the workplace. The equation quantitatively links labor costs with qualimetrically calculated volume of product output at the workplace and its available productive forces.

2.9. Labor economics

As a summary, we pint out:

1) labor economics is a science that studies the principles and forms of the manifestation of the law of labor saving in the social system;

2) labor economics is an economic category reflecting the functioning of living labor in the social system;

3) labor economics is the social and practical activity of people in managing work in the social system with the aim of decreasing the labor input of products and reproduction of labor force.

Chapter 3
Labor process

At dawn of political economics as a science, progressive people of that time found out that "labor is the father of wealth, Earth – its mother". Under the conditions of modern way of production when humanity turned out to be the noosphere of Earth in general aggregate, it became not only the wealth creator but the powerful factor of the transformation of society and nature. Public useful activity of people is diversified and mediated by multiple circumstances that need to be analyzed to address issues of economics correctly.

Labor economics as any other science should have its primary base, the element that would have properties and attributes, definitions and quantitative measures that are peculiar to this scientific direction. Hence, we talk about the primary element, whose description and learning do not contradict the essence of all labor economics, that learns *living labor saving law* manifestation forms at concrete spheres of production and social relations. If we consider labor economics without regard to social form of human labor organization, then it is common for all ways of production and management and, after all, goes to achievement of social labor on each stage of product manufacturing. However, every type of social labor organization relates to its own methods and techniques of achievement of labor economics.

The problem is to select methods of labor processes structural analysis, finding their description algorithms. Based on this, we need to work out the mathematical model of a single labor process that would be able to analyze it in physiological, intellectual, energy, technological aspects and made up a precondition of quantitative expression of work time via living labor coefficients, i.e. through exact measurement of labor costs. For this purpose we introduce the notion of *single labor process*.

3.1. Diversity and unity of labor types

Any item has its own history: raw materials are made into the product of labor with its relevant consumer attributes. Such transformation takes place within the production process which is built up on *technological process* made for each particular case.

Within the production process a man purposefully changes the product geometrical shape, its physical and chemical qualities or its parts location and even develops its new qualities so the product of the man' activity turns to be tangible evidence of his labor cost.

In particular, machine-building production is seen as the complex of interrelated main and supportive production units, the activity of which results in semi-manufactured and ready-made products. *Technological operation* is a part of technological process that is used for product planning, accounting, monitoring, as well as labor rating and payment. That is part of technological process which is made by a worker, a group of workers or at worker's supervision and without it (in case of automated production) to make manipulations over one or several products at the work place (machine, hammer, press, conveyor belt etc.).

Consequently the operation is characterized by the permanence of processed product, workplace and workers. The content of technological operation is presented in the operation process chart (Fig. 2). The chart indicates where, what methods, what tools and material, how much time should be used to manufacture the part.

Any technological operation is characterized by concrete qualitative certainty. For example, the operation chart of machining given above shows the required and sufficient symptoms, properties and sequence for concrete conditionality of this operation. What is concerned is the hot-forming workpiece from 45Xsteel with the surface layer hardness within 173-217HB by Brinell hardness test. The ultimate aim of the operation is to produce semi-finished products with the following measurements: d_0=38B_7; d_1=43B_7; d_2=50B_7; l_1=69A_7; l_2=9A_7. All surfaces have the same physical-chemical properties of the workpiece material, i.e. they do not undergo the change in physical-chemical properties.

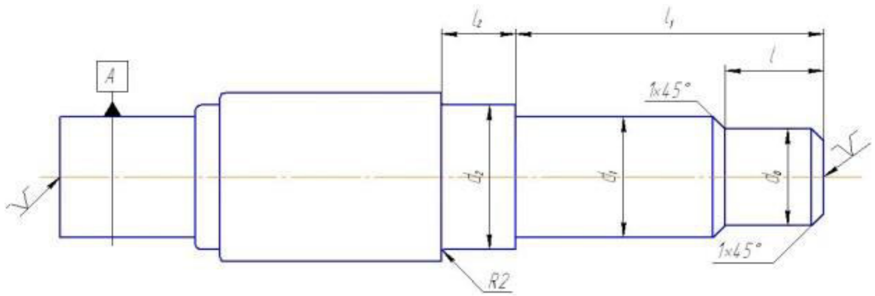
To transform the geometrical shape of the hot-forming workpiece stamped blank the required equipment is indicated in the operation chart – turning hydro-copying semi-automatic machine, model 1722 with 10 kW drive. (This machine was allotted the "personal name"–inventory No 951 at the gearbox plant). The machining attachments required for fulfilling the operation are specifically indicated: *jig* – special2-cam chuck 7122-6044; *cutting tools* – cutter 2103-0061 T15K6-III; *cutter* 2120-4007 T15K10-III; *auxiliary tool* – center 7032, 0029, bushing 6010-0061; *measuring tool* – clamp 50B_7, height 9A_7, clamp 38B_7, height 23A_7, clamp 43B_7, height 69A_7; use master cam 7054-5070 *in setting up the jig*.

The production engineer should make the turner aware that to achieve the successful result the spindle must make 630 revolutions per minute, depth of cut should be 1 mm, set the automatic longitudinal feed of cutting tool at 0,63 mm by one revolution of the spindle, to machine in single pass. Following these machining procedures (algorithm of activities), the turner will perform the operation (target function) in 11 seconds. Let us point out that this is sufficient time for the basic process of changing the geometrical shape of the workpiece. This is machine or, as it sometimes called, basic time t_0=0,18 min. At the beginning, in the middle and end of the shift the inspector of the quality control department must check whether the geometrical shape and machined surface of the workpiece correspond to the specified requirements. The machining

Lenin gearbox experimental plant	Workshop	Operation chart of mechanical process	Item	Cylinder gearbox	RCD 250
	26		Part	Gear shaft	13 251
			Material	Steel 45X	Solid HB 173-217

№ of operation	Operation	Equipment	Model	Drive capacity	№	Part	Panel stock
10	Rough lathe turning	Hydro-coping semi-automatic lathe	1722	10 kW	951	Special 2-cam chuck 7122-6044	Boxed weight – 4,8kg Net weight – 2,4kg

№ Oper.	№ Stage	Stage content	№ Oper.	№ Stage	Stage content
10	A	Set in and remove a part	10K		Quality control at the beginning, in the middle and at the end of the shift (2 parts per shift)
10	01	Turn sequentially diameters d_0; d_1; d_2, for sizes l_1, l_2, l_3; beveled edge 1×45°; turn simultaneously *A* butt with in-out support		1	Check diameters d_0; d_1; d_2 and sizes l_1, l_2, l_3.
				2	Check the machining quality by superficial examination



Operation №	Stage	Material grade	Part net weight, kg	Number of parts, pcs	Machining dimension						Equipment setting up		Tool			Machining diameter	Cutting depth, mm	Calculated length	Number of cuts	Cutting speed, m/min	Number of revolutions, min	Feed mm/rev	Time, min				Output rate	Work category	Price, thsd.rub.
					d_0	d_1	l	l_1	l_2	d_2	Code	Time, min	Cutting	Backup	Measuring								Machining	Backup	Servicing	Final			
10	1	Steel 45X GOST 4543-61	2,4		38h14	43h14	23H14	69H14	9H14	50h14	Copiers 7054-5070		Cutter 2103 0061 T5K10 -III 2120-4007 T5 K10-III	Center 7032-0029 Bush 6101-0061	Clamp 50h14 height 9H14, Clamp 38h14, height 23H14 Clamp 43h14 height 59 H14	40 45	1	72	1	79,13	630	0,63	0,18						
Operation chart of machining. Roughness samples (working) GOST 9378-60																													

Fig. 2. Operation chart of machining

cleanness is checked by visual inspection and comparison with roughness references.

Now we can give the brief definition to the description – it is *the information model* of the technological operation "rough turning".

The sequence of a number of technological operations shown in the compiled operation chart of machining is needed to produce the "gear shaft" for assembling cylinder gearbox RCD (Table 1).

Table 1

Optional list of machining operations on the gear shaft of gearbox RCD250

Name of operation	Equipment (name, model)
Milling-and-centering	Semi-automatic milling-and-centering machine MP 71
Drilling	Vertical drilling machine 2A125
Turning	Turning hydro-copying semi-automatic machine 1708
Heat-treatment	Heat-treatment shop equipment
Shot blasting	Shot blaster
Grinding	Face cylindrical semi-automatic grinding machine 3T161
Metal working	Manual operation
Stamping	Manual operation
Gear milling	Gear milling machine 5306
Gear chamfering	Special machine
Washing	Washing machine 996-29 000 000
Shaving	Gear shaving semi-automatic machine 5702

3.2. Labor division

To manufacture gearbox RCD 250 from source materials and semi-finished products it is required to fulfill 453 operations only at one gearbox plant.

The aim of scientific research is to find uniformity in the diversity of technological operations, to identify general principles and ideas describing each single production operation in technical, economic, physiological, psychological, cybernetic, mathematical and other scientific contexts.

To achieve this goal we have to possess some insight knowledge of economics theory and other abstract sciences.

The notion of a "single labor process" is directly coming from the economics theory and labor division study.

There are three interrelated labor division types:

- social,
- intra-industrial,
- intra-company.

Karl Marx called social division of labor as the division of labor in general, differentiating it from the particular intra-industrial labor division. As for intra-company labor division, Karl Marx called it as the single labor division. The general and particular divisions of labor are closely connected with the single labor division. If we split the labor division inside the company, a technological operation is the *starting point*, *specialized* form of the labor process manifestation.

Thus, the theoretical generalization of *specialization* and *cooperation* and uniform target function of getting the labor product.

The method of expanding the labor process as such into abstract constituent elements became widely known in economics theory: object of labor, means of labor, labor itself, process of uniting these elements (direct labor process as a purposeful activity), product of labor resulting from the process. However, not every combination of these factors is a labor process. The labor process can only be a purposeful combination of the object of labor and means of labor under the impact of physical and intellectual powers of the subject of labor, i.e. a man, capable of conforming this combination of material factors to the previously designed aim.

Lying at the base of purposefulness is the society's consciousness of the legitimacy of interaction (interconnection) of labor factors, stemming from which the product of labor is derived from the object of labor, with properties and form corresponding to that mental model which man works over before effecting the given single labor process. The mental model becomes the beginning and structure of the internal organization of the labor process. From the standpoint of cybernetics the single labor process in the general production system appears as an elementary self-organizing system having an entropic (indefinite or probable) character of process. The mental model of the product in such a system is exactly what a self-organizing system needs to counteract the growth of entropy. The target aimed at has a definite level of detailing, which determines the level of activity counteracting the disorganizing effect of various limitations, the capacity to diminish or maintain entropy of the system at a constant level, raise the degree of its organization.

On examining single labor processes, working force is to be understood in a broader context, taking into account the psychological and physiological properties of labor. That point is: in self-organizing systems man's role is not merely confined to expenditure of living energy (working force) but has a much broader aspect – man acts here as a controlling factor. The control boils down to determine a system of communication whereby the behavior of the object, in some particular connection, acquires the desired character.

Organization of purposeful limiting actions in the labor process proceeds under conditions connected with the search for a better order of internal structure of the controlled object. At the same time, either stabilization takes place or partial-complete changes in parameters or condition of controlled object.

3.3. Labor sciences

It is exactly in this light that the new scientific discipline – human engineering – views the role of man as a controlling link in the system "man-machine". This science directs investigation into the area of study of problems of transmitting information to man-operator, those controlling his actions, operative thinking, man-operator's memory, analysis of operator's activity, reliability of man-operator.

Thus, engineering psychology examines the intellectual aspects of labor processes, basing itself on the general principles of theory of information. That is why researchers into questions of labor psychology define man as "subject of labor" [23].

Physiology of labor is concerned with study of the direct outer appearance of the labor process through man's motive activity and considers the latter as a "working force" factor. Physiology of labor investigates manifestation of the law of energy transformation in man's working activities, the issue of man's potential energy output [22, 52].

Physiology and labor psychology are interconnected. However, the latter broadens the energy horizon of physiology, amplifies it with information. In line with this, the labor process is examined as an elementary part of production. "Subject of labor" is now understood as being more capacious and broader, embracing the idea "working force", supplementing it with psychological properties and symptoms, and is, therefore, preferable.

In the course of the development of SOL, there was a special discipline called ergonomics at the junction of technical sciences, physiology, psychology, occupational health, technical regulation and labor economics. The complex nature of this science is manifested in the desire to take full account of human and technical factors in considering the effectiveness of the human–machine–production environment.

Achievements of ergonomics, cybernetics, general theory of systems allow to deepen researches of processes of concrete work, to give to practice more exact methods of studying expenses of work and, therefore, the most effective methods of its public organization. The solution of practical problems of optimization of human labor activity in modern production is possible on the basis of a comprehensive and systematic approach to the labor process analysis.

3.4. Structure of a single labor process

Concrete forms of labor processes also have concrete structural schemes. Let us examine the simplest working process of a navvy. His labor process may be represented by the following structural scheme (Fig. 3):

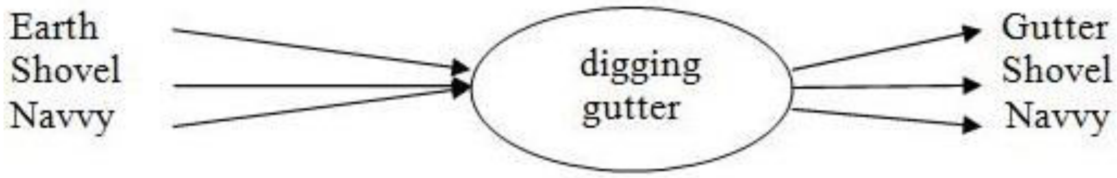


Fig 3. Structural scheme of navvy's labor process

Here is another working process joining the previous one involving sharpening of shovel blade (Fig. 4):

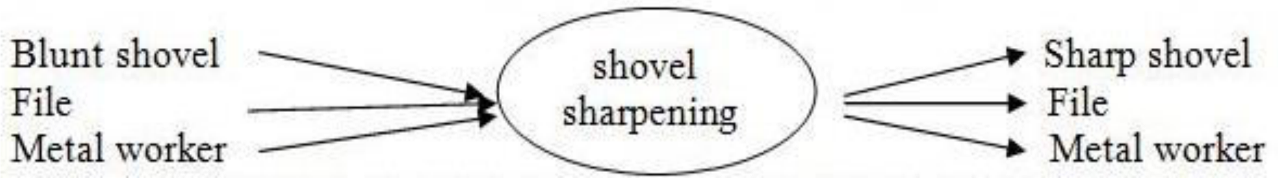


Fig 4. Structural scheme of metal worker's shovel sharpening labor process.

In the first and second schemes the navvy and metal worker are active factors, while shovel and file are passive, carrying out the purposeful action of subject of labor; the ground and shovel are passive counteractive factors. The processes of gutter digging and shovel sharpening, as interacting active and passive factors, actually form the labor process itself. The gutter and sharpened shovel now appear as the product of the given labor process. They actually are the result of the purposeful action of the subject of labor. However, the results of these labor processes are not only the gutter and sharpened shovel. In the first case the shovel got blunted from digging the gutter, in the second case the file got blunted.

A fundamentally different position is obtained by the subjects of labor, navvy and metal worker. The subject of labor, having physical force and intellectual capacity on the one hand, left the labor process with expending physical force, and, on the other hand, enriched with working experience. "In order to appropriate a substance of nature into a form suitable for our own life, he sets in motion natural powers belonging to his body: hands and feet, head and fingers. Having an impact on outer nature through the medium of this movement and changing it, he, at the same time, changes his own nature. He develops his dormant powers and bends them to his power" [27, P.188].

Every single labor process, as an elementary part of total social labor, may be presented in abstract form by the following scheme (Fig. 5):

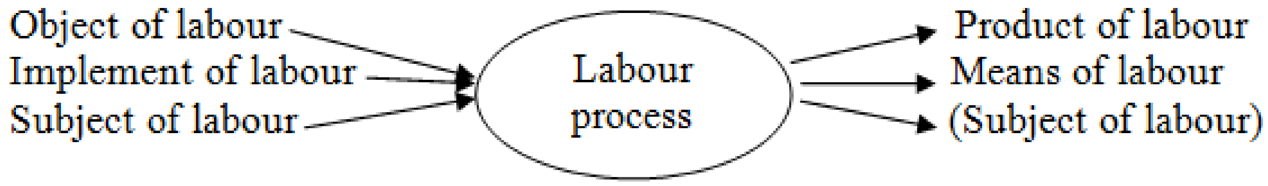


Fig 5. Structural scheme of simple single labor process

The study of labor processes in modern form reveals new facts, which cannot be fully attributed either to the object of labor, means of labor, or to the subject. During the process of shoveling up the gutter it was supposed that the navvy himself sets the aim; the energy bearer (energy source) is also the navvy – subject of labor. In the process of sharpening the blunted shovel the aim and program of action are worked out by the metal worker-sharpener; earlier acting as navvy, the energy bearer (energy source) is himself also the metal worker-sharpener.

In the process of turning the gear shaft on the lathe there is a graphical description of the aim (drawing of the part) of the turner's labor product, action program – machining production process. An added power source appeared in this process – electrical power converted by the lathe electric motor into mechanical power.

The drawing becomes an information model of the labor product, and production process becomes an information model of the labor process. The information model may be expressed verbally, in oral or written form, as well as graphically or in natural material form.

Information and power sources are, on the one hand, independent labor factors cut off from the subject of the given labor process. This separation results from the historical development of people's lives, division of labor and man’s subordination to nature's natural powers. On the other hand, information and energy involving the subject of the given labor process are previously given from external sources and thereby added factors, raising the subject's purposeful action. One way or the other, information and energy acquire an independent factor, partly attached to means of labor and partly to the subject of labor.

Let us consider the information and energy as a variety of the means of labor. Practically and technically, these factors of the labor process are considered as independent.

Arising from the above, the structural scheme of the single labor process will take the following form (Fig. 6):

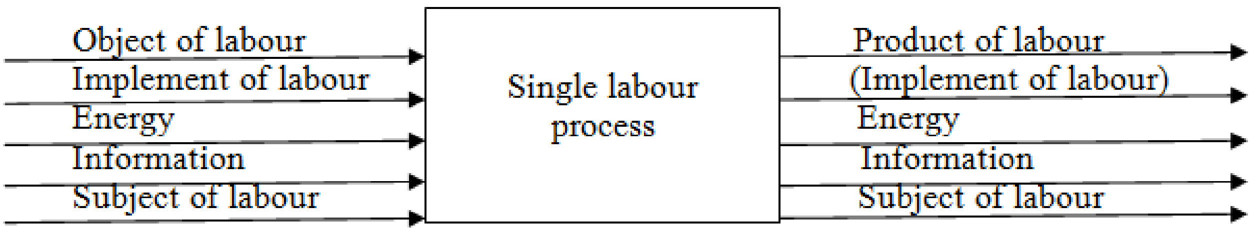


*Fig 6.*Structural scheme of the single labor process

The single labor process is illustrated here by an abstract structural scheme, but in practice we are always concerned with concrete types of work, i.e. with an individual form of labor processes. In this connection it must be underlined that *the single labor process always and everywhere has an individual form of manifesting itself.*

As already noted, 453 various production operations are involved in manufacturing gearbox RCD250. Each operation has its own particular form of undergoing the process: its name, tool, devices, machines, auxiliary and basic materials, individual techniques and labor methods, etc. However, despite the difference in form they have one common essential feature. The subject of labor – man – is an active element in all production operations. He sets the aim, builds a mental picture of the end-product, shapes the labor process, realizes the aim, i.e. leads the labor process himself. Each element of the labor process taken separately, at a definite moment of the labor process, can be considered as an integral system. It follows that any production operation may be considered as a process of separate interacting systems. At the moment before the start of the labor process its elements (object, means, subject) may be considered as in the state of relative rest. The subject of labor itself has definite functional capacities marked by senses: gravity, space, time, hearing, eyesight, taste, smell, touch. The following features are peculiar to the object of labor: form in space, moment of time, clutching force, chemical composition, gravity force, etc. Examining the labor process from the standpoint of man's intellectual capacities, one should refer to modern achievements in cybernetics, theory of information in particular. The level of a person's intellectual development is measured by the extent of his thesaurus, i.e. amount of information he possesses. In the labor process he not only uses a priori information but also absorbs new information, widening his own thesaurus. Therefore, decreasing entropy of the system of material factors of the labor process, man enriches himself with information. Thus every production operation is not only a process of working power expenditure but also its improvement through the transformation of information.

3.5. Factors and states

Any operation has three logical moments or states:

first state: when all labor factors are static and do not interact. Also, every material factor has independent symptoms, properties, which can be quantitatively expressed through geometrical, physical-chemical, information, physiological, psychological and other parameters;

second state: when all labor factors are dynamic and interact. The actual state of the labor process itself is marked by constantly changing (uninterruptedly or discretely) dynamic links and relations of properties and symptoms of the labor factors;

third state: after the process (result of the process), when each labor factor does not interact with the others and is marked by different properties, acquired or lost.

Every labor process can be seen in different aspects, particularly:

1. Technological – as a process having a technical effect on the subject of labor, when all moments of the labor process are examined with an eye to the

change of definite geometrical parameters and physical-chemical properties of the object of labor.

2. Energy – as a process of energy conversion and setting up of corresponding proportions isolated from the subject of labor.

3. Physiological – as a process of working force expended by the subject of labor in overcoming counteraction of passive labor factors, i.e. as a process of human energy exchange.

4. Intellectual – as a process of method, working over and transmission of information by the subject of labor, i.e. as a process of changing the entropy of the labor process.

The synthesis of all aspects gives a full quantitative and qualitative picture of the single labor process. We can, therefore, get a quantitative expression of any production operation through a common synthesizing index.

3.6. Physical and mental labor

We often see a substantial difference between mental and physical labor. On examination of any type of work performed by engineering-technical personnel and workers the abilities displayed by the subject of labor show that the physical and mental go hand in hand and cannot be separated. Actually, digging a trench is not feasible, if the navvy shows no intellectual capacity in the labor process. Fulfilling any designing work according to the estimate and drawing of the gearbox, the workpiece can hardly be imagined without any physical actions on the part of the designer. Consequently, any labor process unaccompanied by a simultaneous manifestation or the subject's physical and mental (intellectual) capacities cannot proceed normally.

Let us assume that Ivanov, a mechanical engineer by education, designer and turner by profession, is set the task of designing a workpiece and producing it on a lathe. Our designer shows nothing to distinguish himself from the turner, being one and the same person. However, on carefully observing the labor process of Ivanov-turner and Ivanov-designer, the basis arises for a more clear-cut distinction between the labor processes of turner and designer.

We have the diagram of the gearbox gear shaft. However, it is not yet an actual gear shaft. It is simply a graphical specimen – its information model. But the diagram of this workpiece is the product of the designer's single labor process obtained after the study, transformation, serious consideration of initial information a priori set to the designer by standards, normals, methods, descriptions, formulas, tables, etc. The designer's task comes out as the initial information, with the designer as the subject of the intellectual labor process. The product of the designer's labor–the gear shaft information model – enters the turner's labor process, for example, as obviously expressed information. The result of the designer's labor, in the form of the diagram, enters the turner's labor process as an aim. The transformation of information merely took place in the designer's labor. The object of labor is given in substance as a form of semi-finished product of natural material (hot stamping, 45X steel) in the process of machining. The result of the turner's labor – the shaft with the geometrical parameters corresponding to its information model.

Thus, a mental image of the gear shaft took the form of the graphical information model, and only after the completion of the physical labor process it was materially realized. In modern production intellectual forms of labor in the working-out of production methods have become very significant. The production engineer's labor process assumes an obviously expressed informative character. It picks out and finds specific means and rules of selection, coding, transmission, storage, working over and decoding of information satisfying the set system of purposeful limitations; i.e., he finds the method of solving the problem. The problem itself is set by the designer. The solution depends on the turner's ability, a representative of physical labor.

Intellectual labor is divided into kinds, groups, types of activity. Now considering the work of designers in collecting, analyzing and working over the information, this type of activity may be broken up into the following groups:

1. Theoretical research, production in the form of scientific hypotheses, concepts, theories, formulas, etc.

2. Inventive activity; production takes the form of authorship certificate and patents with the invention formula.

3. Designing, characterized by qualitative innovation enabling adaptation of known machinery to new concrete conditions, and application of known technical solutions with modified quantitative features. Production from such activity is represented by diagrams.

4. Production forms and records – drawing, copying, multiplication, etc. – connected with technical documentation.

Each group represents a totality of homogeneous concrete forms of labor. Where groups of intellectual activity are concerned, the product of labor is represented by scientific works, authorship certificates and patents, drawings and descriptions, being material bearers of semantic information. If information comes out as a product of intellectual labor then the object of its labor is also information.

The turner must have definite reserves of information. Where does he get it from?

In one of the theses about L. Feuerbach, K. Marx noted that Feuerbach considered civil society instead of investigating the socialized mankind. One powerful factor of socialization is shown by the constantly widening occupation of teaching and enlightening each member of society. Hence, teaching people in society represents an important branch of man's working life, having an exclusively intellectual character.

The teacher's labor, for example, belongs to the category of mental activity. The object of labor for several years is children. However, the teacher does not affect their bodily organism, but their *thesaurus*. The labor process is of an intellectual nature and involves repletion of the pupils' thesaurus with information. The teacher's labor product is the knowledge he or she imparts to his or her pupils, going through the definite cycle of informative processing. The concept “teaching process” corresponds to its analogy –“production process”; the concept “class” may be contrasted with “production group” or, rather, “production conversion”.

Latterly, programmed teaching has become widespread, where particular importance is attached to the concepts: portion of teaching material, process of feeding and assimilating this portion. The production operation and process of fulfilling the operation are, no doubt, analogous to these concepts.

Therefore, in cybernetics terms, we have a full and partial isomorphism of labor processes. In all likelihood it won't be long before the 5-mark system of testing knowledge of teaching material will get a stricter quantitative scale of marking based on the concepts: quantity of a priori information, quantity of reports and assimilated information.

To avoid misunderstanding it must be mentioned that it is not a question of identity of “production” and “teaching” processes. Regarding their analogy and similarity it can be said only with “preciseness up to isomorphism”.

The use of isomorphism and isomorphous systems is usual and very important. It is used everywhere. The fundamental and essential difference between the physical and mental single labor processes lies in the basically different labor factors. *In physical labor the substance of nature is exposed to transformation*, *and the product of labor is expressed by the substance of labor*. *In mental labor the object of labor is information*; *the product of labor is also information*, *appearing in the physical labor processes in an aspect of conformity*, *in the form of the aim and program of achieving it*. That is the result of the historical process of development of labor productivity forces and, following in its wake, division of labor and specialization of its forms. On the other hand, such division of labor is in itself a powerful factor in developing productive forces, i.e. science becomes a direct productive force in society. The concrete manifestation of science as a productive force is always felt on analyzing single labor processes in production and energy aspects. The indicators of this force – supply of technical equipment and use of power-driven tools.

The foregoing does not mean that information processes in mental labor are ideal. They are also material processes since the carriers of information and process of its perception are material.

Despite essential differences in physical and mental labor they have a common structural scheme.

The principle of examining labor processes, as outlined above, remains the same for physical, as well as mental labor, i.e. they are examined from the same positions in production, energy, physiological and intellectual aspects.

It must be particularly noted that the essential differences and contradictions between mental and physical labor in a social plan are not examined here.

3.7. Mathematical summary

Based on this, it is possible to bring the working hypothesis and express it by functional dependence

$$T=\varphi\left(T_p\right)=\varphi[\mathrm{f}(E, J, t)] , \qquad (1)$$

where T – technological labor input of labor product; T_p – living labor costs; E – magnitude of the human labor expenditure in the physiological sense; J – amount of information (diversity) that a person processes in labor process; t – duration of labor process.

Hence the definition follows: *the amount of living labor is a function of the energy exchange magnitude*, *the perception and processing of information by a person in the labor process and the duration of this process*.

Chapter 4
Labor energetics

Every concrete labor process has its qualitative definition. It is expressed by the totality of properties, symptoms and parameters defining the labor process as such. Thus, for example, any production operation is a qualitative manifestation of the single labor process. If we say, “Operation No 10 – rough turning of diameters d_0, d_1 and d_2 of workpiece 013251 of gearbox RCD 250”, then we give almost complete characteristic – qualitative – of the single labor process. One look at the production operational chart will permit determining a collection of properties, symptoms and parameters stipulating the concrete form and content of this single labor process.

It follows that a qualitative definition of labor is expressed in concrete individual labor processes, the totality of which, on the scale of an enterprise, determines the quality of production. The unity of 453 different production operations connected with the production of gearbox RCD250 determines the qualitative aspect of the basic production process. The quantity of such operations, showing to good effect the distinctiveness of the whole plant, is considerably greater, tens and hundreds of ones are counted.

The given figures quantitatively express the plant's production process, namely the scale and extent of production. The whole qualitative heterogeneity of operations must also be expressed through the medium of quantity of living labor or, as economists have it, a reduction of labor must be carried out.

4.1. Labor intensity

For quite some time, for practical purposes, the method of dividing work and professions into heavy and harmful, especially heavy and especially harmful categories has been used, based on physiological, sanitary-hygienic research and generalization of inquiries by certain enterprises. At the present time, when a strictly scientific approach towards rate fixing and organization of different aspects of the labor process is required, the need for more accurate, detailed standards and analyzing methods in any labor process becomes apparent.

For example, as established by provision, heavy work, as a rule, refers to lifting weights of over 50 kg for men and over 20 kg for women. The questions arise: What is the periodicity of lifting weights? What is the speed of movements, i.e. time taken to lift the weight? At what ambient temperature does the weight lifting take place? etc.

Hence the rough approach to the physiological aspect assessment of labor processes is quite evident. The necessity for theoretical research into the problem is equally evident.

The core and results of various investigations published in the press on the issue of labor hardness and intensity, without touching on the social aspects, may be boiled down to the following:

1) hardness is the labor feature in physiological aspect;

2) intensity is the labor feature from the standpoint of the production environment effect on analyzer systems;

3) level of hardness and labor intensity depend on material factors and environmental conditions, in which the labor process proceeds; different notions of hardness and labor intensity are seen, in practice, in the context of different types and amounts of wage payments, in the forms and means of material incentives to workers.

The essence and factors of the labor process were revealed earlier. Labor subject is an active creative labor factor. Other factors are passive, counteractive. Therefore, the labor subject strains its organism to overcome the counteractive, passive factors of the labor process. The greater the counteractive burden, the greater the strain on the subject's organism.

Intensity is the notion referred to the labor subject only. While functioning, the human organism strains itself in two ways: (a) it strains its muscular-skeletal system to resist physical counteractive forces; (b) it strains its neuro-cerebral system for perception and mental transformation of information. One type of strain does not exist without the other as it is the general process of the unified system. However, for analysis (only for scientific analysis) the expediency arises of breaking the common intensity into two types – physical and intellectual. The first type concerns labor physiology and hygiene; the second – general and engineering psychology. In this sense the actual labor processes are divided into two types: with explicit physical intensity (physical labor) and explicit of intellectual intensity (mental labor).

In general analytical form:

$$S = f(h) , \qquad (2)$$

where S – strain of the human organism; h – hardness of material and information labor conditions at the workplace.

It follows that *labor intensity is the function of hardness of material and information conditions of its process* at the workplace. The greater the hardness, the greater the labor intensity (in this sense labor hardness and intensity are understood as equivalents).

4.2. Physiological energetics of labor process

Examining labor in the physiological aspect means investigating man's physiological manifestations in the labor process. Man's physiological reactions are his response to counteractive factors of the labor process, which are labor object, labor tools, labor product. To learn the functional dependence of man's actions on counteractive factors it is necessary to split the labor process in time into separate *procedures and movements*, to determine the factors affecting sensory organs of the labor executor.

The basic fact, which labor physiologists come across when investigating the movements in the labor process, is the wide diversity of causes for their appearance and limited means of external expression.

To learn the functioning of the human system in labor processes it is necessary to examine the physiological manifestation of the organism as an integral system in physiological abstraction subordinated to common laws of nature.

Any living organism exists in close interaction with the surroundings. There is a constant metabolism between the organism and environment. Nutritious life-giving substances and gases enter the organism from the environment. After their use, the products formed are ejected from the organism into the environment. In man's organism the thermal energy from food burning is mainly transformed into mechanical power. Due to such transformation the body functioning organs–muscles–contract, i.e. the work is performed.

The amount of energy spent by a human organism in the state of rest is called in physiology the energy of standard metabolism, or simply *"standard metabolism"*.

The transition from standard metabolism to decrease the metabolism energy leads to the stoppage of the human organism vital activity. The transition from standard metabolism to increase metabolism energy leads to the acceleration of the organism vital activity, i.e. the body at relative rest starts the motive activity. Consequently, standard metabolism is the physiological boundary of the human organism transition from rest to labor (when examining labor activity).

The amount of heat produced by the organism is determined by two methods: direct calorimetric measurement in special calorimeter chambers and indirect calorimetric measurement by measuring the level of oxygen consumption and carbon dioxide release. 1 kcal is taken as one unit of thermal energy, i.e. the amount of heat warming 1 kg of water by 1° in the range from 19,5°C up to 20,5°C.

It has been found that a middle-aged person weighing 60 kg consumes 60 kcal/hr at rest, and his standard metabolism in 24 hours is 1440 kcal. If the daily energy consumed is considered as uniform every hour and minute, the average energy of standard metabolism is

$$\frac{1440\ \text{kcal/24 hours}}{1440\ \text{kcal/24 hours}} = 1\ \text{kcal/min}.$$

Researchers have found that the metabolism of every organism is different in magnitude and is in the range of 800-1750 kcal, depending on the body size, age, weight and sex.

From the practical point of view and for theoretical research the standard metabolism of 1440 kcal/24 hours and 1 kcal/min is quite obviously interesting as the measure and dimensionality of physiological energy spent during labor processes, moreover, this magnitude is well consistent with physical magnitudes.

Thus, *labor processes in the energetic aspect may be measured in the units of standard metabolism of the human organism.*

4.3. Physico-mathematical representation of labor energetics

To get a quantitative estimate of the labor physical intensity, its process needs to be examined as the system of interacting physical forces.

Active forces:

a. man's motive physiological force;

b. natural forces enhancing man's strength – various forms of energy used by man in his labor activities.

Passive forces:

a. man's weight – force of own gravity;

b. counteractive forces arising from the labor object;

c. counteractive forces arising from the labor means.

The interacting forces are acting under definite physical conditions of the environment, which is characterized by certain values of temperature, speed, air humidity, air chemical composition, level of aerosols, lighting, noise, vibration and radiation. Man's actions in the labor process are carried out at a definite speed. This can all be expressed by the following logical dependence:

$$I_{ph}\text{–}l(W_{ls},W_{lm},W_{lo},S,t^{\circ},V,\ \gamma,A_{er}), \qquad (3)$$

where I_{ph} – physical intensity felt by human organism during the labor process; W_{ls} – weight or labor subject (65 kg will be taken in all calculations); W_{lm} – counteractive effort of the labor means, in particular, turning on and off of flywheels, levers, handles in kgs; W_{lo} – counteractive effort of the labor object, in particular, weight of the workpiece; S – man's working speed measured by a number of micro movements in 1 unit of time or derived by the calculations based on determining the speeds and accelerations of various organs of the human body together with the labor object and means; t° – ambient temperature, °C; V – air velocity, m/sec; γ – air humidity in % according to hygrometer; A_{er} – various aerosols in the working zone atmosphere.

As seen from the given dependence, it did not include such conditions as noise, vibration, lighting and radiation. Not going into detail as to their impact on the human organism, it may be noted that these factors have a significant effect on the organism fatigue, only slightly changing the energy spent [19]. Fatigue, being a particular problem in labor physiology and organization, is not examined here.

Interactive forces in any labor process referred to physical types of labor may be boiled down to mechanical work, expressed in kgm or kgm/min. In particular, the index of physical intensity in most forms of physical work is derived from the following analytical dependence:

$$C_{pi}=f(A_b,A_{lo},A_{os},A_{ma})\cdot C_m\cdot C_y, \quad (4)$$

where C_{pi} – coefficient of physical intensity; A_b – mechanical work by man's body shifting from one place to another, and movement of certain parts of the body, kgm/min; A_{lo} – work performed by a worker impacting on the labor object, kgm/min; A_e – work performed by a worker handling the equipment controls, kgm/min; A_{os} – work performed by a worker handling equipment attachment controls; C_m – coefficient characterizing the effect of temperature, humidity and air speed on the human organism strain; C_y – coefficient characterizing the effect of various aerosols on the human organism.

Analyzing the dependence of the value of internal energy produced by the human organism upon the parameters of counteractive factors of the labor process, it is necessary to proceed from the fact that physiology makes a distinction between two basic manifestations or muscular activity. Man's muscular activity accompanied by the total or part shifting of the body in relation to each other has been called *dynamic work*, and muscular activity without active total or part shifting of the body – *static work*. Dynamic and static loads are quantitatively expressed by the corresponding physical values.

According to mechanics, the work is measured by the product of force acting in the direction of displacement by the value of the force application point displacement, i.e.

$$A=F\cdot S \quad (5)$$

For example, lifting the load of 10 kg from the ground to the height of 1 m, 10 kgm of useful mechanical work are produced. However, applied to the man, it is merely a part of that work which is actually fulfilled. Performing the useful mechanical work, the man, at the same time, carries out the work of shifting the weight of his own body or part of it in vertical or horizontal direction. Besides, this work quantitatively involves much more useful work and depends on the production process, system of organizing production and workplace.

In the physiological aspect the concrete form of the labor process makes no difference. Here, only the counteractive forces in dynamic state are considered, therefore, the dependence derived earlier can be simplified. Let us assume that a labor process is carried out under the following climatic and sanitary-hygienic conditions $t°$=18–20°C, γ=50–60%, V=up to 2 m/sec, A_{er}=0, i.e. the conditions are comfortable and the air is practically pure. Under these conditions the coefficients taking into account microclimate C_m and surrounding atmosphere C_y may be assumed equal to 1. Coefficient or physical intensity is determined from the derivation of dependence

$$C_{pi} = f(\sum A_i), \tag{6}$$

where the left side represents the output of internal energy in the human organism, while the right side – the total of external mechanical works performed by the physical system of interacting factors of the labor process.

Having carried out quite a number of experiments on the measurement of human energy exchange in various forms of concrete work, the total volume of mechanical works can be calculated to derive a formula, based on which it will be possible **to determine the coefficient of physical intensity without resorting to measurement of human energy exchange.**

To calculate the external mechanical work carried out by the system "man–labor means–labor object" in various types of labor activity, the laws of mechanics are applicable.

Let us explain the calculation methods by concrete examples. The quarry stone is loaded onto a motor vehicle under the following conditions: average weight of 1 stone is 4 kg, total amount of the stones – 1000 pieces, time – 1 hour, height of throw – 2 meters, length of throw – 1,5 meters, assumed weight of the loader – 65 kg. It is required to calculate the mechanical work (in kgm/min).

Taking a man's average height as 170 cm, length of his legs may be assumed to be 0,9 m, length of arms – 0,7 m, length of step with legs apart – 0,6 m. The relative weight of separate parts and links of human body:

head	– 0,0724	trunk+head	– 0,5114
trunk	– 0,4390	whole arm	– 0,0577
shoulder	– 0,0299	whole leg	– 0,1865
forearm	– 0,0205	head+trunk	
thigh	– 0,1206	+ 2 arms	– 0,6268
hand	– 0,0075	shin	– 0,0500
foot	–0,0158		

In simultaneous movements of the human body and stone as a common system the following fixed states of the transition from one position to the next can be singled out:

1. Initial position: legs at the length of a footstep apart, arms at sides;
2. Legs bent at knees, trunk vertical, body lowers from the initial position by 0,2 m;
3. Legs bent at knees and trunk lowered, right hand seizes a stone, trunk lowers by further 0,2 m;
4. Legs straightened, trunk rises by 0,2 m;
5. Trunk with the stone in the right hand rises to the initial position by further 0,2 m;
6. Hand with the stone stretches back from equilibrium position by 0,4 m;

7. Right hand throws the stone into the truck body. The stone flies like a body thrown up at an angle to the horizon. The height is 1,2 m, length – 1,5 m;

8. Arm lowers to the initial position.

Based on the laws of mechanics the kinetic energy of each of the 8 positions and of the total work can be determined with practically sufficient accuracy.

1. Work of lowering the trunk:

$$A=W\cdot\Delta h\ , \tag{7}$$

where W – weight of the body – 65 kg; Δh – height of lowering – 0,2 m;

$$A=65\cdot0{,}2=13 \text{ kgm}.$$

2. Work of lowering the trunk not counting the weight of legs:

$$A_2=W\cdot0{,}63\cdot\Delta h=65\cdot0{,}63\cdot0{,}2=8{,}2 \text{ kg};$$

3. Rise of the trunk:

$$A_3=W\cdot\Delta h=65\cdot0{,}2=13 \text{ kgm};$$

4. Rise of the trunk with the stone not counting the weight of legs:

$$A_4=(W\cdot 0{,}63+W_s)\cdot0{,}6=(65\cdot0{,}63+4)\cdot0{,}6=27 \text{ kgm};$$

5. Work of stretching the arms back:

$$E_5=m_5\cdot\left(\frac{\varphi\cdot l_a}{t_5^2}\right)^2, \tag{8}$$

where m_5 – mass of the arm with the stone.

$$m_5=\frac{65\cdot0{,}06+4}{9{,}8}=4{,}4\frac{\text{kg/sec}^2}{\text{m}}\ ,$$

φ – angle of swinging the arm back by 40 cm and arm length of 70 cm; $\varphi=35°=0{,}51$ rad.

Time t_5 (sec) is determined assuming that 1000 stones are loaded in 1 hour, i.e. 1 stone in 3,6 sec, one movement in 3,6/6=0,6 sec.

$$E_5=m_5\cdot\left(\frac{\varphi\cdot l_a}{t_5^2}\right)^2=4{,}4\left(\frac{0{,}61\cdot0{,}7}{0{,}5}\right)^2=3{,}1 \text{ kgm}.$$

6. To throw the stone to length S and height h it must be given an initial speed that would release sufficient kinetic energy to cover the horizontal movement to length S.

According to the laws of motion of a body thrown up at an angle without air resistance, the following can be found as follows:

a. distance of flight – $S=\dfrac{\sin 2\alpha\cdot V_0^2}{g}$; (9)

therefore, the maximum value will be at the angle $\alpha=45^{\circ}$;

b. height of flight – $h=\dfrac{\sin^2\alpha\cdot V_0^2}{2g}$; (10)

c. work of free fall – $A_g=Wh$;

d. work of translational motion with constant speed –

$$A_t=\frac{m\upsilon^2}{2}\ . \qquad (11)$$

At distance S=1,5 m and α=45°

$$\upsilon_0=\sqrt{S\cdot g}=\sqrt{1{,}5\cdot 9{,}8}=3{,}9\ \text{m/sec}\ ;$$

i.e. for the stone to fly 1,5 m it must have the speed of 3,9 m/sec at the moment of throwing.

The additional lifting height:

$$h_1=\frac{\sin^2\alpha\cdot\upsilon_0^2}{2g}=\frac{0{,}49\cdot 14{,}7}{2\cdot 9{,}8}=0{,}4\ \text{m}\ .$$

The work performed during the direct throw of the stone:

$$A_6=\frac{mv_0^2}{2}+W_1\cdot(h_1+h-0{,}6)\ , \qquad (12)$$

where m – mass of the stone; V_0 – speed of the stone on being thrown from the hand; W_1 – weight of the stone; h_1 – additional height flown by the stone after being thrown; h – given height of the stone placement (height of the truck body is 2 m); 0,6 – height of the stone in position 6.

$$A_6=\frac{W\cdot\upsilon_0^2}{2g}+W_1\cdot(h_1+h-0{,}6)=\frac{4\cdot 3{,}9}{2\cdot 9{,}8}+4(0{,}4+2{,}0-0{,}6)=10\,\text{kgm}\ .$$

7. Work performed by the hand falling to the initial position can be determined, with permissible approximation, by the formula:

$$A_7=W_1\,h=65\cdot 0{,}05\cdot 1{,}5=5\ \text{kgm}\ .$$

The total work in the loading cycle of 1 stone:

$$A=A_1+A_2+A_3+A_4+E_5+A_6+A_7=13+8{,}2+13+27+3{,}1+10+5=80\ \text{kgm}.$$

The total work of loading stones in 1 min:

$$A=1000/60\cdot 80=1280\ \text{kgm/min}.$$

This is the way the mechanical work is calculated in any aspect of physical labor. From the formulas given in the example it is seen that the external mechanical work is calculated not taking accelerations into account. Actually, in concrete types of work the movement of the body and its separate parts, as well as labor means and object, pass through complex spatial systems with speeding up or slowing down. Therefore, an error, principally affecting the absolute values of work, is introduced into the result of the mechanical work calculation by the given formulas. To reduce the error the work process can be broken up into separate types of movements (microelements), and the mechanical work can be calculated applying still more precise methods.

However, to elucidate the general regularity of the energy exchange dependence on the value of external mechanical work it is sufficient to apply the approximate calculating methods.

4.4. Dynamics and statics in labor process

The human organism experiences static and dynamic loads simultaneously. Their various proportions depend upon organizational-technical conditions under which the labor process proceeds. The nervous-muscular process of turnout of dynamic and static proportions of muscles is linked with tonic and titanic muscular strain combined.

The function of a muscle involves drawing together the two points to which its ends are fixed, at the same time, overcoming external resistance. In static work the function of muscles is to maintain these points in a definite position, resisting external influence – in the event of "negative" work, to counteract their running into opposite directions. Static and dynamic muscular activities usually complement each other; statically working muscles furnish initial body position, on which basis the dynamic work is performed.

While the value of static work is determined only by the value of external counteractive forces and interrelationship of levers, the demands on the dynamically working muscle depend, in addition, on the mass of moving parts and moment of inertia. It has been established [22] that static work is more strenuous and fatiguing than dynamic work. More or less regularly alternating contractions and relaxations are characteristic of dynamic work.

For further analysis we denote the ratio of static and dynamic loads arising in man's skeletal musculature, while performing some concrete work, by letter "a". This magnitude is nondimensional, and probably for each type, the same as the coefficient of useful action, it has its own definite value. There are almost no quantitative measurements, concrete values of ratio"a" in publications.

Let us suppose that a=1,0 for such labor process, for which the ratio between the external mechanical work and internal energy are maximum, i.e.

$$\frac{A}{E}=\text{max} \tag{13}$$

Let us try to find such type of activity.

A list of the simplest and most frequently met forms of physical activity in ordinary practice has been introduced in the fundamental work on labor physiology [22]. The results of research of human energy exchange in kcal/min for every variety of activity are given in the list.

The analysis of this data (Supplement 2) allowed making a number of useful conclusions. When calculating the ratio of mechanical work to internal energy it was found that that the most "productive" form of activity of the human organism was walking without load at the speed of 4–4,5 km/hr. Actually, this form of activity has the greatest ratio of mechanical work to internal energy spent – 337 kgm/kcal. This is confirmed by physiologists and engineers – labor organizers: "economy" of walking at 4 km/hr.

Going up a vertical ladder with load turned out to be the least "productive". In other cases, ratio A/E is found between these two forms of activity.

Based on the set for theoretical principles of the work of skeletal musculature, the following mathematical expression can be presented:

$$E = a \cdot \frac{A}{C}, \tag{14}$$

where E – internal energy of human organism spent, kcal/min; A – external mechanical work performed by the system "man–tool–object of labor, kgm/min; a – ratio of static and dynamic loads in man's skeletal musculature during the concrete work,– nondimensional magnitude; C – transfer coefficient of mechanical work into heat, kgm/kcal.

The foregoing formula refers to the energy spent to overcome external physical forces, i.e. to perform mechanical work. However, apart from this, the energy is spent for standard metabolism E_{sm}, maintaining pose in the initial position E_0 (stand, sit). Consequently, we can write down

$$E_c = E_{sm} + E_o + a \cdot \frac{A}{C} \ . \tag{15}$$

The energy of standard metabolism, as a constant value for some particular individual, can be excluded, i.e.

$$E = E_c - E_{sm} = E_o + a \cdot \frac{A}{C} \ , \tag{16}$$

where $E = E_c - E_{sm}$ – energy spent by human organism in the process of performing work, deducting standard metabolism. In Supplement 2 it is actually this energy that is presented.

To calculate the coefficient of physical intensity connected with various forms of human activity we take as basic, standard "labor process" walking at the speed of 4 km/hr, a=1,0. Energy to support the pose "stand" E_0=0,7 kcal/min.

The transfer coefficient can be calculated for walking:

$$C = \frac{\alpha \cdot A}{E - E_o} \tag{17}$$

and, based on the data in Supplement 8 and assumed conditions, we can determine that

$$C = \frac{1{,}0 \cdot 710}{2{,}1 - 0{,}7} = 473\ \text{kgm/kcal} \approx 500\ \text{kgm/kcal}\ .$$

If we take into account some simplifications made in the calculations of mechanical work, then the coefficient obtained is actually the mechanical equivalent of heat used in physics. From here we finally get

$$E = E_o + a \cdot \frac{A}{500}\ . \tag{18}$$

By conversion coefficient "*a*" is expressed from this formula:

$$a = \frac{(E - E_o) \cdot 500}{A}\ . \tag{19}$$

To calculate concrete values of "*a*" by forms of work given in Supplement 2 it is necessary to insert the corresponding numerical values E, E_0 and A from this supplement into this formula.

4.5. Index of labor intensity

To transit from the energy expenditure to the coefficient of physical intensity the right and left parts of equation of energy expenditure are divided into the energy a man uses up walking at 4 km/hr, i.e.

$$C_{pi} = \frac{E}{E_b} = \frac{1}{E_b}\left(E_o + a \cdot \frac{A}{500}\right) \cdot C_m \cdot C_y\ , \tag{20}$$

where C_m – coefficient of micro-climate; C_y – coefficient of air environment conditions.

For concrete works not indicated in Supplement 2 and not investigated by physiologists the expenditure of internal energy is calculated in the following sequence:

1. Certain fixed states are singled out in the labor process. If necessary, a movement chart of the system "man–tool–object of labor" is worked out.

2. External mechanical work performed by the system "man–tool–object of labor" is calculated according to the laws of mechanics or specially worked out standards.

3. Coefficient of the ratio between static and dynamic loads on muscles (*a*), either for the work, in general, or for its separate elements, is selected by analogy or based on calculations (Supplement 1). Types of work indicated in Supplement 2 serve as analogies.

4. Coefficient of physical intensity is calculated on the condition that C_m=1,0 and C_y=1,0.

For greater clarity let us continue with the example of quarry stone loading. Coefficient "*a*" is to be found and coefficient of physical intensity calculated.

For the type of movement: bending the body, raising the body with simultaneous movement of arms with load, we find "*a*" by the formula:

$$a = 2{,}3046 + 0{,}0786l + 0{,}4067h -$$

$$- \sqrt{0{,}0265n + 0{,}067l + 0{,}0711h + 0{,}0272l \cdot h - 0{,}0141l^2 - 0{,}0314h^2 - 0{,}4323} \quad ,$$

where *l* – length of the load throwing, m; *h* – height of the load throwing, m; *n* – number of throws, pcs/min.

In the considered example of stone loading

l=2,0 m; *h*=2,0 m; *n*=100/60=16,7 pcs/min; hence

$$a = 2{,}3046 + 0{,}0786 \cdot 2 + 0{,}4067 \cdot 2 -$$

$$- \sqrt{0{,}0265 \cdot 16{,}7 + 0{,}067 \cdot 2 + 0{,}0711 \cdot 2 + 0{,}0272 \cdot 2 \cdot 2 - 0{,}0141 \cdot 2^2 -}$$

$$\overline{- 0{,}0314 \cdot 2^2 - 0{,}4323} = 2{,}83 \ .$$

Coefficient of physical intensity when E_o=0,7 kcal/min, *a*=2,83 and *A*=1280 kgm/min, $C_{pi} = \frac{1}{E_b} \cdot \left(E_o + a \cdot \frac{A}{500} \right)$, i.e.

$$C_{pi} = \frac{1}{2{,}1} \cdot \left(0{,}7 + 2{,}83 \cdot \frac{1280}{500} \right) = 3{,}8 .$$

The coefficient derived shows that with 8 kcal/min of internal energy spent without standard metabolism, the work of loading 1000 stones of 4 kg each on a lorry is 3,8 times more strenuous than walking at the speed of 4 km/hr without load under favorable micro-climatic and air environment conditions.

4.6. Heat exchange in labor process

The corrective factor applied to the energy spent by human organism depending on changing microclimatic parameters, can be expressed by the functional dependence:

$$C_m = \mathrm{f}\,(E, t^\circ, P, \gamma, \upsilon), \qquad (21)$$

where *E* – level of energy spent for concrete type of work; t^o – air temperature in the working zone; *P* – year season determined by the outside air temperature; γ – relative humidity in the working zone; *υ* – air velocity in the working zone.

There are two physiological-hygienic microclimatic evaluation schemes under domestic and production conditions. The first scheme: the calculation method in which it is necessary to study experimentally only the microclimate. In the second scheme the calculations are based on physiological observations, in which, together with microclimatic data, the organism state by a number of physiological indexes needs to be taken into account.

The majority of native and foreign researchers consider possible and promising the use of calculation formulas for evaluating the state of thermoregulation. However, this method of characterizing the organism thermal state is connected with a number of theoretical and practical difficulties. At the present state, when resolving various practical problems, the formulation of physiological research is usually extremely complicated, and at times – for instance, at the planning stage – mostly impossible. For this reason the study and evaluation of human heat exchange under the described microclimatic conditions by applying the calculation methods, though of approximate value, is quite justified.

The labor intensity corrective factor on microclimatic deviation from the comfortable (favorable) state is determined by the undernoted method without physiological experiments, and can be used for evaluating the existing, as well as designed workplace.

Under the conditions of machine-building enterprises, where the overwhelming majority of work is performed in premises with practically constant air velocity (υ=0,1–0,2 m/sec) and relative humidity near comfortable (γ=60–70%), it is possible, with sufficient accuracy in practice, to apply N. K. Witte's approximate method. The essence of it is as follows:

It is assumed that heat exchange by radiation, convection and evaporation is a function of meteorological conditions and internal energy output. The energy consumption is determined through calculations by empirical formulas and tables.

a) for heat losses by radiation R;

b) for heat losses by convection C;

c) for heat losses by evaporation P.

Heat losses by radiation and convection are calculated by formulas:

1. For a person at rest (sit, stand, lie) at working zone air temperature t_A<35ºC,

$$R+C=0{,}08(t_A-35) \text{ kcal/min}; \tag{22}$$

at air temperature of $t_A \geq 35$ºC,

$$R+C=0{,}13(t_A-35) \text{ kcal/min}. \tag{23}$$

2. For a person performing light work and work of medium hardness (work with corresponding physical intensity coefficients $C_{pi} \leq 2{,}2$) at working zone air temperature t_A<35°,

$$R+C=0{,}17(t_A-35) \text{ kcal/min}; \tag{24}$$

at air temperature of $t_A \geq 35°$,

$$R+C=0{,}17(t_A-35) \text{ kcal/min}. \tag{25}$$

3. For a person performing heavy work (physical intensity coefficients C_{pi}>2,2) at air temperature of t_A=0÷50°C

$$R+C=0{,}20(t_A-35) \text{ kcal/min}. \tag{26}$$

Heat losses by sweat evaporation are determined by empirical formula:

$$P=[0{,}6+\alpha(t_A-10)^2]\cdot 0{,}585\cdot \eta_p \text{ kcal/min}, \tag{27}$$

where α – coefficient of specific moisture evaporation, value of which is determined experimentally depending on the air temperature. The values α are introduced in Table 2. t_A – working zone air temperature in ºC; 0,585 – experimentally found average heat value required to evaporate 1 gram of sweat; η_p – coefficient of effectiveness of moisture disengagement, i.e. ratio of the amount of moisture disengaged to maximum amount of moisture which can be evaporated under the given conditions. This coefficient is introduced as not all the watered moisture evaporates while the work is being performed. The values of η_p are given in Table 3.

Table 2

Value of coefficient α (according to N.K.Witte)

Air temperature, ºC	α	Air temperature, ºC	α	Air temperature, ºC	α
12	0,0015	24	0,0029	41	0,0045
14	0,0018	32	0,0038	44	0,0045
16	0,0020	34	0,0040	46	0,0047
18	0,0022	36	0,0042	48	0,0048
20	0,0024	38	0,0043	50	0,0049
22	0,0027	40	0,0044		

Table 3

Value of coefficient ŋ (according to N.K. Witte)

Air temperature, ºC	**ŋ**
22	0,75 – 0,90
32	0,69 – 0,84
45	0,49 – 0,58

The formulas and tables for heat loss calculations connected with radiation, convection and evaporation have been taken from work [11]. Other, more accurate heat loss calculations varying with microclimatic changes are also given in this work.

Based on heat loss calculations connected with radiation, convection and evaporation and production of internal energy, the balance of heat exchange of the human organism with the environment is drawn up:

$$Q = E \pm R \pm C - P \ \text{kcal/min} , \tag{28}$$

where Q – value of unbalance in heat exchange: can be negative (heat loss) and positive (heat accumulation), kcal/min; E – internal energy production in the given (investigated) type of work or technological operation, kcal/min; R – heat losses by radiation, kcal/min, taken with the corresponding sign (+ or –); C – heat losses by convection, kcal/min, taken with corresponding sign (+ or –); P – heat loss by evaporation, kcal/min.

To be given the working zone air temperature, it is possible to estimate and draw up a table of heat exchange unbalances. By this table the comfortable zones of temperatures can then be found.

Microclimate correction factor:

$$C_m = \frac{Q_{he} + E}{Q_c + E} ,$$

where Q_{he} – heat exchange unbalance with the given air temperature, kcal/min; in spite of the sign the unbalance is taken as a positive magnitude; Q_c – heat exchange unbalance at air temperature corresponding to comfort zone, kcal/min; E – internal energy produced determined by the formula

$$E = E_o + a \cdot \frac{A}{500} \text{ kcal/min},$$

where E_o=1,7 kcal/min for works performed while standing; E_o=1,3 kcal/min for works performed while sitting; a and A are determined by the method previously outlined to calculate the coefficient of the ratio of static and dynamic loads on muscles and definition of the value of mechanical work.

4.7. Calculation examples

Let us examine several examples:

1. A man weighing 65 kg, 170 cm high, dressed in ordinary room clothes (underwear, shirt, half-woolen suit) is in a state of rest:

$$E=1{,}5 \text{ kcal/min}.$$

2. A man similarly dressed (example 1) walks on a smooth, hard surface at 4 km/hr.

3. A man with the same (example 1) anthropometric data loads a quarry stone onto a lorry.

For each of these examples it is necessary to determine the comfortable temperature zone and correction factors C_m by calculations.

For the state of rest $R+C$ is calculated by formulas:

$$R+C=0{,}008(t_A-35) \quad \text{and} \quad R+C=0{,}13(t_A-35).$$

For walking at the speed of 4 km/hr

$$R+C=0{,}11(t_A-35) \quad \text{and} \quad R+C=0{,}17(t_A-35).$$

For loading the stone

$$R+C=0{,}20(t_A-35).$$

Heat losses by evaporation for all examples will be determined by the formula

$$P=[0{,}6+\alpha(t_A-10)^2]\cdot 0{,}585\eta_p.$$

The amount of energy produced is taken from the previously obtained solution:

1. At rest – E=1,7 kcal/min;
2. Walking at 4 km/hr – E=3,1 kcal/min;
3. Loading stone – E=10,0 kcal/min.

The calculation results are given in Table 4. The internal energy (heat output) has been taken with standard metabolism considered. If we take as invariable the value of internal energy output in view of surrounding air temperature change, then C_m will vary from 1,00 to 1,83. The air temperature rise beyond the optimal (comfort zone) causes a slowingdown in man’s work, thereby, affecting the value of internal energy output. This further leads to less moisture exudation and evaporation. With the air temperature reduced below the comfortable, man changes clothes and, consequently, lowers heat yield by convection and radiation. Therefore, these are the factors regulating the heat exchange.

In the light of the above, by practical considerations, the limit of C_m can be restricted to 1,50.

Different groups of hardness have respective comfort zone temperature limits, marked with the broken line (Supplement 1).

The microclimate correction factors under various combinations of temperature, humidity and air velocity in the working zone demand particularly exclusive calculating methods.

4.8. Labor environment conditions

The rate fixing of air environment conditions in industry is one of the most important problems in labor hygiene. Some researchers divide the air environment conditions into 4 zones: zone of exceptionally favorable conditions, favorable conditions and unfavorable conditions (psychological boundary), impermissible conditions (physiological boundary).

The sanitary norms in designing industrial enterprises are a basic legal document approved by the State Construction Committee and it applies to all branches of industry. It contains requirements for various production and utility premises, sanitary engineering mechanisms, etc.

The supplements to the norms contain the classification of productions and protection zones, norms of meteorological conditions in production premises, maximum allowable concentrations of harmful gases, fumes, dust in the working premises environment, norms of artificial and natural lighting, noise and vibrations.

The degree of harmful work is fixed by specialists of medical-sanitary departments, as well as safety engineering departments of enterprises and sanitary-epidemic stations of cities.

The research of the biological effect of surrounding air conditions on animals' organisms composing of manganese oxide (MnO_2= =0,57 Mg/M^3),chromic anhydride (Cg_2O_3)=1,45 Mg/M^3), fluorine (F= =4,45 Mg/M^3), nitric acid (NO=5 Mg/M^3), nitrogen oxide (HO_2=traces), hydrogen fluoride (HF=3 Mg/M^3) was carried out by the specialists of Leningrad Institute of Labor Protection [45, 46]. The environmental temperature was maintained at 24ºC and relative humidity 72–78%. The observations continued for 9 months, 5 to 6 hours a day, except days off.

To study the harmful effect of dust and gases an integral method was chosen, by which the changes not in certain organs or systems but throughout the organism are determined.

Table 4

Results of C_m calculations for 3 examples

Form of activity	**Working zone air temperature, °C**	**Heat losses by radiation and convection (*R*+*C*),** ±kcal/min	**Coef-ficient α**	**Moisture effectiveness factor η_p**	**Heat losses by moisture exudation** (evaporation) ***P***, kcal/min	**Internal energy output** ***E***, kcal/min	**Heat exchange balance *Q*,** ±kcal/min	**C_m factor**
1	2	3	4	5	6	7	8	9
At rest	0	–2,80	–	–	–	1,5	– 1,30	1,80
	10	– 2,00	–	–	–	1,5	– 0,50	1,29
	18	– 1,36	0,0022	1,00	0,43	1,5	– 0,29	1,15
	20	– 1,20	0,0024	1,00	0,50	1,5	– 0,20	1,10
	25	– 0,80	0,0029	0,90	0,65	1,5	+ 0,05	1,00
	30	– 0,40	0,0036	0,84	1,00	1,5	+ 0,10	1,03
	35	–	0,0041	0,84	1,75	1,5	– 0,25	1,13
	40	+ 0,65	0,0044	0,70	1,85	1,5	+ 0,30	1,16
	45	+ 1,30	0,0046	0,58	2,10	1,5	+ 0,70	1,42
	50	+ 1,95	0,0049	0,58	2,87	1,5	+ 0,58	1,35

Continuation of Table 4

1	2	3	4	5	6	7	8	9
Walking at 4 km/hr	0	– 3,96	–	–	–	3,1	– 0,86	1,23
	10	– 2,75	–	–	–	3,1	+ 0,35	1,07
	12	– 2,53	0,0015	1,00	0,35	3,1	+ 0,12	1,00
	15	– 2,20	0,0019	1,00	0,38	3,1	+ 0,48	1,10
	20	– 1,65	0,0024	1,00	0,50	3,1	+ 0,95	1,26
	25	– 1,10	0,0029	0,90	0,65	3,1	+ 1,35	1,38
	30	– 0,55	0,0036	0,84	1,00	3,1	+ 1,55	1,44
	35	–	0,0041	0,84	1,00	3,1	+ 1,35	1,38
	40	+ 0,85	0,0044	0,70	1,85	3,1	+ 2,10	1,61
	45	+ 1,70	0,0046	0,58	2,10	3,1	+ 2,70	1,80
	50	+ 2,55	0,0049	0,58	2,87	3,1	+ 2,78	1,83
Loading quarry stone onto a lorry, 1000 pcs/hr	0	– 7,0	–	–	–	10,0	+ 3,00	1,00
	10	– 5,0	–	–	–	10,0	+ 5,00	1,15
	12	– 4,6	0,0015	1,0	0,35	10,0	+ 5,05	1,15
	15	– 4,0	0,0019	1,0	0,38	10,0	+ 5,62	1,20
	20	– 3,0	0,0024	1,0	0,50	10,0	+ 6,50	1,27
	25	– 2,0	0,0029	0,90	0,65	10,0	+ 7,35	1,33
	30	– 1,0	0,0036	0,84	1,00	10,0	+ 8,00	1,39
	35	–	0,0041	0,84	1,75	10,0	+ 8,25	1,40
	40	+ 1,0	0,0044	0,70	1,85	10,0	+ 9,15	1,47
	45	+ 2,0	0,0046	0,58	2,10	10,0	+ 9,90	1,53
	50	+ 3,0	0,0049	0,58	2,87	25	+ 10,13	1,63

During the research the blood morphology, as well as oxygen absorption, dynamics of weight, muscle fatigue, muscle activity, skin electro-sensitivity, dust phagocytosis, coefficient of weight of internal organs, and histological investigations of internal organs were also carried out. The animal behavior and appearance were also observed. Regarding the organism energetics, the change in oxygen absorption after 3, 6 and 9 months was revealed.

It was seen that after the first three months in the chamber the experimental animals consumed 26–30% more oxygen than control animals, but later the opposite was observed: the oxygen consumed was 20–48% less. At first, the internal energy output increased, then decreased. Both have a negative effect on the organism, causing greater strain.

A very important conclusion follows from the experimental facts: it is enough to detect some kind of chemical element or substance in the working zone air environment beyond the boundaries of permissible concentration, it is necessary to apply protective means or stop the working process. To fix the labor intensity level regardless of concrete chemical composition of aerosols (dust and gases) one corrective factor for the presence of aerosols can be established, taking into account only the level of their concentration in the atmosphere.

Table 5 contains the values of the corrective factors for the level of working conditions in the working zone.

Table 5

Labor intensity corrective factors, taking into account the aerosol level

Zone	Conventional signs	Corrective factor
Favorable conditions	Y1	1,00
Normal conditions	Y2	1,25
Unfavorable conditions	Y3	1,50
Impermissible conditions	Y4	∞

Chapter 5
Informational essence of labor

"Abstracting from a definite character of productive activity and, consequently, from the useful character of labor, only one thing remains in it – that it is an expenditure of *human working force* (italics are mine – Yap). Both tailoring and weaving, despite the qualitative difference between these two types of productive activity represent productive expenditure of the human brain, muscles, nerves, hands, etc., and in this sense – one and the same human labor. These are merely two different forms of spending human working force. Naturally, human working force itself must be more or less developed to be spent in one form or another. But the cost of a product is represented simply by human labor. That is the expenditure of simple working force possessed on an average by the bodily organism of every ordinary person not distinguished by any particular development [18, P.52].

5.1. Simple labor

Simple average labor, though bearing a different character in different countries and in different cultural epochs, is in every definite society, nevertheless, something that is given. Comparatively complex labor only means simple labor raised to power or, rather, multiplied, so that the less amount of complex labor equals the greater amount of simple one. The experience shows that such reduction of complex labor to simple goes on constantly. A piece of goods can may be a product of the most complex labor, but its cost makes it equal to a product of simple labor and, consequently, it merely represents a definite quantity of simple labor" [27, P.52].

The definitions given by Marx have the same fundamental scientific importance in social labor organization and economy as, say, Newton's laws applied to scientific research in mechanics and design of mechanisms. Incidentally, Newton's laws used here in investigations into labor processes are of no means insignificant. For example, in computing the mechanical work performed by a man's body jointly with an object or certain parts of the means of labor, the formulas used were deduced exclusively from Newton's laws of force, acceleration, mass, momentum and mechanical work.

There is still no quantitative expression of simple and complex labor corresponding to Marx's definition in the science of social labor organization. However, modern achievements in labor physiology and psychology, economy and social rate fixing, cybernetics and theory of information permit making a multisided quantitative analysis of various forms of labor, and give grounds for formalization and presentation of the above definitions as formulas.

In fact, simple labor, if it is expenditure of simple working force which every ordinary human system possesses, is quantitatively expressed, on the basis of modern achievements in labor physiology, through expenditure of human energy measured in kilocalories of heat. Over and above, expenditure of working force may be determined before completion of the labor process.

Therefore, in the formula

$$E = E_O + a \cdot \frac{A}{500} \tag{29}$$

quantitatively expressing the coefficient of physical intensity, the value of simple labor is reflected.

Analyzing the above provisions on the physiological energy of the labor process, we can draw a number of conclusions.

1. Physical intensity coefficient is always a positive magnitude, but C_{pi} may assume any values up to the maximum marking the utmost the human organism is capable of.

2. Simple labor – that is a labor process with a physical intensity coefficient equal to one unit. However, there is actually not a single labor process which would be marked by merely one physical intensity coefficient as that would run counter to the evident fact that there is no sense talking of an individual's purposeful activity, i.e. of the labor process itself, without a display of intellect.

3. All actually existing labor processes are complex in accordance with their manifestation and result.

It now remains to clarify the core of the labor process from the standpoint of a complex process and find quantitative methods of determining labor complexity.

5.2. Complexity of labor process

We meet the notions "complexity" and "complex systems" practically in all sciences. They have acquired a special role in cybernetics, where the prime problem is working out methods of analysis and synthesis of complex dynamic control systems.

To give meaning to and quantitatively express the complexity of a system, process, phenomenon it is necessary to understand and express the component parts of the notion complexity, characteristic features of which can be established by following statements [51].

1. Everything complex is made up of simple elements. Therefore, for quantitative expression of complexity it is necessary to determine *simple* as the beginning of count off, as a measure of complexity.

2. Complexity is marked by internal and external bonds of the object, system, phenomenon, process and situation; bonds determine their organization (structure).

3. The most important sign of a complex system is variety, heterogeneity. Indeed, other similar conditions would make it seen natural to consider that the more complex an object or process is, the more is its variety.

4. Complexity is a category reflecting, above all, dynamic systems. That is why, to explain the value of complexity, the law of *accumulation of experience* now assumes prominence. Based on this law, methods of simplifying systems are worked out, i.e., permissible lowering, in practice, of complexity of system.

5. For cybernetic systems (they are always complex dynamic systems) receiving, working over, storing and transferring information are appropriate. The quantity of information going through the system is the only criterion at present for quantitative expression of complexity level of any system.

In this way, among various methods applied in the study of behavior of complex systems, the theory of information is well in the forefront.

6. The possibility of quantitatively evaluating a complex system permits, theoretically and practically, making a purposeful choice of existing methods of research of cybernetics systems. Particular interest in study of the intellectual aspect of labor processes is aroused when the object being investigated is interpreted as “black box”, as a system whose internal structure is unknown, but which (system) allows, examining its “inputs” and “outputs”, making an appraisal of its “external” (functional, from behavior standpoint) complexity. The method of “black box” is the most important strategy for mastering complex systems which, as such, play a preeminently important role in society. This method of studying complex systems is not new as it had been used by man both in theory and practice.

Examination of a simple case confirms the above reasoning. One of the lathe handles is switched on and the spindle starts rotating. From a cybernetics viewpoint it may be represented on the scheme (Fig. 7):

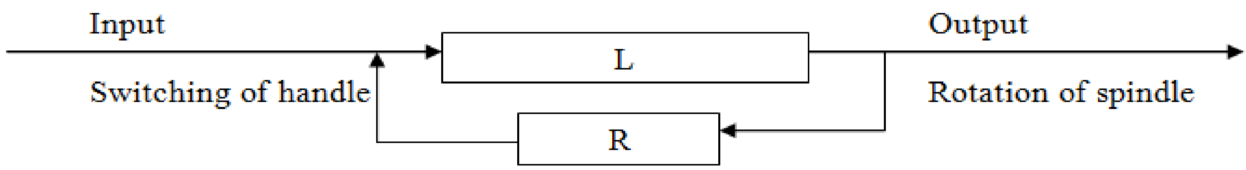


Fig.7. Scheme of work on a lathe

The man switching on the spindle may have no idea of the principle of action of the internal system of the machine’s mechanisms, but he cannot fail to note rotation of spindle after switching on the handle in the corresponding direction. The internal system of machine mechanisms in the case under consideration becomes “black box”. The general view of “black box”: it is a system with known input and output magnitudes, but with unknown internal design. What is remarkable is that cybernetic methods and their “grammar”– theory of information – permit finding a direct quantitative expression to understand the complexity applied to many phenomena, situations, processes, and start to create a harmonious, logically sound system of quantitative research of labor processes heterogeneous in quality.

In practice, the intellectual labor intensity is identified with the labor process complexity, quantitatively determined by the corresponding work category. The classification of single labor processes according to complexity, given in job rating- qualification reference books and staff lists, is based on the principle of mental (intellectual) intensity growth from the simplest to the most complex types of labor.

Various recommendations on defining physical labor complexity, accepted in practice and described in literature, can be boiled down to 4 methods: expert method, analytical method with complexity estimate by points, estimate by the performer's skills, logical-probabilistic (informational) method.

5.3. Expert method

The core of the method lies in the fact that specialists of the given profession or rate fixers of the corresponding branch (experts) can evaluate, according to a definite method, examples of concrete jobs. These jobs are then grouped into the corresponding categories. Long practice in use of the expert method in tariffing jobs and professions in capitalist countries, as well as experience in our country in applying various types of by-the-job and time wage rates, have produced a rather sound system of tariff coefficients and works categories.

5.4. Analytical method with complexity estimate by points

This method is a further development of expert method and figures prominently in our system of tariffing jobs, professions and wage rates. The given type of work or profession as a whole is evaluated by expert method intuitively based on experience of specialists. The following order of labor complexity by analytical method is the methodology recommended:

1. Functional structure of labor process (composition of functions) is defined.
2. Each function is divided into degrees of increasing complexity.
3. Scale of points is worked out applicable to functional structure of labor process.
4. On the basis of job rating cards filled in for each job (or groups of approximately the same complexity) the degree of complexity of each function is determined, which is then expressed by a concrete number of points.
5. Complexity interrelationship of various jobs is determined by comparing the number of points set down against each job evaluated on all functions.

To estimate the job complexity typical functions and semi-functions are singled out: preparing work and servicing the workplace (preparing the labor object), preparing labor tools and instrumentation (servicing the workplace), calculation before and during the work, taking charge of the labor process (performing basic working operation, equipment control, checking).

Along with these factors, determining the complexity level in the analytical method, two additional factors (functions) are introduced: managing other people and responsibility (reliability) for work fulfillment.

To estimate the complexity of functional structure of labor processes at work a standard scale of points is recommended.

5.5. Estimate of labor complexity by the level of performer's skills

The method of determining labor complexity through the performer's skill is based on Marx's statements, namely: that "labor of higher complexity compared to average social labor is a manifestation of such working force, formation of which requires higher expenditure and production of which entails more working time…" [27, P.204]. This is the basis on which the methodology of determining labor complexity has been worked out, proceeding from socially needed expenditure for production of working forces consistent with skill.

Undoubtedly, work of higher complexity demands a more highly skilled performer, towards which end comparatively longer training is called for, entailing higher expenditure on education and technical training. However, in the present instance it is not amiss to ask whether the time spent preparing for profession and length of practice can serve as a criterion for qualified clarification of jobs and professions in workers' tariff systems?

Suppose a turner, after finishing a middle school, completes a vocational course. After 5 years of practice he is rated the 6^{th} category. Later, because of production needs, he is sent to work on the construction site. This is often the case due to shortage of unskilled labor. Our turner is now a loader, loading quarry stone on to a lorry. Does loading by a 6^{th} category turner make the loading process more complex? It is quite evident that, in regard to labor complexity – the performer's skill – complexity of the labor process is the point of argument, and the function of the argument is the performer's skill.

5.6. Logical – probabilistic (informational) approach to determination of labor process complexity

Specialists engaged in the field of engineering psychology are working out methods of labor process research using mathematical logic and theory of information.

The most interesting and hopeful method of uncovering the essence of intellectual labor intensity is, in our eyes, the analysis of working process control based on drawing up logical schemes of the working process algorithm.

Human labor activity is considered by G.M. Zarakovskiy based on psychophysiological characteristics. It allowed him to introduce the concepts of elementary operations of control type, stereotype and logical complexity in the sense of the logical operations volume.

Among the existing principles and those advanced regarding the quantitative expression of labor process complexity, the analytical method is most significant, proceeding from the technological structure of labor process and logical-probabilistic approach with the algorithmic description of working process, permitting quantitatively expressing the logical labor complexity.

However, for practical problems and theoretical research it is considered possible to combine both methods, and to conduct any labor process research from the position of receiving, working over and transferring information.

5.7. Labor process as cybernetic system

The single labor process represents a complex of various material factors combined by man's purposeful actions. The exchange of information inside the system as well as between the system and environment takes place in this process. The exchange is put into effect through various channels along which the flow of information circulates. Such communications are a particular feature of any cybernetic system.

Feedback – the channel through which data on the results of control are introduced into the system – is especially important for cybernetic systems. Talking about man's purposeful actions in the labor process, control signals are always assumed and observed to enter the human organism (establishment of control communications) through the organs of sense, which manifest themselves in the given aspect as feed forward and feedback channels.

As far as "information is the basic attribute of the control process", the single labor process can be presented in an informational aspect by the following diagram (Fig. 8).

The informational aspect of labor process illustrated in the diagram can be shown by the following functional dependence:

$$S \equiv I_{lp} = \mathrm{f}(I_{lo}, I_{lm}, I_e, I_i, I_s), \qquad (30)$$

where S – labor complexity; I_{lp}– quantity of information on labor product; I_{lo} – quantity of information on labor object; I_{lm} – quantity, of information on labor means; I_e – quantity of information on energy; I_i – quantity of a priori (initial) information; I_s – quantity of information in subject.

The single labor process in the informational aspect proceeds in the following sequence: the labor subject feels, through the organs of sense, definite symptoms and affinities on the basis of which it takes in information (*I* initial, *I* labor object, *I* labor means, *I* energy sources), compares the information taken in with the information accumulated in the memory (*I* subject) and produces actions (A – labor object, A – labor means, A – energy source, A – initial information). Realization of the program of this cycle is manifested in labor product.

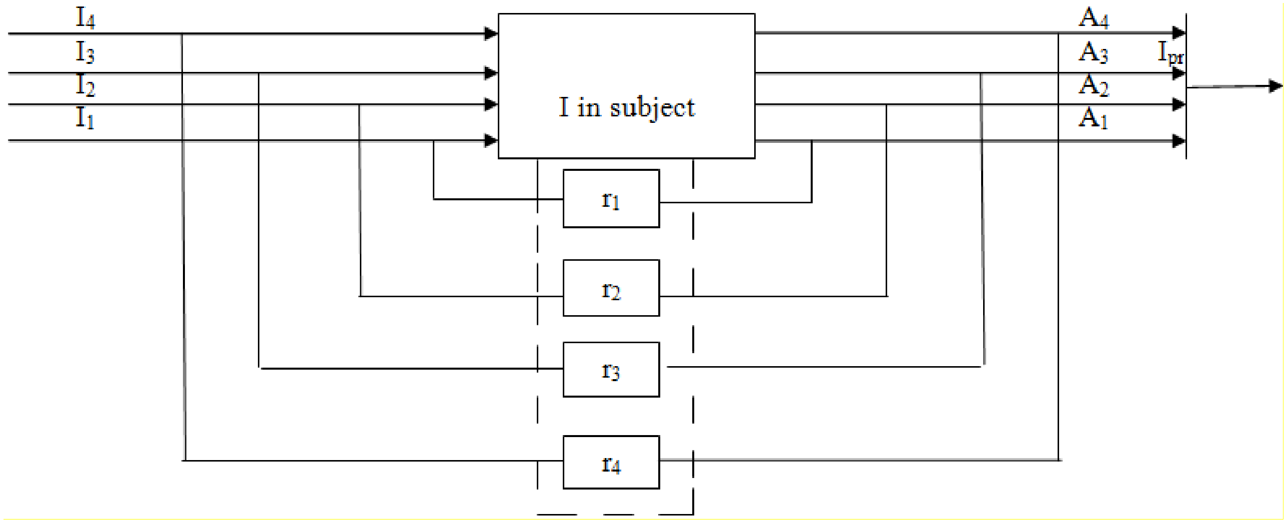


Fig 8. Informational flow diagram in the single labor process
(*I* – information, *A* – action, *r* – feedback regulators)

Consequently, the cycle of receiving, processing, storing, transferring the information by a person can be considered *an informational aspect of the labor process only when* the result of motive actions – labor product – is present.

Psycho-physiological processes taking place in a person's organism during the information transformation are not examined here. In the present case ("black box" method) it is not important. What is important is that the information comes in through inputs (sense organs); motive actions (generally physical actions of hands, feet and trunk) are output parameters.

In the overwhelming majority of labor processes the information transfer to a man-operator passes through optical and auditory analyzers, and only a small part – through tactile analyzer (touch). After receiving and processing the information, the operator performs some actions directed at changing the condition of the controlled object. By these actions the information is passed from man to machine.

All these working movements also have a physical significance as they result in physico-chemical change of properties, changed geometrical shape or location in space of labor object; at the same time, these movements display an informational character insofar as they change the internal structure and organization of all factors of the labor process (initial information, labor object, labor tools, energy sources and labor subject itself). The labor subject accumulates information within itself (experience), i.e., enriches its thesaurus.

In labor processes a part of phases runs along strictly determinate bonds, established beforehand, from cycle to cycle by repeated algorithmic rules (stringently regulated mass production operations); part of phases runs along probabilistic bonds, heuristic rules unforeseen beforehand. In particular, the process of corrective adjustment of equivalent and static character of resultant rejects in production can be attributed to this part of phases. Such actions as observation of scale showings of instruments, establishing a number of rotations of spindles, feed values, etc., are also of a probabilistic character, but only in the absence of the data given earlier.

On examining single labor processes as a manifestation of cybernetic systems, a relative character of complexity becomes highly important. In deciding practical job-rating and tariff questions, the chief problem is to find a common legitimate basis, according to which one complexity process can be compared with another.

Research can prove especially helpful in studying issues of labor complexity.

In a methodological plan the analysis of interrelationship of algorithmic and heuristic rules in working-over information processes is of particular interest.

Working over information processes in control may come into effect on the basis of definite combinations of heuristic and algorithmic rules. The method of purposeful processing of coded information brought about by a chain of mathematical and logical operations based on algorithmic and heuristic rules is called eurhythmy.

Eurhythmy is not the most flexible and universal means of processing coded information in control processes. Depending on quantitative interrelationship between heuristic and algorithmic rules included in eurhythmy, the latter can be marked by different heuristic and algorithmic depth. The more the specific value of heuristic rules in the structure of the given eurhythmy and the less the value of algorithmic rules, the more this eurhythmy is characterized by heuristic depth. In an extreme case, when the eurhythmic structure is determined only by heuristic rules and does not contain a single occurrence of algorithmic rules, the eurhythmy is transferred to heuristics. Another extreme case – eurhythmy comprises occurrences of only algorithmic rules and, therefore, goes over to algorithm, characterized by the greatest mathematical and logical depth. All gradations of heuristic and logical-mathematical depth of eurhythmy lie between these two extreme cases.

All regulating, self-adjusting, optimal control, etc. processes apply to algorithmic control processes; those based on pattern recognition, generalization, intuition, creativeness, etc. apply to heuristic; the following processes can be considered as eurhythmic: process of controlling function of human and animal internal organs, conditional on external situation, modern non-automatic and semi-automatic control processes in various parts of culture and everyday life [52].

In this way, all single labor processes in an informational aspect apply to eurhythmic processes. The interrelationship of heuristic and algorithmic methods of perception and processing of information has an impact on their complexity.

The interrelationship of heuristics algorithms in single labor processes can be expressed by the following interrelationship:

$$C_h = \frac{I_{tot} - I_{ini}}{I_{tot}} , \qquad (31)$$

where C_h – coefficient characterizing the interrelationship of heuristic and algorithmic rules of information processing applied by the labor subject in his work; I_{tot} – total quantity of information proper to the given labor process; I_{ini} – initial information coming in the given labor process in algorithmic form (drawing, production process instructions, methods, verbal instructions of a foreman, technologist, team leader, help of auxiliary workers, and adjusters).

On examining the labor processes in the informational aspect, the extent of the subject's contribution to labor complexity must be made clear.

Every labor subject is strictly individual. Personal habits, cognitions and skills give concrete expression to his stature as an individual –labor subject. That is why it often happens that the complexity of one and the same labor process performed by various individuals is appraised differently in each case. What is complex to one person may be less so to another, or quite simple to still another.

Actually, as applied to labor processes, it is important that, with new information coming in regularly, the labor subject (receiver) can enhance its capacity to take in and work over information (a navvy, after a course of training in turning operations, can start performing the simplest turning operations). This circumstance is not reflected in the information model proposed by Shannon, where the increase in the receiver a priori knowledge will lead to the decrease in the information quantity in the given message.

Let us suppose that a man with no practical experience nor any idea of turning were assigned to produce a hexahedral bolt 100 mm long, 20 mm in diameter, metric thread. Time-per-piece rate is 10 minutes. In this case, a situation arisen whereby a man in the role of receiver of information will possess minimum a priori information, narrowing his thesaurus to such an extent that the objective information proper to the given process cannot be taken in by it. As a matter of fact, the labor process will not be completed in this case.

Further, the labor subject has little experience in turning: at aschool workshop he had formerly, once or twice, produced cutting of a round bar into separate billets. Such a person can generally produce the assigned bolt. However, he will manage to do so only after several attempts and in a longer space of time than rated. In production practice it is said, in such cases, that the worker's category does not suit the work category. The individual will say that the assigned task was very complex.

After a certain amount of experience the thesaurus of the turner referred to will be broadened, his memory enriched with information acquired during the labor process, which ended for him according to the heuristic rules of trial and error. The turner has now worked out his own eurhythmy of conversion of information and actions conforming to eurhythmy worked out by practice applied to processes of producing the given type of bolt. It is a case when it is said in production that the worker's category is in line with the complexity category of the job. The turner will manage within the set time without reject and return.

Another case: turner-pattern maker, after becoming familiar during technical study and production practice with all the known lathes in society, and forms of machining on them, was assigned the task of producing the same bolt. The job will turn out to be the least complex to him, and he will finish it rather before the set time. In such cases, ineffective use is made of a person's capabilities in production. This contradiction is evident particularly on conveyor and production lines, where people with 8-10 years of secondary school education work.

We will express the above examples in the information aspect.

1st case $I_\theta << I_T$; $I_{(T,\theta)}$ – absent
2nd case $I_\theta < I_T$; $0 < I_{(T,\theta)} < I_T$.
3rd case $I_\theta \equiv I_T$; $I_{(T,\theta)} = I_T$.
4th case $I_\theta > I_T$; $I_{(T,\theta)} < I_\theta$,

or limit receipt of information by receiver Θ on message T equal to zero due to the excess of a priori information.

The most typical case in highly organized production, when $I_\theta \equiv I_T$, is characteristic of socialist production, where the whole system of professional training and use of workers and engineering-technical staff is built according to 3rd case. Deviations are considered as violations of social norms.

At the same time, it must be noted that the level of subject preparedness to perform a concrete type of labor is always reflected in the results of labor (level of rejects, return, productivity). Here, there must be social prerequisites and conditions for leading 1st, 2nd and 4th cases to typical 3rdcase.

While clarifying the subject's role in forming labor complexity, the 3rd case is taken as basic, *and the impact of a priori level of information which the labor subject possesses on the magnitude of complexity of the single process is not taken into account*.

5.8. Quantity of information

Information has the property of measurability and quantitative expression. The phrase "quantity of information" was coined as a result of study of technical information systems (systems of communication and electronic calculating systems), where the quantitative aspect of information plays the leading role in its functioning.

Information is knowledge or message to be kept on record, passed on or transformed [49]. The subject of information theory is represented by the processes of transferring, storing, transforming and using information.

Three methods of determining information quantity are known to science [17]. The first method of determining information quantity was the principle proposed by R.Hartly in 1928, called combinatorial method in science. Here, the quantity of information is determined by dependence

$$H=n\cdot\log S \text{ or } H=\log S^n \qquad (32)$$

where H – quantity of information; n – quantity of successive choices; S – number of characters used for transferring the message.

Regarding this method R.Hartly noted: "What we have done boils down, consequently, to the fact that as a practical measure of information we take a logarithm of the number of possible successions of characters" [12, P.12].

The choice of one or another base of the logarithm defines the unit of information measurement. When decimal logarithms are selected, the unit is called hartley, at the base of 2 – b i t, with natural logarithms – n i t.

W.R. Ashby has an identical approach towards computing quantity of information. It ought to be always remembered that the notion "variety" used in this book and the notion "information" used in theory of communication do not refer to any individual object but to a certain plurality. Any attempt to treat information as something that can be contained in another thing usually leads to "difficult" problems which should never have "arisen" [1, P.215]. Arising from this, Ashby identifies the notions "variety" and "information", and the magnitude of variety is determined as follows: "The word 'variety' applied to a multitude of different elements will be used in two senses:

1. as a number of different elements;
2. as a logarithm of that number according to base 2.

So, the sex diversity is 1 b i t, and the diversity of 53 playing cards is 5,7 b i t s ... To say that the set has got "no" variety, that all its elements are of the same type, it means essentially measuring it logarithmically; because the logarithm of one is zero" [1, P.179,180].

Consequently, the amount of information is defined as the amount of diversity according to the formula

$$I = \log_2 R, \qquad (33)$$

where R – number of different elements in the event, process, phenomenon, system.

Further development of combinatorial approach was the method of determining the quantity of information through probability of events suggested by C.Shannon. Signals, with the help of which information is transferred, are considered random variables having different probability. Quantity of information according to Shannon if determined by formula

$$H = -\sum_{i=1}^{n} P_i \cdot \log_2 \cdot P_i \ , \qquad (34)$$

where P_i – probability of n^{th} random event.

Shannon's formula determines the quantity of information contained in the message about the exact value, which liquidates the present indefiniteness. The message that event "e" has a kind of definite value X_1 eliminates indefiniteness (entropy), i.e., it carries information on event "e".

Probability notion of information quantity is generally accepted and is widely used not only in modern theory of information but in its various supplements.

However, besides a combinatorial and probability approach to the notion of information quantity, an algorithmic approach is possible. A.N. Kolmogorov directly links information with complexity notion [17]. His main idea is the following: the initial principle is the thesis regarding communication between two objects (y; x). Communication appears as information source. Hence A.N. Kolmogorov proposes to have information quantity understood as minimum length (complexity) of "program" $l(p)$ obtaining y from x. As communication between two objects can comparatively easily be exhausted, the minimum length, or complexity of program (quantity of information in x relative to y), can be determined with the accuracy up to a definite constant.

The algorithmic approach, despite the unlimited ("infinite") complexity of two separately taken objects, by finding relative complexity, permits "taking off", excluding this "infinity". By algorithmic method the complexity is determined as a final value, which becomes highly important for quantitative expression of complexity of many systems and processes.

5.9. On the information quantity measures

It is known generally that the information unit is a bit (binary digit). It's like an information atom. It can be represented by one of two digits of the calculus binary system – 0 or 1 – and it means as much information as contained in the answers like "yes" or "no" to any posed question about the object properties. Practical attempts to apply bits for the quantitative analysis of many questions posed by life did not lead to success. The probabilistic approach, as we can see, is sometimes absurd even by the very essence of the phenomenon. In this regard, the search for information quantity measures that adequately reflects the essence of the process is conducted.

With the view of this, A. Wilson's and M. Wilson's ideas of measuring the quantity of information seem to be very important. They indicated in 1955: "in order to measure the quantity of information in a message or a signal three types of units can be used: measuring uncertainty, structural complexity and fidelity". The first one is in the focus of scientific literature. As for the other two, they are not widely used.

5.10. Measure of uncertainty

To measure the amount of information using the notion of *uncertainty*, specialists of information transfer consider a specific amount of information as a sample of many possible alternative quantities of information. So, when throwing dice, the probability of number 5 equals 1/6, because the dice has only six faces. A significant part of the information theory is closely connected with the theory of probabilities. Quantity or volume of information contained in the message is determined by the number of bits in this message. The number of bits per unit of time is called the speed of information transfer. The quantities of information are added if you have several sources.

5.11. Measures of structural complexity

Logon content is a number of logons in some presentation. *Logon* is a unit of structural information – it means that the existing presentation can be added to one new distinguishable group or category.

The number of logons, given by a device, per one volume unit of space coordinate (cm, cm^2, sec, etc.) is called logon power. For example, in case of microscope logon power is a measure of the resolution in logon/cm. In the time area, channel, bandwidth which allows to make *n* independent samples in 1 sec, has logon power $\frac{n}{c}$.

5.12. Measures of metric information

Metron is a unit of metric information measurements. In case of numeric parameter, this unit is a measure of "accuracy", with which this parameter is specified. Each metric unit of information can be considered as a measure related to some basic event of a sequence of physical events that represent the object. Thus, the volume of metric information in one logon (logon's metron content) is determined by the number of elementary events, through the interaction or "condensation" of which it is formed. *Condensation* (Latin condensatio) – is the concentration, congestion, sealing.

These events are indistinguishable; their number is not the number of bits, which is equivalent to 1 logon. Accuracy increases monotonically with increasing metron content, however, only a few characteristics are associated with it in a linear way. Among these few exceptions there are power and energy in the classical meaning. The number of metrons per unit volume of the coordinate space is called metron power or metron density of a physical system [36].

5.13. Three aspects of information

The above reasoning is so important that the further development of the information theory could not be fruitful without it, especially in the area of human communications. The concept of information is the fact that cannot be ignored, it has become universal now, and it is a basic concept of cybernetics, as well as economic information is the basic concept of economic cybernetics.

If we proceed from the needs of economic management and, consequently, economic cybernetics, then information can be defined as all information, knowledge, messages that help to solve a problem of management (i.e. to reduce the uncertainty of its outcomes). Then some possibilities for the information assessment are opened: it is the better and more valuable, the sooner it leads to solving a problem with less expense. The concept of information is close to the concept of "data". However, there is a difference between them: data is the signals, out of which the information have to be extracted. Data processing is the process of adapting information required to extraction.

The process of transferring data from the source to the consumer and perception as information could be seen as the passing of three filters:

1) *physical* or statistic (purely quantitative limit on bandwidth, regardless of the data content, i.e. from the point of syntactics);

2) *semantic* (selection of the data that can be understood by the recipient, i.e. match to the thesaurus of his knowledge;

3) *pragmatic* (selection among the information that can be understood, which is useful for solving this problem).

Accordingly, there are three aspects of studying the problems of information – syntactic, semantic and pragmatic. By the content, the information is divided into the social-political, social-economic, scientific and technological, and etc. In general, there are a lot of classifications of information, they are built on different bases. For example, there are statistic information (constant) and dynamic (variable) information, and data is fixed and variable. Another division is the primary, derivative, output information; the third division is the controlled information and notified information; the fourth – redundant information, useful and false.

5.14. Universal law of transformation and accumulation of information

With all interpretations of the concept of information it assumes the existence of two objects: a source of information and customer (recipient) of information. Transfer of information from one person to another is performed with the help of signals, which may not have a physical connection with its meaning: this connection is defined by agreement. For example, a clam in the veche bell meant that people must gather on the square, but it did not report any information to those who did not know about this order.

As for the definition of the value, usefulness of information for the recipient, there are still many unresolved and ambiguity things. In the last decades philosophers have had a great interest to the problems of information: they tend to consider information as one of the universal properties of matter associated with the concept of reflection [55].

We keep to the same opinion and claim that along with the universal laws of transformation and conservation of matter and energy, there is a universal law which we formulate as follows: *in the evolutionary process information is generated by the transformation of matter and energy*, *it is also undergoes the transformation in this process*, *but unlike substance and energy*, *it does not only keep the quantity but tends to accumulate it*. *Accumulation of information is the universal principle of the evolutionary development*.

It is possible to connect the concept of information and another very important concept “complexity” through the concept of reflection in the evolutionary process. The algorithmic approach to the determination of the amount of information proposed by academician A.N. Kolmogorov is ultimately reduced to quantified complexity of the algorithm. The same is evident in the concept of *logon* as a unit of measurement of structural complexity.

Chapter 6
Categories of labor complexity

Before analyzing quantitative relationship in the matter of receiving, processing, storing and transferring information by the labor subject, the question: "What is the bearer of elementary material information?" should be clarified.

For the labor act to be completed, the labor subject must establish links with the external environment, i.e., focus attention on objective parameters of labor factors. Therefore, material information bearers (signals) are objects of attention.

6.1. Object of attention

Object of attention is a definite attribute, *property*, *parameter of the object perceived*, *whereby the perceiving labor subject establishes discrete or uninterrupted ties through its sense organs to achieve targets in labor actions*.

In the general theory of systems it is assumed that "objects are essentially simply parts or components of systems, there being an unlimited multiplicity of such parts. The majority of systems that interest us is composed of physical parts: atoms, stars, switches, masses, springs, bones, neurons, genes, muscles, gases, etc. We also take as object such abstract objects as mathematical variables, rules and laws, processes, etc." [12].

The notion "attribute" here means everything, in which objects or phenomena resemble or are distinct from one another: index, side of an object or phenomenon, by which the latter can be recognized, defined or described.

Property is what is proper to objects, what distinguishes them from other objects or make them resemble other objects (e.g., hardness, roughness, elasticity, heat conductivity, etc.). Every object has an infinite number of properties. Properties become apparent in the process of interaction of objects – they become apparent, but do not appear.

Variables not included in the system are called parameters. A change of parameter may change the system field, so that the system which, under one parameter value, was steady relative to the given area, may become unsteady under another parameter value relative to this area. For example, for the system of consumers of electrical energy the voltage of 220 V is a parameter.

Definitions of an attribute, property, parameter, object introduced above will help clarifying the meaning and content of the notion "object of attention", elucidation of which is crucial for successful quantitative analysis of labor processes.

Certain individual properties, attributes, parameters or their totality, proper to objects entering the labor process become familiar and change in the course of labor actions. There are two sides to the notion "object of attention": objective, characteristic of objects independently of the perceiving subject, and subjective, arising merely in conformity with the labor subject's aims. The point is that real objects are extremely complicated in internal structure and can be linked by a countless number of bonds with surrounding objects. The labor subject, establishing bonds with real objects, precludes endless indefiniteness. The target and sub-targets in labor actions appear as limiting rules for selecting bonds only with those attributes and properties of real objects, which are directly included in the algorithms of target achievement.

Actually, targets and sub-targets, worked out on the basis of known laws of nature, have a limiting character: they prohibit showing some events and phenomena and allow manifestation of others.

Objective and subjective sides in the notion "object of attention" are closely blended as the subject can attract attention and perceive only that which exists, voluntarily or not, in the real object.

6.2. Necessary variety and experience accumulation

The basis for quantitative research of the information aspect of labor processes is the law of necessary variety and the law of experience accumulation, *substantiated by W.R. Ashby*.

For information purposes we present a short definition of these laws. "Only variety can destroy variety" [1, P.294]. For clarity the following example may be cited: a car can be started and driven only by a person familiar with it and knowing the traffic regulations. "Changed value of parameter engenders less variety up to the new, lower minimum" [1, P.196]. This law of accumulated experience is actually shown by decreased variety in labor processes on transfer from experimental production to mass production.

The following definition ensues from the above: *complexity of any single labor process is directly proportional to the quantity of variety of objects of attention participating in this labor process and inversely proportional to accumulated experience*.

Further, a unit of measurement of variety quantity must be determined and a way found of quantitatively expressing the level of accumulated experience and then complexity of labor process determined.

The structure of information processing that is circulating in man's organism is found out through deep theoretical and experimental researches.

Transfer of information and control orders takes place by means of signals circulating in the nervous system which, besides, provides storing and most complex processing of information sustaining the vital functions and purposeful behavior of the organism.

It is believed that man has five senses: sight, hearing, taste, smell and touch. However, besides this group of receptors, which perceive irritations falling on the external body surface, there are senses characteristic of the human organism as a whole, namely: intuitively clear senses of space, time, gravity (balance). Therefore 8 different senses are uninterruptedly active in the human organism. In a state of sleep (relatively full rest) seven senses are active: sight, hearing, touch, smell, taste, senses of time and gravity – i.e., the psycho-physiological normal minimum.

As defined by Ashby, quantity of variety uninterruptedly circulating in a normal physiological system man-environment will be:

$$r=\log_2 7=2{,}8 \text{ bit}.$$

The derived number closely approximates number e=2,782. Considering that system of sense organs acts as an interconnected receptor field, to which the characteristic of partly mutual substitution is proper, then it is quite possible to take number e as a unit of measurement (category) of information. Further, $e^1=2{,}72$; $\ln 2{,}8 \approx 1{,}028 \approx 1$ nit. That would be a peculiar "meter" for measuring quantity of variety in labor processes, information quantum.

Introducing the notion "object of attention", logarithmic measure of variety, nit – unit of measurement, the complexity of the labor process can be expressed through quantity of variety, i.e.

$$S=c\cdot\ln N, \tag{35}$$

where $\ln N$ – quantity of variety, nit; N – number of objects of attention in given labor process; c – coefficient of proportionality.

To pass over from quantity of variety in nits to complexity coefficient we introduce a value marking quantity of variety in 1 base point, i.e. in labor process which will be taken as a base minimum. $S_b=e=2{,}72\approx\ln 15=2{,}708$ can be taken.

Consequently, the base labor process will be a process which has 15 objects of attention. Then the complexity coefficient of any strictly determinate labor process will be:

$$S=\frac{S_i}{S_b}=\frac{\ln N}{\ln N_b}=\frac{\ln N}{e}\ . \tag{36}$$

To calculate the impact on the complexity of labor process arising from irregularity of bonds between certain factors due to the absence of definite social experience, we introduce coefficient of irregularity (heuristics) of the labor process

$$C_h=e^p\ , \tag{37}$$

where e=2,72; p – process irregularity.

Taking into account coefficient of irregularity introduced, the definition of labor complexity given earlier is expressed as follows:

$$S=\frac{\ln N}{e}\cdot e^p=\frac{\ln N}{e^{1-p}}\ \ , \tag{38}$$

where e^{1-p} – coefficient of accumulated experience; $1-p$ – value of labor process regularity, conditional on value of initial information coming in during the labor process; p – indefiniteness of given labor process.

6.3. Description of objects of attention

To determine quantity of objects of attention the following methods will be practicable:

1. Analytical method, according to which the photo of the sequence of logical-analytical and motive actions of labor process performers is given. At the same time, all objects of attention are fixed, i.e., certain properties, attributes, parameters of object and means of labor, energy sources, initial information, with which a man must establish corresponding communications to achieve labor targets. This is the simplest method and it can be applied in almost all machining labor processes.

2. Method of algorithmic description of man's activity in the labor process. The idea of this method lies in singling out elementary operations performed by the operator, and the whole activity is described in the aspect of their sequence by means of definite symbolism; logical conditions are indicated, evaluation of which is necessary for passing from one operation to another. At the same time, the labor subject is considered as the operator, taking in information and changing the run of the process in the purposeful direction.

3. Method of studying micro-movements of man's motive organs and fixing of objects of attention preceding or accompanying them. In this case, the system of MTM (micro-elemental system) can be applied, with subsequent shifting of micro-elements and objects of attention to a network. The advantage of this method lies in the possibility of studying objects of attention in the structure of by-the-piece time (network is built over time) and simultaneous working out of measures to save the workers' movements and simplify the work.

4. Matrix method of depicting labor process. Sub-targets of labor actions (transitions and operational techniques) are filled in matrix columns; in the rows – material factors of the labor process (cutting tool, workpiece, headstock, etc.); in the intersection of columns and rows objects of attention are filled in.

Regardless of specific content, objects of attention have common as well as distinctive properties. What they have in common is that every object of attention:

- is an elementary information carrier in the labor process;
- is a component of algorithm of target achievement;
- is an element of variety;
- is equally probable, i.e., no single aspect of object of attention, objectively, is more probable than the other;

- is discrete, i.e., lends itself to separation of one from the other in time and space;
- their quantity is countable within the limits of the given labor process.

Objects of attention are subdivided into determinate (simple) and entropic (complex). For example, in the mathematical expression y=f(x) argument x is a simple object of attention, but y – a complex one as it is not directly given to us, and the knowledge of the other object is required for its concrete definition. Further, $v=\varphi(y)=\varphi[f(x)]$; x – simple object of attention, y – simple object of attention. However, the same y in the expression f(x) is a complex object of attention. Consequently, a complex object of attention differs from a simple one in more or less indefiniteness, problematic character. A complex object of attention requires for its purport the establishment of supplementary logical bonds or application of "hit or miss" method. This distinguishing feature will be understood from concrete examples.

From the properties of objects of attention enumerated above, the following basic rules for searching them out ensue.

1. Only those objects of attention are examined, which are fixed by the performer and, therefore, represent an intellectual load to him. For example, objects of attention established during setting up of a machine are not examined if this function is not performed by the worker himself.

2. Property of object of attention being a component of algorithm of achieving target means that, from the manifold of possible objects of attention, only those that correspond and contribute to (are necessary and sufficient) achievement of target of the given labor process are singled out. For example, objects of attention, arising in previously unforeseen cases of breakages of tool, are not taken into account. Nor are such objects of attention as "length of clamp bolt", "type of lock-nut thread", "diameter of external thread of clamp bolt", etc., while performing the function of fastening a part in the device with the help of clamp bolts and nuts.

3. For the found objects of attention to be the elements of variety, only those objects of attention should be considered which differ in point of informational content; i.e., one and the same object of attention must not be taken into account twice. For example, the object of attention "machine start button" must be taken into account once despite repeated switching on of the machine during the labor process.

4. Singling out complex objects of attention from their total number, it is necessary to follow the principles of cause and effect. For example, the object of attention "type of cutting tool" will be complex if not given beforehand in the production process. In this case, to determine the type of cutting tool, it is necessary to determine beforehand the object of attention "rough turning of diameter". Only after this, it is possible to determine the object of attention "straight-turning tool". It is required to understand the object of attention

"number of rotations of milling cutter", which is complex because of having to determine many objects of attention ("depth of cutting", "feed to tooth", "material machined", "stability of cutter", "cleanness of machining", "material of cutting edge of cutter"). Thus, the basic of object of attention belongs to the category of complex if its determination requires additional objects of attention.

Complex objects of attention have a different value of informational capacity. For example, the object of attention "type of cutter" has a complexity of the first order following the determination of the additional object of attention "rough turning of diameter" given previously and directly in the production process. The object of attention "number of rotations of milling cutter" has multi-order complexity as additional objects of attention of various levels of their interdependence are required.

Every object of attention can become simple if indefiniteness is removed beforehand. For example, the type of cutter –"straight-turning tool"– can be indicated beforehand in the prediction process.

As the preliminary study of production processes being generally accepted in machine-building industry, it is legitimate to assume the equality of all complex objects of attention according to their informational capacity; i.e., it is assumed that all complex objects of attention require, for their intelligent interpretation, only the determination of additional objects of the first order.

For informational equality it can be assumed that all labor subjects have sufficient knowledge, qualifications and training for the labor process to be carried out within the prescribed limits.

Initial data is collected on the basis of analysis of the following documentation: task (job order), drawing or sketch of workpiece and part; route or transitional production process of workpiece machining; certificate of machine used; rules of maintaining equipment and safety precautions; standards of cutting, measuring and auxiliary tools, and special drawings for them; reference books with information on modes and methods for the given type of machining, etc.

From the foregoing documentation the initial data is entered into corresponding chart, in which, apart from the initial data from the documentation, the conditions of maintaining the workplace are indicated as well.

6.4. System of labor complexity categories

It is now possible to use the previously introduced logarithmic measure of variety and object of attention for quantitative expression of any labor process. The quantity of variety or complexity of labor is equal to natural logarithm of number of objects of attention in the given labor process, determined completely by the production operation ($S=\ln N$).This aspect of complexity will be measured in nits.

To go over from quantity of variety in nits to relative values, the notion of base labor process can be used, with complexity coefficients determined by formula

$$S = \frac{\ln N}{e^{1-p}}. \qquad (39)$$

The effect of the law of experience accumulation on the change of the value of labor process complexity can be explained by reviewing the properties of a self-organizing system. A self-organizing system is one whose degree of order grows with time. But a sell-organizing system itself cannot be examined isolated from its environment. Actually, energy and order cannot come from nothing, they can only be taken from the corresponding sources.

The value of accumulated experience is linked with heuristic depth of labor process, which, in turn, depends on the development level of production process, importance of job, new features of certain elements and stages of job performance. A visual idea of the law of experience accumulation and ordering of labor processes connected with it is given by subdividing production into mass, large-batch, batch, small-batch, piecework ones. They differ by the scale of production, nomenclature and repetitive manufacturing of products.

In piecework production articles of various nomenclatures are manufactured in single specimens, or in a small quantity, standard sizes of which, as a rule, are not repeated during the year. Here, the detailed production process is not usually worked out, relying on the skill and "imagination" of the performer.

In batch production articles of a definite nomenclature are manufactured in batches or series of various standard sizes repeated during the year. In batch production, depending on the total number of operations on all workpieces assigned to workplaces, small-batch (9–15 parts-operations), medium-batch (4–8), large-batch (2–3) production are differentiated.

In mass production a considerable quantity of articles is manufactured of an extremely limited nomenclature, for a lengthy period.

From the organizational-technical attributes introduced it follows that complexity diminishes from piecework to mass production, which may be expressed as follows:

$$\frac{\ln N_s}{e^{1-p_e}} > \frac{\ln N_{\grave{\imath}}}{e^{1-p_{\grave{\imath}}}}, \qquad (40)$$

where N_s and $N_{м}$ – number of objects of attention in single labor process and mass production, respectively; p_s and $p_{м}$ – indefiniteness in labor processes of piecework and mass production, respectively.

The inequality shows that the variety of objects of attention and entropy (value in inverse ratio to accumulation of experience) in labor processes of piecework production is higher than in mass production. Actually, in mass production, differentiation of operations is carried through to highly specialized movements with minimum quantity of logical functions of labor subject. If we assume that lnN_s=ln$N_м$, the inequality introduced is possible only under the condition

$$e^{1-p_s} < e^{1-p_m};\ 1-p_s < 1-p_м \text{ and } p_s-p_м > 0.$$

Taking indefiniteness of labor process in mass production $p_м$=0, then p_s>0. Therefore, the entropy of labor processes in piecework production is higher than entropy of labor processes in mass production. This involves the fact that the number of entropic (indefinite, heuristic) objects of attention in labor processes of piecework production is higher than in the others.

Magnitude of indefiniteness "p" varies from 0 to 1, i.e., from complete indefiniteness to its absence. This means that complexity in the given fixed number of objects of attention (N) will vary within the limits:

when p=0 $$S = \frac{\ln N}{e^{1-p}} = \frac{\ln N}{e^{1-0}} = \frac{\ln N}{e},$$

when p=1 $$S = \frac{\ln N}{e^{0}} = \ln N.$$

To elucidate the law of discrete change of coefficient of experience accumulation during the transition from simple to more complex labor processes, it is again necessary to refer to the notion of system stability so widely applied in cybernetics. Stability characterizes one of the most important features of system behavior and is a fundamental notion used in physics, biology, engineering, economy. The concept of stability is used in describing constancy of some feature of system behavior interpreted in a very broad sense. This may be constancy of system state (its invariability in time) or constancy of a certain sequence of states.

From the angle of such definition, the balanced state of human organism (state of relative rest or given constancy of a certain sequence of states affecting man during labor process) can be stable within the limits of internal and external disturbing influences. The latter are perceived by the human organism through sight, hearing, touch, smell, taste, gravity, space and time – 8 senses altogether. The given state of equilibrium can be stable only so long as even a single sense is not taken out of balance by internal or external disturbing influences.

Minimum information necessary to take the human organism out of the given balanced state, based on Shannon, will be equal to:

$$H = -p_1 \cdot \log_2 p_1 = -\frac{1}{8}\log_2\frac{1}{8} = 0{,}375 \text{ bit}.$$

Maximum information when all senses are taken out of their given balanced state $H_м$=3. Then the system man-environment will be most stable, i.e.

$$R = 1 - \frac{H}{H_m} = 1 - \frac{0{,}375}{3} = 0{,}875.$$

This means that on changing disturbing influences by over 12,5%, the organism loses its stable balanced state and goes over to the force of self-organizing properties in another balanced state of a rising or falling order.

On the basis of the above, the coefficient of experience accumulation for piecework production is determined.

$$C_{pw} = e^{1-p} = e^{1-\frac{N_h}{N}} = e^{1-0{,}125} = e^{0{,}875} = 2{,}4$$

- and for batch production – $e^{0,94}$=2,56;
- for large-batch production and mass production – $e^{0,99}$=2,68;
- for strictly ordered (ideal) production – $e^{1,0}$ =2,72.

For practical application of the indicated values definite conditions must be observed. The point is, that in piecework production, and in mass production as well, a part of production operations may have this or that heuristic depth, in conformity with which their coefficient of experience will not coincide with those introduced above. In such cases, the coefficient of experience is calculated separately for every production operation according to the above formula.

The calculation results of complexity connected with certain types of work are shown in Table 6.

Table 6

Calculation results of labor complexity

Content of work	Number of objects of attention	Number of heuristic objects of attention	Coefficient of experience accumulation	Coefficient of complexity
Loading of quarry stone into motor-lorry	17	0	2,72	1,04
Finish turning of the gear of gearbox RM 1000 on carousel lathe (according to available technological process)	416	68	229	264
Production of drilling machine spindle on screw-cutting machine (according to drawing)	1276	335	2,09	3,42

6.5. Tariff coefficients

Dozens of years of socializing practice among people led to the development of a definite system of classifying jobs according to complexity, an example of which is the system of tariff coefficients. In literature devoted to tariff systems, it is stated that the value of tariff coefficient for each category shows in how many times the wages (of workers) of given category exceed those of the first category.

For many years, the most widespread row of tariff coefficients was the one, in which the ratio between tariff coefficients corresponding to extreme categories of tariff scale was 1:2. However, there formerly has been and now are the rows with smaller and bigger range of tariff coefficients.

Calculated on the basis of the law of variety and law of experience accumulation, the rows of complexity values coincide with the rows of tariff coefficients. In the complexity rows the inter-category difference of information quantity is 12,5%. As was seen, this value is based on determining the degree of order and stability of balanced state of self-organizing systems. This accounts for the value of 12,5% being fully reliable. In this connection, the following statement can be of interest: "Transition to a unified tariff wage scale applied to workers of various branches presupposes the establishment of a unified inter-category coefficient. If the common tariff scale has six categories and the ratio between extreme categories is 0,1:1,8, the inter-category for all branches of industry will be equal to something like 12,5%" [16, P.230]. The methodology serving as the basis for determining the work complexity, supported by the legitimacy of labor economics, has to provide the following:

- objective complexity evaluations of various forms of labor;
- universality of these evaluations, their application to all forms of physical and mental labor;
- quantitative definiteness of these evaluations; eliciting the measure of labor complexity. Only then there can be solid scientific grounds for justification of tariff-qualifications categories, tariff scales and salary schemes.

A cybernetic approach to the determination of labor process complexity is quite satisfactory for meeting these requirements. The objectivity of complexity evaluation is conditional upon the objective character of the material information carriers – objects of attention. In the system of informational approach a countable number of attributes, properties, measured parameters, possessed by material factors of the labor process, have a corresponding countable number of objects of attention carrying information for the perceiving subject. Naturally, absolute objectivity is impossible as measurements and evaluations, in the final analysis, are subjective. However, an informational approach allows a more radical change in the interrelationship of objective and subjective labor complexity evaluation.

Let us analyze the tariff scale for workers in the machine-building industry (Table 7).

Table 7

Tariff scale for workers in machine-building industry

Coefficients	Categories					
	I	II	III	IV	V	VI
Tariff coefficients	1,00	1,13	1,20	1,48	1,72	2,00
Inter-category difference	–	13	14,1	14,7	16,2	16,3

The dependence of these rows is expressed by the exponential function

$$C_{tc} = e^{a(C-1)} \cdot e^{-c}, \qquad (41)$$

where C_{tc}, – tariff coefficient of the corresponding category; a – inter-category difference in %, divided by 100%; C – category corresponding to the tariff coefficient; e^{-c}– coefficient of proportionality between the tariff coefficient and expression $e^{a(C-1)}$.

Transforming the formula introduced, value c may be calculated:

$$\ln C_{tc}=a(C-1)-c\ ;$$

$$c=a(C-1)-\ln C_{tc}\,.$$

Value c for the corresponding categories:

I category – c=(1–1)–ln1,00=0;

II category – c=0,13(2–1)–ln1,13=0,008

III category – c=0,141(3–1)–ln1,29=0,027;

IV category – c=0,147(4–1)–ln1,48=0,049;

V category – c=0,162(5–1)–ln1,72=0,106,

VI category – c=0,163(6–1)–ln2,00=0,122.

Based on cybernetic laws of required variety and accumulation of experience we have:

Complexity category	0	I	II	III	IV	V	VI	VII
Complexity	1,00	1,13	1,27	1,43	1,62	1,80	20,3	2,30

The dependence between the complexity category and complexity is expressed by exponential function

$$S = e^{aC}, \qquad (42)$$

where a – inter-category difference in %, divided by 100%, a=0,125; C – corresponding complexity category. On the other hand, to determine the complexity the following formula is derived

$$S = \frac{\ln N}{e^{1-p}}\ .$$

Therefore,

$$e^{aC} = \frac{\ln N}{e^{1-p}}\ ;\ \ e^{aC} \cdot e^{-p} = \frac{\ln N}{e}\ .$$

Categories used in job tariff rating can be moved one category to the right. Then instead of I category – zero category; instead of II category –

I category, etc. And formula $C_{tc} = e^{a(C-1)} \cdot e^{-c}$ will take the form of $C_{tc} = e^{aC} \cdot e^{-c}$.

The transformation leads to the right-hand part of the last equality and left-hand part of equation by which complexity is determined, acquire the same form, namely:

$$e^{aC} \cdot e^{-c} \text{ and } e^{aC} \cdot e^{-p}.$$

The equality between them can be achieved under the condition of the equality of power indices "*c*" and "*p*". In determining the complexity formula it was shown that labor processes have entropy, the value of which varies from 0 to 0,125 from mass production to piecework production. This indicates that power indices "*c*" and "*p*" are equal. The complexity determined on the basis of cybernetic laws and tariff coefficients used in job rating are essentially the same.

Thus, an important conclusion can be made: *social practice has long made use of the law of necessary variety and the law of experience accumulation, and these laws are, therefore, objectively manifested in all single-unit labor process.*

If the labor complexity equals 1 with indefiniteness p=0, the number of objects of attention N=15. In people's practical activities there are probably no labor processes of zero category with complexity equal to 1 as that is a transitional moment from "no labor" to labor.

In the tariff system with a row of tariff coefficients: 1,00; 1,13; 1,29; 1,48; 1,72; 2,00, the entropy grows from category to category. But this row is not broken up into types of production but is likewise applied to mass, batch and piecework production types of work.

Arising from the above, it is possible to construct an optimum row of tariff coefficients applicable to all types of physical work (Table 8).

The row of tariff coefficients given in Table 8 by no means signifies that in practice there are no labor processes with the complexity exceeding 2,95. In designing the production processes it is necessary to proceed from this maximum value. Many labor processes, especially intellectual and partly physical (certain forms of template, experimental, adjusting, regulating work) still cannot be planned in advance. This accounts for the uncertainty of all forms of labor with the complexity below 2,95. Only the concrete analysis of objects of attention and corresponding calculation by the formula can show whether the given single labor process comes within the complexity range between 1 and 2,95.

Table 8

Systems of labor complexity categories

Type of production	Coefficient of experience	Name of coefficients	Complexity categories								
			0	I	II	III	IV	V	VI	VII	VIII
–	–	Number of objects of attention	15	22	32	50	82	137	258	530	1212
		Quantity of variety	2,72	3,06	3,45	3,90	4,40	4,92	5,55	6,25	7,10
Massflow production	2,72	Complexity coefficient	1,0	1,13	1,27	1,43	1,62	1,80	2,03	2,30	2,61
Large-batch production	2,68	–"–	1,0	1,15	1,29	1,46	1,64	1,84	2,08	2,33	2,65
Batch production	2,56	–"–	1,0	1,20	1,35	1,52	1,72	1,91	2,17	2,44	2,78
Piecework and small-batch production	2,40	–"–	1,0	1,28	1,44	1,62	1,84	2,05	2,32	2,61	2,95

The organization and payment of wage to employees in the state and municipal spheres of activity is carried out according to the categories of "Unified tariff scale for the employees' labor payment in the budgetary sphere" approved by the Decree of the Government of the Russian Federation dated August 24, 1995, № 823. It provides an 18-category scale with an approximate range of tariff coefficients *a*=0,16 (Table 9). It is operated by the same information principle, which was considered earlier.

Table 9

Unified tariff scale for the employees' labor payment in the budgetary sphere

Category of wage	Tariff coefficient	Category of wage	Tariff coefficient
1	1,00	10	3,99
2	1,30	11	4,51
3	1,69	12	5,10
4	1,91	13	5,76
5	2,16	14	6,51
6	2,44	15	7,36
7	2,76	16	8,17
8	3,12	17	9,07
9	3,53	18	10,07

The difference in the absolute values of tariff coefficients is due to the difference in the approach to calculations.

6.6 Informational (intellectual) labor intensity

Complexity is the basis for intellectual labor intensity. However, it is not a complete definition of the latter. As seen from the complexity determination formula, objects of attention (N) and coefficient of experience accumulation (e^{1-p}), and quantity of variety ($\ln N$) are not concerned with the duration of performance of the given type of work. The need to study them in time context has long been a methodological rule.

Actually, one and the same type of work having an altogether objective algorithmic length can be performed at different times. The faster information is processed, the greater the strain on the sensory organs, and vice versa. That is why in engineering psychology speed (rate) is one of the most important characteristics of information transfer, as a process unfolding itself in time. It is usually defined as quantity of information processed over one or another interval of time by formulas:

$$\upsilon = \frac{I_{(x,\ y)}}{t}\ , \qquad (43)$$

where υ – rate of transferring information; $I_{(x,\ y)}$ – quantity of information transferred; t – time during which the information is transferred.

The maximum rate with which one or another channel can transfer information is called the channel capacity.

The measurement of information quantity in “bits” in actual labor processes is quite complicated. The thing is, that probability of event is the initial value for determining the numerical measure of information.

These definitions applied to usual labor processes are not, at the present time, applicable from a methodological viewpoint, as it is not known what to take for signal, symbol, alphabet, and particularly how to determine, in each specific case, the length of alphabet and probability of events.

All this, the same as when determining labor complexity, precludes the use of probability methods to determine the information quantity to clarify the issue of perception intensity of information by man in single labor processes. The most practical method, evidently, is that of applying measure of intensity of the controlled labor process determined by formula:

$$\delta = \frac{W}{t}\ , \qquad (44)$$

where δ – measure of intensity of controlled labor process; W – number of algorithm components in working process; T – duration of working process.

Instead of the number of algorithm components the number of objects of attention can be taken. Then the average perception intensity of information

$$\delta = \frac{N}{t}, \qquad (45)$$

where N – number of objects in the process of performing the assigned work; t – time to perform the work.

To register the impact of information processing intensity on the general intellectual intensity of the labor process, the intensity value must be expressed in relative units. For this it is possible to introduce the notion of optimum intensity (δ_{opt}) corresponding to a definite constant rate of information processing, making the operator's work more reliable. Both the maximum and optimum "carrying capacity" of man in processing information has not been established yet in engineering psychology and is still a matter of discussion [9, 23, 41].

However, using the method of base point, the intensity value of information processing in some concrete labor process can be taken as a base, comparing other forms of work intensity with it. This makes it possible to determine relative intensity levels and express them in non-dimensional values. After collecting sufficient statistical data on concrete forms of labor from the accepted base point, it is possible to pass over to the optimum intensity value of information processing. To determine the optimum point the statistical material can be processed with the methods of mathematical statistics.

The relative intensity levels can be found by formula:

$$\Delta = \frac{\delta}{\delta_0} \quad , \tag{46}$$

where δ – intensity of information processing in the labor process under research; δ_0 – intensity of information processing in the base labor process, to be more exact, the optimum intensity of information processing.

Chapter 7
Labor costs

In the course of labor socialization, scientific bases of technical rate fixing and methods of fixing time rates for performing one or another concrete labor process have been taking shape.

7.1. Duration of labor process

The fundamentals of developing labor technology and determining the duration of its process were created by F.W. Taylor at the end of the 19^{th} century. Since then, the public system for the standardization of labor processes has been formed as an independent scientific direction.

One and the same work can be performed by various ways and means under different production conditions. Conditional on this, the time needed for its performance will likewise be different. It depends primarily on the quality level of labor tools used, selected working modes of equipment, organization of labor at the workplace, performers' skill, and other factors. For example, manual labor undoubtedly requires more time than the work with the help of modern equipment, flawless tools and devices. A forged workpiece can be produced by the method of open-die forging or hot stamping. However, stamping requires almost tenfold less time than forging. Depending on the number of revolutions per minute of the workpiece, the feed of cutting tool per revolution and depth of cutting, more or less time on machining the workpiece on a lathe is required.

Evidently, the better the production possibilities of equipment are used, the less time is spent in performing an operation. The amount of time necessary to produce one unit also depends on the quantity and sequence of working movements. The performer's skill also has an impact on the time rate.

To establish correctly the time necessary to perform the given work, the following factors are of primary importance: study of organizational, technical conditions, analysis of the technology applied, use of equipment, composition and sequence of work performance. After an overall analysis, making use of data collected and experience of progressive production workers, it is possible to plan the working mode of equipment, make corresponding alterations in production process, establish sequence of workers' actions. Only after this, the time spent by the worker in performing the production operation can be determined.

The essence of determining the labor process duration lies in bringing out the following functional dependence:

$$t = \mathrm{f}(x_1, x_2, \dots, x_n), \quad (47)$$

where t – duration of labor process; x_1, x_2, … , x_n – material factors of labor process forming its duration.

In technical rate fixing this dependence acquires the aspect of time per piece formula:

$$t_{pp} = t_b + t_a + t_{ots} + t_{mn} + \frac{t_{pc}}{n} , \qquad (48)$$

where t_b – basic (machine) time; t_a – auxiliary time; t_{ots} – time of organizational-technical servicing of workplace; t_{rnn} – time for rest and natural needs; $\frac{t_{pc}}{n}$ – time of preparatory-conclusive work connected with parts lot.

The time per piece and its particular elements are determined by different methods, among which the following are most widespread:

- photographing the working time, time-study;
- photo time-study;
- experimental-statistic rate fixing;
- rate fixing based on typical, aggregated, branch and all-union standards;
- micro-elemental rate fixing.

The method of micro-elemental rate fixing of auxiliary time is examined in the present monograph.

However, for economic planning and forecasting of production the methods set forth are inadequate. This necessitates a search for ways of determining, on an enlarged scale, duration of production of articles in full or their components and parts. From the methods available the most widely used is that based on application of regression equations and mathematical correlative analysis of labor input factors, using computers, especially under conditions of experimental and piecework production of articles.

Nowadays, especially because of the development of forms of so-called small business, large-scale methods for calculating the labor input of production (technological labor input) are developed on the basis of qualimetric analysis of the interrelationships of factors in the articles production (quality factors) with the time costs for their production. The qualitative approach in the standardization of the labor processes duration allows the establishment of enlarged time norms to manufacture a product per one qualimetric unit.

7.2. Working time

To express the amount of working time mathematically Marx's definition should be examined in more detail: "Just as time is the quantitative existence of movement, so working time is the quantitative existence of labor. The difference in duration of labor itself is the sole difference proper to it, assuming its quality. The same as working time, labor gets its scale in natural measures of time, hours, days, weeks, etc. Working time is the essence of living existence of labor, regardless of its form, content, individuality; it is a living quantitative existence of labor and, at the same time, an immanent yardstick of this existence" [34, P.16].

Analyzing this definition, we draw the following conclusions:

1. Working time is living existence of labor, but living existence of labor is the labor process itself, i.e. the process of expenditure of "working force in a physiological sense" and, at the same time, the expenditure of "human working force in a particularly purposeful form". The essence of such "living labor" can be quantitatively presented in the form of energy spent by the human organism and as purposeful information processing by that organism. Physical and intellectual intensity are the measure of these magnitudes.

2. Working time is the essence of living existence of labor, regardless of its form, content, individuality. It follows that, speaking of working time, no concrete form of labor process is referred to. For working time it makes no difference how the tool was connected to the labor object: in the form of reciprocally vertical or reciprocally horizontal movement; whether the main drive of the machine was switched on manually or by foot, etc. Working time cannot give us the content of the labor process itself; it is not affected by whether the workpiece was machined by hard alloy or high speed tool, whether the drawing of the workpiece was given in advance or made according to pattern, etc.

Working time does not reflect the person to whom this living existence of labor refers to, it does not matter whether this form of work is performed by a man or woman, young or old, turner Petrov or metalworker Ivanov.

3. Working time is living quantitative existence of labor. Consequently, the form, content and individual character of the labor process in working time lose their concrete parameters, features, properties, quantitatively expressed with different measures and dimensions. Only one thing remains: quantity of living existence of labor as the quantity of purposefully spent energy of the human organism.

4. Working time is living quantitative existence of labor and, at the same time, an immanent yardstick of that existence. Working time is formed quantitatively in the process of living existence (functioning) of labor itself. This explains why, when working time is expressed quantitatively, it attests to the completed labor process; therefore, it is a measure of its own formation, disappearing in the labor product of living existence of purposeful activity of some individuals.

5. Just as the quantitative existence of movement is time, so working time is the quantitative existence of labor.

From the last definition it is evident that K. Marx resorts to the method of analogy to explain the phenomenon that actually exists in social life, but does not have its name and procedure for quantitative expression. The analogy is borrowed from physics, which after the scientific discoveries of I. Newton and the metric system of physical quantities and their meters, established in the period of K. Marx's life, became the main support of all scientific researches. K. Marx adds the word "working" to the physical analog "time is the quantitative existence of motion", and derives the definition: "working time is the quantitative existence of labor".

This moment is of exceptional importance for the labor economy, since working time as a category of scientific analysis becomes the fundamental category of quantitative analysis in the labor economy and through it – for the entire social and economic system.

In everyday life such expressions as 8-hour working day, 1000 hours of working time spent in a shop, technological labor input of gearbox of 50 norm-hours are known to everyone without any explanation. But as soon as people pass from the notion of working time in everyday use to such categories as wage, cost, price, it immediately becomes clear that the notion of time can have different interpretations. Each person reacts differently to an 8-hour working day: one has a hard one, another – easy, the third – simple, the fourth – complex, etc. Thus, different time and per-piece scales of wages and salaries occur.

7.3. Rate

It follows that with the same duration, heterogeneous in quality labor processes also have different quantity of living existence of labor, i.e. different quantity of working time.

Actually, the following formula of determining the rate of the work performed is generally accepted:

$$E = T_1 \cdot T_c \cdot T_n , \tag{49}$$

where T_1 – tariff for a worker of the 1st category, rubles; T_c – tariff coefficient; T_n – time norm for one unit of work, hours.

Thus, expressing working time simply as the work duration in time, is totally inadequate. Tariffs have to be appealed to, which differ according to hardness and harmfulness of working conditions, i.e., basically, according to the expenditure of working force in the physiological sense; tariff coefficients have to be referred to, which vary quantitatively with labor complexity, i.e., principally according to the quantity of processed information by man in the given labor process.

7.4. Work-hour

Hence, if movement can be expressed quantitatively in hours, then working time – in work-hours. In this light, the undernoted functional dependence is fully justified:

$$W_t = L_i = \mathrm{f}(P, P_a, t) \ , \qquad (50)$$

where W_t – working time, work-hours; L_i – labor input, work-hours; P – working force expenditures in physiological sense; P_a – concrete form of purposeful activity; t – duration of living existence of labor, hours.

As it was shown in previous chapters, the physiological aspect of labor process can be quantitatively expressed by the coefficient of physical labor intensity and intensity of purposeful activity in the given labor process – through the coefficient of intellectual labor intensity. Then, labor input

$$L_i = C_{pi} \cdot C_{ii} \cdot t \, , \qquad (51)$$

Let us recall the coefficient of physical intensity

$$C_{pi} = \frac{1}{e_b} \cdot \left(E_o + \frac{A}{500} \right) \cdot C_m \cdot C_y$$

and coefficient of intellectual intensity

$$C_{ii} = \frac{\ln N}{e^{1-p}} \cdot \Delta \ ,$$

where e_b – energy spent by human organism in labor process; taken as base, kcal/min; E_o – energy spent to support the initial pose (stand, sit), kcal/min; a – coefficient expressing the interrelationship of static and dynamic loads on organism; A – mechanical work carried out by man in labor process, kgm/min; C_m, C_y – coefficients taking into account impact of microclimate and surrounding atmosphere on energy expenditures by organism; N – quantity of objects of attention in the given labor process; Δ – value of relative intensity of information processing in the labor process under research.

The product (formula 51) marks the intensity of labor process, i.e. intensity of "living existence of labor".

Every product of labor comes out as capacity of:

a. substance of nature

b. consumer properties for people

c. labor expenditures.

Hence, each labor product as a materialized result of the "living quantitative existence of labor" of the cooperative people community embodies a substance with consumer properties suitable for personal consumption or exploitation, and the costs of living labor, fixed in any information documents (time sheets for work, payroll statements). If the natural substance and use properties in the labor product can be quantified by measuring metrology procedures, then the amount of labor, as well as the amount of the wage given, no matter how much we try, cannot be measured directly in the labor product (article) yet. Here, it is necessary to address to other sources – accounting documentation, which is a labor product of corresponding experts.

7.5. Labor input

Based on the received data, it is possible to perform the following measurement (calculation) operations:

1) amount of labor costs is divided by the amount of substance in the labor product;

2) amount of labor costs is divided into the number of consumer properties in the labor product.

In the first case, we get the *labor input* value of one piece of product; in the second case, the *labor input* of one unit of useful property.

Thus, labor economics includes a *primary labor indicator* that quantifies the specific form of manifestation of living labor economics law, which is the first economic law of the society management system functioning.

Every single labor process (technological operation) is an elementary process comprising general combination of single processes of directly social labor. For a certain combination of operations we will have the following technological labor input:

$$T = \sum_{i=1}^{k} L_{i_i} = \sum_{i=1}^{k} C_{pi} \cdot C_{ii} \cdot t_i , \qquad (52)$$

where L_{i_i} – labor inputs at i^{th} technological operation; i=1,2,3, …, K – number of consecutive technological operations to produce the type of item being examined; t_i – duration of work at the production operation (time per piece).

Where all values in the formula are determined on the basis of standards, *standard labor input* is obtained. If these values are obtained based on determining actual parameters, features, properties of labor processes, then *actual labor input* is obtained. In production practice the technological labor input is determined by formula

$$T = \sum_{i=1}^{k} t_i ,$$

i.e. it is obtained by summing up time rates for all technological operations to produce the given type of product. Thus, it is seen that in the formula suggested by us an important correction for physiological expenditure of energy and purposeful processing of information is introduced. The proposed formula quantitatively adequately expresses the essence of technological labor input of production of articles through "quantitative living existence of labor" and immanent measure of this existence – working time.

It is expedient to show some of its particulars.

1. C_{pi}=1,0, C_{ii}=1,0, t=1,0 hour, and therefore, labor expenditure (labor input) L_i=1,0 work/hr. What is the real content of this value of 1 work/hr? This is explained by revealing the essence of coefficient of physical and intellectual labor intensity. As a matter of fact

$$C_{pi} = \frac{1}{e_b} \cdot \left(E_0 + \frac{A}{500} \right) \cdot C_m \cdot C_y \, .$$

Let us assume that C_{pi}=1,0, E_b=2,1 kcal/min, C_m=1,0, C_y=1,0, e_0=0,7 kcal/min, a=1,0. Then mechanical work performed by a man during labor process A=700 kgm/min. This corresponds to walking at a speed of 4 km/hr under normal microclimatic conditions and satisfactory atmospheric environment.

Further, in the formula of coefficient of intellectual labor intensity

$$C_{ii} = \frac{\ln N}{e^{1-p}} \cdot \Delta$$

let us assume that C_{ii}=1,0, Δ=1,0, P=1,0; then ln$N$=2,72, which corresponds to the number of objects of attention N=15. This is exceptionally simple labor. (Compare with loading quarry stone manually onto motor lorry when there are 17 objects of attention).

Thus, 1 work/hr is a quantitative characteristic of a simple labor process, having a medium physiological hardness, and can be applied as a unit of measurement and basic dimension of work expenditure. Introduction of this unit will obviate one-sidedness, inaccuracy of the indicator "technological labor input" used in practice.

2. Change in the value of labor duration without changing the very essence of the process leads to increase or decrease of the values of physical and intellectual intensity. Let us suppose that "t" has changed and become t_1, with $t>t_1$. How do C_{pi} and C_{ii} change? With "t", let us assume that C_{pi}=1,0 and C_{ii}=1,0. With the same values of E_b, E_0 and "a" coefficient of physical intensity change with changed mechanical work in a unit of time. But the change in duration value gives rise to change in the movement speed of the system "man –labor tool–labor object". Therefore, mechanical work performed by a man in a unit of time increases or decreases. The latter conjures up a change in the coefficient of physical intensity.

The value of the coefficient of labor intellectual intensity depends on the complexity and speed of information processing. The change in the duration of labor process does not affect labor complexity, but gives rise to change in information processing. In other words, the number of objects of attention remains as before since the essence of the labor process does not change, but the speed of establishing contacts with these objects of attention changes because of the increase or decrease in labor duration. Hence the change in the labor process duration engenders the increase or decrease in the intellectual intensity of a person, performer of this labor.

3. Change in the essence of labor process gives rise to the change in all parameters of labor input (C_{pi}, C_{ii}, t). Here, several variants are possible. The latter process can be simplified at the expense of lessening the number of

objects of attention, thereby reducing the duration of the given labor process without affecting physical intensity. Simplifying the work through the introduction of mechanisms can cause longer duration of labor process, etc.

In this way the result of any organizational-technical arrangement adopted in production can be quantitatively expressed through the change in the value of labor expenditure (labor input). At the same time, the assessment can be given at the stage of designing technological processes and development of organizational-technical plans.

The following coding system can proposed for assessment: *Ph* – physical intensity; *M* – microclimate; *Y* – atmospheric conditions; *D* – duration of labor process.

Every form of work or technological operation has its own code according to the system accepted at the enterprise. For fixing the results of process assessment, the code according to the coding system outlined here is added to this system. Let us examine the tentative example: IZHYU3-71 lathe 51, Ph 1,20, M1,07, Y1,5, I1,48, D0,06, Decoding, we have:

motor-cycle of trade mark IZHYU.
part number: 3-71.
turning operation No 51.
coefficient of physical intensity, C_{pi}=1,20.
coefficient of microclimate, C_m=1,07.
coefficient of atmospheric conditions C_y=1,15.
coefficient of intellectual intensity C_{ii}=1,48.
calculated time per piece t=0,06 hr.

Production labor input (labor expenditure):

$$T = C_{pi} \cdot C_m \cdot C_y \cdot C_{ii} \cdot t = 1{,}2 \cdot 1{,}07 \cdot 1{,}15 \cdot 1{,}48 \cdot 0{,}06 = 0{,}13 \quad \text{work/hr} .$$

Let us assume that this operation was rationalized, as a result of which the code of the operation will be: IZHYU 3-71 lathe 51 Ph1,20, M1 1,00, Y1,00, I1,48, D0,06, The physical intensity remains as before. The measures led to improving the microclimate and atmospheric conditions and lowering C_y and C_m. The labor complexity and intensity of information processing remain the same as before, the duration was decreased to 0,05 hr resulting from the improved sanitary-hygienic labor conditions.

The labor input after the rationalization:

$$T^1 = 1{,}2 \cdot 1{,}00 \cdot 1{,}48 \cdot 0{,}05 = 0{,}089 \text{ work/hr.}$$

The effect can be expressed through saving labor expenditure by one part

$$ef = T - T^1 = 0{,}130 - 0{,}089 = 0{,}041 \text{work/hr,}$$

and for a yearly program with P=150000 parts:

$$ef_y = ef \cdot P = 0{,}041 \cdot 150000 = 6150 \text{ work/hrs.}$$

Hence it is seen that even the result of measures for improving sanitary-hygienic labor conditions can be expressed through decreasing labor expenditure. At present, the effectiveness of such measures is almost incalculable, if it directly has no impact on reducing work duration, tariff rates or other conditions of labor payments.

4. For purposes of amalgamated planning and forecasting of technological labor input we can use average coefficient values of physical and intellectual intensity deduced on the basis of industrial statistics of parameters technological processes for the given, e.g., machine-building industry. Then

$$T = C_{pi} \cdot C_{ii} \cdot \Sigma t_i \, , \tag{53}$$

and, as noted correctly by K. Marx, "the difference in the duration of labor itself is the only difference to which it is capable, if one assumes its quality" [34, P.16].

The creation of nature and society is a human being capable of labor. And through labor, mankind creates and transforms Earth. The noosphere, sphere of the mind, is essentially the labor sphere. But the labor sphere is not a self-sufficient area of human interaction that is torn away from natural dependence. Here, the bearer of work ability, Homo sapiens faber, is a result of the evolutionary process of Earth. In the evolutionary process, mankind becomes a geological force that manifests itself as a comprehensive transforming factor on Earth.

The primary element of noosphere functioning – the sphere of mankind mind, as shown in the first chapters – is *a single labor process*. The detailed examination of the structure and content of the labor process confirms that the general laws of nature are manifested here: the law of transformation and conservation of the substance mass, the law of transformation and conservation of energy, and the law of transformation and accumulation of information.

As a result of the study, we come to the most important conclusion that socioeconomic laws are only the transformed forms of manifestation of the general laws of nature, and, therefore, labor as the creator of consumer values, as useful labor, is the condition of human existence independent of all social forms, eternal, natural necessity: without it the exchange of substances between man and nature would not be possible, i.e., human life itself would not be possible" [16].

Chapter 8
Workplace

A single labor process, no matter how specific it could be, can always be represented only as a material-tangible, energy and information process. Any process (Latin processus – passage, advancement) is a successive change of states, a close link between successive stages of development, which represent a continuous unified movement. The change of states arises as a result of the interaction of individual constituent elements that occur in space and in time. In case of labor processes, a workplace is such space.

8.1. On the concept "workplace"

The workplace is given dozens of different definitions, which have common and different formulations. The founders of Scientific Organization of Labor (SOL) (A. K. Gastev, P. M. Kerzhentsev, O. A. Ermansky) did not have a clear definition of the workplace, because it was considered intuitively clear as the place where the work is done. With the improved scientific analysis of the organization of labor and production, disagreements and discussions between various specialists and representatives of the same profession have increasingly arisen. As the work on the organization of production expanded, so did the terminology associated with this work. Over time, an increasing number of people involved in the production management came to the conclusion on the necessity of clear definition of the terms in the field of production organization and creation of uniform terminology. Therefore, in 1943 the Committee for Standardization of Works of the Production Management Section of American Society of Mechanical Engineers decided to concentrate its efforts on the unification of terminology.

In the materials of the Committee in 1950-1956 the following definition of the term "work station, workplace" was given: "Part of the production site where the worker performs the work assigned to him, comprises the space necessary for placing equipment and attachments (bench, machine, all racks, containers, transportation devices, etc.) and materials" [38].

Due to this new period in SOL development in 1960s, the need for standardization of terms in the field of labor organization became evident. In one of the first textbooks on SOL, the following definition was given: "A workplace is a zone of labor actions of a worker or a group of workers (brigade), fitted up and equipped with everything necessary to fulfill a production task. Apart from the worker himself, the necessary items and tools used to accomplish certain elements of the production process, as well as the necessary means of equipping the workplace (production furniture, vehicles, etc.) are placed at the workplace" [5].

It seems that the word combination "worker's zone of labor" is unsuccessfully applied in the definition. First, "zone" is the Greek word, meaning "belt", "region". Probably, it is preferable to replace the word "zone" by the word "space". If we take into account that the workplace is an elementary part of the production unit, it would be possible to characterize the workplace as an elementary space of production, or as an elementary production space.

It is incorrect to define the workplace only as a field of labor, since according to the accepted definitions the state of "sitting" or "standing at the workplace" are not a labor activity. The place of fixing an electric bulb on the ceiling cannot be characterized as the zone of worker's labor. It will be more correct to say that the workplace is an elementary production space in which something is placed.

In GOST 19605-74 (State Standard), the following definition is given: "Workplace is a zone equipped with the necessary technical means, in which the labor activities are fulfilled by the executor or group of executors, performing one work or operation together". Not labor activity but only its part – a single labor process, is fulfilled at the workplace. If we separate a job from an operation, we introduce a different meaning into each concept, in which case they must be also defined in the standards. It is well known that there is no work without operations and the operation cannot exist beyond the work.

The workplace is also equipped, in addition to technical means, with mechanized auxiliaries, technical documentation, lubricants, electrical energy supply, etc. – labor means, in general.

After the GOST 19605-74 release, most researchers involved in the issues of SOL (N.A. Koltsov, N.A. Lobanov, I.B. Levin, S.L. Melnik, I.M. Razumov, S.V. Smirnov, E.L. Smirnov), follow a more or less standard definition of the workplace. One work, published back in 1983, should be considered. N.A. Koltsov wrote in the textbook for students of the economic specialty: "The workplace is a part of the production area with technical, auxiliary, lifting and transport equipment and devices, tooling and various implements necessary for the execution of the production task. The very labor process takes place in a limited area of the production area – in the work area" [18].

The workplace is not only an area, but space. The author of this definition clearly opposes technical equipment and devices to lifting and transport equipment and devices, which are also technical. And auxiliary ones? They can simultaneously be technical. It also makes no sense to include rigging and various inventory in the definition in parallel with the technical and auxiliary equipment and devices. The word "necessary" indicates that only those means are installed that are necessary for the performance of the production task. And if the tool table is not needed at the moment, then, hence, should it be excluded from the definition? The author's definition of the workplace lacks the object of labor. Where is it located? Or is the production task carried out without a labor object? Moreover, in determining the workplace as a part of production area, the most important part is missing – the active acting force is the labor subject that is placed outside the workplace. In this definition given by N.A. Koltsov the workplace is not a dynamic, functioning part of production process, but only a static part in the form of an elementary production area. The "necessities" placed at it do not work, they are unproductive.

In connection with the above remarks, we attempt to give the following definition: *the workplace is an elementary part of the production space in which the placed means of labor*, *objects of labor and subject* (*subjects*) *of labor are interrelated for the implementation of single labor processes in accordance with the target function of obtaining the product of labor*.

With this definition of the workplace, its characteristic concepts: means of labor, objects of labor, subject of labor, process of labor, product of labor are scientific categories of economic theory.

The organization of labor as a science studies single labor processes based on the provisions of economic theory, therefore, the definition of a workplace through its categories and concepts is legitimate and reliable. Further, when we say that the workplace is an elementary part of the production space, we emphasize that the workplace is an element, indivisible, in production sense, a part of something whole, namely, the production of products. Here, there is an objective necessity of deciphering the political economic concepts: *means*, *object*, *subject*, *product of labor* through the concepts and categories of production organization. For example, when we clarify the notion "means of labor", we enlist specific forms and properties: technological equipment, technological accessories, cutting tools, measuring tools, lubricating and cooling materials, organizational accessories, etc. In turn, the concepts and categories of the science of production organization are determined and specified through the concepts of production technology. For example, technological equipment is specified through its technological varieties: screw-cutting lathe, vertical milling machine, hydraulic press, etc.

In the above definition of the workplace, the allocated means, objects, subject of labor are characterized as interrelated for the implementation of single labor processes. Interrelation is a characteristic feature of systemic formations. Consequently, the workplace is not simply the placement of individual elements, but such arrangement that forms a system through the interrelation. From cybernetics and general theory of systems it is known that "a system is a set of elements that are related and connected with each other, which forms certain integrity, unity". Thus, the elementary part of the production space, in turn, appears as the interrelated set of elements (even smaller ones, figuratively speaking, in comparison with the previous elements).

In addition, in the above definition all elements of the workplace are interrelated in accordance with the target function of obtaining the product of labor. The development and formulation of the target function is the area of information modeling and systems analysis that deal with cybernetic systems and information theory.

8.2. Target function of workplace

There is a whole number of definitions of the concept “system”, which, with some conventionality in economic and mathematical studies, are divided into three groups. *The first group* of definitions considers the system as a complex of processes and phenomena, as well as the links between them, existing objectively, independently of the observer. The task is to distinguish this system from the environment, i.e., to determine its inputs and outputs (then it is considered as “a black box”) as minimum, and as maximum – to analyze its structure (to structure), to clarify the functioning mechanism, and, based on this, to act on it in the right direction. Here, the system is the object of research and management. *The second group* considers the system as an instrument, way of investigating processes and phenomena. The observer designs (synthesizes) the system as some abstract representation of real objects, therefore, the concept of system almost merges with the concept of model. *The third group* of definitions is a kind of compromise between the first two. The system here is an artificially created set of elements (for example, groups of people, technical means, scientific theories, etc.), designed to solve a complex organizational, economic, technical problem. The system is a real object and, at the same time, the abstract representation of the relations of reality. It is in this sense that the science of system engineering understands the system [16].

Proceeding from the foregoing, let us repeat once again the definition of the system given earlier by us: *system is a set of elements interconnected in such a way that the impact of the environment (another set) on some part of the elements leads to a change in the state of the whole set*.

8.3. Block diagram of the workplace functioning

Taking into account the technological principles of forming workplaces and the above systemic considerations, it can be asserted that material-energy and psychophysiological information processes take place at the workplace, where there are manageable and managing parts. The manageable part is the system: equipment-accessory-tool-part (EATP), and the managing part is a worker of certain profession with certain knowledge and experience. Based on the theory of regulation in the system with feedback, the workplace functioning can be demonstrated with the diagram (Fig. 9).

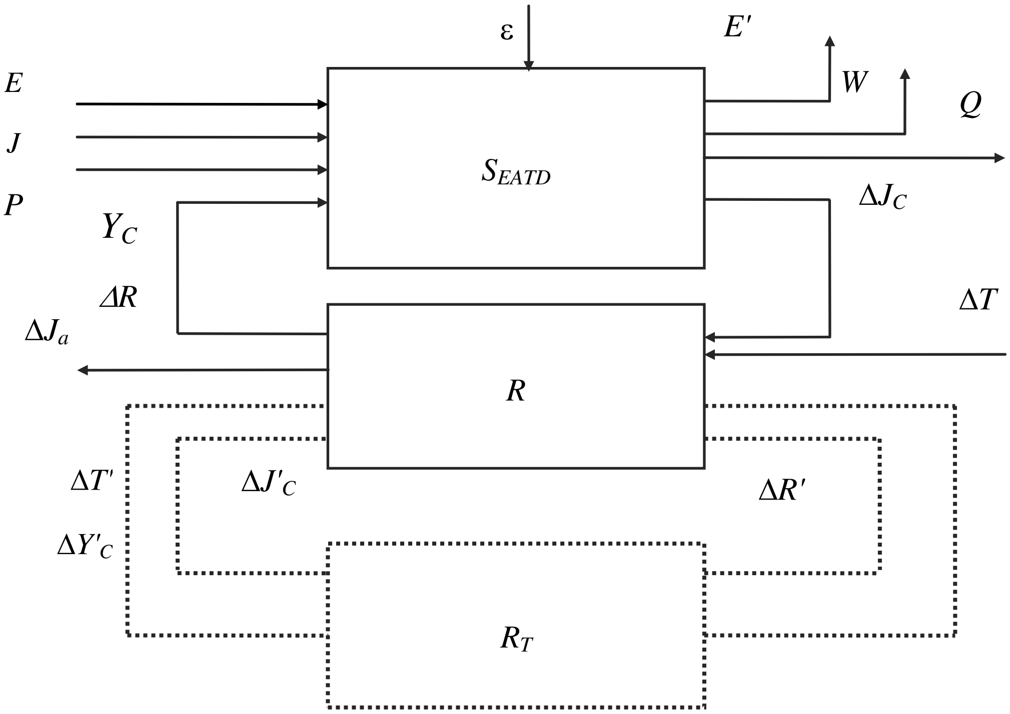


Fig. 9. Block diagram of the workplace functioning

S_{EATP} system at the workplace is managed by worker *R*, who receives the instructions from the foreman (headman), work order, technological map, operational-normalizing card – in short, the worker receives the primary information from the higher level of management – Δ*T*. In addition, worker *R* has knowledge, skills, i.e., speaking the language of information theory – his own thesaurus (a priori information) – R_T, the value of which varies in accordance with the law of experience accumulation.

In R_T scheme the corresponding bonds $\Delta T'$, $\Delta J'_C$, $\Delta R'$, $\Delta Y'_C$ are indicated with dashed lines, since the allocation of the knowledge block, process of information perception and its comparison with the thesaurus (memory) in relation to the workplace can be represented only conditionally, i.e., perception, reception, processing, transfer of information is the internal attribute of the subject of labor, acquired, speaking psychophysiological language, as a result of sensorimotor reaction.

The worker in the process of management (regulation) of the labor process constantly receives information ΔJ_C on the results of S_{EATP} system operation. The fruitful result of the system operation, the product of labor, is designated as *Q*. At the input of S_{EATP} system, we have the object of labor – workpiece *P*, energy *E* (for example, electrical energy) and information *J*.

From the external environment S_{EATP} system is affected by interference ε, for example, case-chilled crust on gray iron casting, unexpected electrical current switch-off, and the like.

The workplace system functions according to the following interrelated chain: worker R receives primary information (task) ΔT, compares it with the information available in his own memory, activates his own forces ΔY_C and directs them to separate parts of S_{EATP} system, i.e., he manages the interrelated functioning system of material-energy processes occurring in the chain: equipment-accessory-tool-workpiece (part). As a result of the operation of S_{EATD} system, workpiece P is converted into product Q – item and waste product W; energy E in EATP system undergoes transformation (it is converted into mechanical force, heat, sound) in E'; information ΔJ_C on the results of the functioning of EATP system is perceived by worker R who sends the message about his activity ΔR to the superior level (foreman, controller, accountant, headman); from this moment the process is repeated again, but with another subsequent copy of part P. Each time, the above cyclic process can be stereotyped (the same) or different. The process takes place in space and time and has its own, inherent in this workplace, *algoheurhythm*, i.e. the combination of algorithmic and heuristic rules for the system functioning. Since the algoheurhythm exists, it can be described by appropriate informational and mathematical symbols, that is, *a technical-economic-mathematical or*, *as it should be*, *engineering-qualimetric model of the workplace can be created*.

In the definition of the workplace, we affirm that single labor processes are carried out at the workplace in accordance with the target function of obtaining the product of labor. The target function is usually “a formal expression of the system purpose”. In relation to the workplace, the target function should formally (mathematically) link the output of the workplace system and the input, i.e., it is possible to write down the main goal of obtaining product Q as the function of all necessary factors within the system of workplace functioning factors: $Q=\varphi(S)=f(P, \Delta T, E, \Delta Y_C, W, E')$, where S – resources; P – objects of labor; ΔT – task (primary information); E – energy sources; ΔY_C – psychophysiological efforts (managing actions) of the worker; W – wastes in production (wastes from the object of labor and operational wear of the means of labor); E'– converted (scattered) energy.

The functional dependence did not include interferencesε, because (as can be seen from the diagram), their influence on the results of EATD system operation is not controlled by worker R. Only some or all of the higher levels controlling coupled systems can manage (study, prevent, legalize) interferencesε, therefore, the impact on possible interferences should be organically included in the primary information (task) – ΔT.

It is well known that the mass of substance and energy in the transformations do not disappear, but they are only converted from one form into another.

From the workplace block diagram it is seen that the equality $Q+W+$ $+E'=P+E$ should be observed.

Let us transform the equation $Q=(P+E)-(W+E')$.

We divide both sides of the equality by $(P+E)$:

$$\frac{Q}{(P+E)}=1-\frac{(W+E')}{(P+E)}.$$

We designate $\frac{Q}{(P+E)}=\eta$, $\frac{(W+E')}{(P+E)}=\varepsilon$, then $\eta=1-\varepsilon$.

It is obvious that $\varepsilon=\frac{(W+E')}{(P+E)}\leq 1$, whereby $0\leq\eta\leq 1$.

8.4. Q-factor of the workplace

The ratio $\frac{Q}{(P+E)}=\eta$ is called Q-factor of the workplace functioning, which is equivalent to the concept of "efficiency coefficient" in the processes of energy conversion. Is it possible to control the change in the quality level of the workplace? Let us assume that all products are rejected because of non-compliance with technical conditions. This can be the result of many technical, technological, organizational hindrances not depending on the worker, as well as interference caused by various omissions of the worker himself, in short, due to the low organization of labor. We write down this argument mathematically $\eta=f(\Delta T, \Delta Y_C)$, where ΔT – primary information coming in the form of the production assignment with the entire set of documentation and list of material and technical supply of the workplace with all the necessary resources; ΔY_C – managing effects of the worker.

As can be seen from the functional dependence, Q-factor of the workplace functioning is Q-factor of the workplace management.

In combination with the form of organization, consciousness and scrupulosity constitute the main qualitative characteristic of labor organization at the workplace. Discipline provides for the conscientious performance of their duties by employees on the rational use of tools and objects of labor, working hours, observance of routines, sequence and methods of processing labor objects, improving its productivity and product quality, observing health and safety regulations. Consequently, intra-company labor discipline is a broad concept. If its meaning is narrowed to the level of an individual and collective (brigade) workplace, then it is possible to consider industrial discipline as consisting of three components: labor discipline, technological discipline and managerial discipline.

The authors of the book [10] in their time, distinguishing between the concepts of "labor discipline", "production discipline", "technological discipline", argue that "labor discipline is a broader concept and includes production discipline and its component – technological discipline". They do not specially distinguish the managerial discipline.

But we must proceed from the obvious fact that any production is an aggregate of workplaces and single labor processes, technological and managerial processes that are taking place. Therefore, we propose to distinguish a special form and component of the production discipline – managerial discipline.

The foregoing can be represented by the following analytical dependence: D_P=f(D_T)=φ(D_Y), i.e., labor discipline (D_P) is a function of technological discipline (D_T), which, in turn, is a function of managerial discipline (D_Y). The aggregate (D_P, D_T, D_Y) constitutes the content and sense of production discipline. Hence it is appropriate to express Q-factor level of the workplace management η=f(ΔT, ΔY_C) through the level of the production discipline state.

The tasks of strengthening the production discipline can be formulated based on the universal law of working time economy, i.e., the law of labor economy:

a) implementation of living labor economy by eliminating downtime and absenteeism, reducing manual labor, labor costs of highly qualified specialists for jobs that do not fit their qualifications, reduce the unplanned movement of workers;

b) struggle for the economy of materialized (past) labor by eliminating downtime for machinery and equipment for various reasons, especially for repairs, ensuring timely development of capacities and increasing efficiency of all types of machinery, mechanisms and equipment, eliminating over-expenditure and loss of materials, tools and accessories;

c) desire to optimize managerial information, streamline the document workflow, improve the reliability of statistical data, complete provision of production managers and workplaces with engineering-technical and organizational and economic information;

d) economy of the future labor by improving the quality of engineering design and, on this basis, obtaining optimal capacity of enterprises, their expedient placement and effective operation, and improving qualimetric indexes (quality indexes) of products.

In the practical use of the previously mentioned ratio, the problem of incompatibility of dimensionalities Q, P, E, W, E' arises, since the product of labor is characterized by its dimensionalities, and the objects of labor and energy have dimensionalities that are not comparable with the product, the production wastes and scattered energy have their respective measurement units. Of course, in principle, it is possible to find fairly acceptable methods for the equivalent translation of dimensionalities, but there are simple and less labor-intensive methods for determining Q-factor of the workplace.

The foregoing ways of struggle for labor economy lead directly to the growth of labor productivity, and, consequently, introducing them into the workplace model through the notion of Q-factor of management and production discipline, it is possible to reflect the basic task of inter-company labor organization quantitatively and at each workplace.

It follows from the aforementioned that the state of production discipline can be characterized by the degree of effective use of working time of all workers and expressed quantitatively by the coefficient of the state of production discipline:

$$K_{pd}=K_{lb}K_{td}K_{md}=\left(1-\frac{t_{in}}{T_{sh}n}\right)\left(1-\frac{t_1}{T_{pl}n_1}\right)\left(1-\frac{t_T}{T_{tech}}\right)\left(1-\frac{t_m}{T_{pl}n_2}\right),$$

where K_{pd} – coefficient of the state of production discipline; K_{lb} – coefficient of the state of labor discipline; K_{td} – coefficient of the state of technological discipline; K_{md} – coefficient of the state of managerial discipline; t_{in} – total inter-shift losses of working time caused by violations of the work schedule; T_{sh} – work shift duration; n – number of workers supervised; t_1 – total day-to-day losses of working hours caused by violations of the work schedule; T_{pl} – planned fund of working time of one worker for the considered period; n_1 – number of workers in this unit, as stipulated in the plan; t_T – total losses of working time caused by violations of technological discipline; T_{tech} – total standardized technological labor intensity of works in this unit, as stipulated in the plan; t_m – total losses of working time caused by violations of the managerial order; n_2 – number of employees in this unit, as stipulated in the plan.

With this approach of quantitative expression of Q-factor of the workplace (workplaces) management through the coefficient of the state of production discipline, we come to the necessity of classifying the losses of working time and, for this purpose, the need to study the experience of their recording at industrial enterprises and divisions, especially in compliance with the requirements of ILO and Labor Code of the Russian Federation, as well as the development of forms of labor organization at workplaces. But this is a special scientific problem, for the solution of which certain prerequisites are set forth in the work [24].

8.5. Qualimetric criteria

In physics, the ratio of the amount of work and time, during which this work is done, is called power and is measured in watts and kilowatts. In economy of an industrial enterprise, the division of the output of products by the operation time of equipment at this workplace is called the productivity index of the equipment [15, 54].

The study of methodological problems of determining the production capacity of industrial enterprises and their subdivisions is a special scientific direction, and there is no possibility to outline the problems and ways of their solution in this work. For a long time, we have carried out the research work to improve the technical and economic planning of multiproduct productions based on qualimetry fundamentals (the science of measuring product quality). Among the technical and economic indexes, the production capacity of the workplace is also considered.

By analogy with the notion of physical power ($N=A/t$), it is proposed to define the production capacity as the ratio of the product manufactured at the workplace to the time during which this product was manufactured at the given workplace ($M=Q/t$).

In this case, the ratio of production capacity to physical power can be called the productivity of equipment, i.e.

$$P_{eq} = \frac{Q/t}{A/t} = \frac{Q}{A} \ .$$

By dividing the amount of product output (Q) at the workplace by the labor input (L_{in}), which can be defined as the product of time (t) by the labor intensity coefficient (C_{li}), we get the expression of living labor productivity (P_l), i.e.,

$$P_l = \frac{Q}{L_c} = \frac{Q}{C_{li}t} = \frac{Q}{C_{li}C_c t} \ .$$

What index can be the criterion of process management at the workplace? It should be such an index, which does not contradict, but, on the contrary, proceeds from the general criterion of the optimality of management in national economy. This criterion for production, from the standpoint of evaluating the inter-company production functioning, is known to be labor productivity.

It can be seen from the structural scheme of the workplace that not only the living (creative) labor of the worker participates in the creation of the product of labor, but also the previous labor (T_{pr}) in the form of the object of labor (P), machine, device, tool, mechanized auxiliaries and energy. Therefore, it is necessary to include past work (T_{pr}) in the index of labor productivity at the workplace, then

$$P_l = \frac{Q}{\left(L_c + T_{pr}\right)} \ .$$

The proposed formula is not new in itself, it is about whether it is possible and how to apply the above formula for practical calculations of labor productivity at certain workplaces?

Of course, in future, apparently, both living and past labor in labor-hours will be taken into account. Unfortunately, at present there is no registration of labor costs in terms of products, but we have a whole system of calculating the production cost and even the cost of a technological operation. Consequently, the cost of technological operation (C) is reflected with one or another error in each particular case of the costs of living and previous labor, therefore, the following expressions can be considered as equivalent ones:

$$\frac{Q}{L_c+T_{pr}} \Leftrightarrow \frac{Q}{W+\sum_1^n C_i},$$

where W – wages of the worker, rub.; C_i – costs at the workplace for the i-th item of expenditure, rub.; $\Leftrightarrow$ – equivalence sign; i=1, 2, 3, ..., n – number of cost items in the estimate for the given workplace.

Since Q is the same in the right and left parts, then

$$(L_c+T_{pr}) \Leftrightarrow \left(W+\sum_1^n C_i\right).$$

We introduce the equivalence coefficient

$$\mu = \frac{\left(W+\sum_{i=1}^n C_i\right)}{\left(L_c+T_{pr}\right)}$$

Let us write equality $\mu\left(L_c+T_{pr}\right)=\left(W+\sum_1^n C_i\right)$.

We can say that in the period between monetary reforms, the coefficient of equivalence applied to wholesale prices of enterprises can be taken as constant. With this assumption, the productivity of labor at the workplace is determined by the ratio of product output Q and cost of living and previous labor in monetary terms.

$$P_l = \frac{Q}{\left(W+\sum_1^n C_i\right)}$$

There remains the problem of quantitative measurement of products produced at the workplace. If a single type or an unchanged set of types of products (parts) is continuously produced at the workplace for a long time, then the output volume can be measured in pieces or sets of parts. However, the majority of jobs are multiproduct, diversely-product, so, in practice they resort to the methods of calculating the output through labor expenditures and costs expressed in money. But, as can be seen from the formula, the costs do not characterize the very essence of consumer properties of products, and it is senseless to divide the production costs by the production costs.

8.6. Qualimetric index of products

Based on the principles of qualimetry, all products can be represented quantitatively through the use of mathematical model that connects various parameters, characteristics and properties of products into a single integral quality criterion, will be called the general qualimetric index. Consequently,

$Q = \sum_{1}^{w} P_i K_{q_i}$, where P_i – value of the parameter of the i-th type of the products manufactured at the workplace; K_{q_i} – general qualimetric index of the i-th type of the products manufactured at the workplace; i=1, 2, 3, ..., w – serial numbers of the products manufactured at the workplace.

Thus, the formula makes it possible to quantify the qualimetric index of products manufactured at the given workplace as the sum of products of the main parameter values of the types of products by their total qualimetric index.

The main parameters of the products manufactured at the given workplace can be the quantities having the following dimensions: piece, kg, m, m^2, m^3, etc.

The general qualimetric index quantitatively reflects what quality this parameter of the product possesses (what it is filled with), i.e., what registered characteristics and properties are acquired by products at the workplace. When we multiply the main parameter by the qualimetric index, which has the quality dimensionality – quali, then we get a quali-parameter, e.g., quali-piece, quali-kilogram, quali-meter, quali-square meter, quali-cubic meter, quali-kilogram-meter, quali-calorie, etc.

In turn, the general qualitative index can be expressed as the product of particular qualimetric indexes, i.e.,

$$K_q = K_1 \cdot K_2 \cdot \ldots \cdot K_m = \prod_{1}^{m} K_j ,$$

where K_j – qualimetric index of the j-th registered characteristic, property characterizing the quality of the manufactured products at the given workplace from one particular j-th side.

Each particular qualimetric index is a dimensionless coefficient that reflects the measured or quantitatively expressed value of a certain characteristic, property inherent in the given product, i.e.

$$K_j = \frac{\mathrm{f}(q_i)_j}{\mathrm{f}(q_\delta)_j} ,$$

where q_i – measured or estimated value of the j-th characteristic, property for the i-th copy of the product manufactured at the given workplace; q_δ – measured or quantified value of the j-th characteristic, property for the δ-th copy of the product manufactured at the given workplace, taken as the base.

Functional expressions in the numerator and denominator of formula K_j have the same dimensionalities, therefore, the value of particular qualimetric indexes becomes a dimensionless coefficient.

The type of functions is derived by the methods of mathematical statistics (applied regressive and correlative analyses) by means of appropriate processing of the collected statistics on the effect of a characteristic, product properties on the socially necessary (standard) time of its production at the workplace, i.e., the following functional dependence is revealed: $t_j=\varphi(q_j)=A_j\cdot q_j^{a_j}$, and the qualimetric index will be expressed as follows:

$$K_j=\frac{(A_i)_j(q_i)_j^{a_j}}{(A_\delta)_j(q_\delta)_j^{a_j}}=\left(\frac{q_j}{q_\delta}\right)^{a_j}=b_j^{a_j},$$

since $A_j=A_\delta$=const for the given kind of function.

8.7. Qualimetric equation of the workplace

It follows from the foregoing that the general qualimetric index of products manufactured at the workplace will be expressed by the following function:

$$K_q=\prod_1^m K_j=A\cdot b_1^{a_1}\cdot b_2^{a_2}\cdot\ldots\cdot b_m^{a_m}.$$

This function is nothing more than production function reflecting the product quality (its qualimetric index).

In economic and mathematical studies, multiplicative forms of production functions are widespread. Their advantage consists in the following: if one of the multipliers is zero, then the result goes to zero. It is easy to see that this realistically reflects the fact that, in most cases, all analyzed primary resources participate in production and without any of them the product output is impossible. The b_i multipliers from the first to the m-th can have different contents depending on which factors influence the overall result (release). The exponential coefficients show the share in the growth of the final product, which each of the multipliers brings in. If the sum of the coefficients is one, this means the uniformity of the function: it increases proportionally to the growth in the amount of resources. But it is also possible that the sum of elasticity coefficients (parameters of the production function) is greater than one. This shows that an increase in costs leads to the disproportionate increase in the output. The development of the production function method cannot be considered complete; the studies on its generalization and refinement are conducted, in particular, in the direction of developing special production functions that meet the specific conditions of individual industries and enterprises [53].

According to available literary sources, it can be claimed that there is no production function for the workplace, in the sense we have proposed, so the qualimetric approach to the calculation of the product output volume opens great opportunities for economic and mathematical modeling at the workplace level – the primary element of production systems. The derived equation of the production function of the workplace is the contribution to the development of the theory of production functions. The production function of the workplace is called *the qualimetric equation of the workplace*.

We have developed and tested the production functions of individual and collective (brigade) workplaces for trial, experimental, tool shops engaged in the production of parts by cutting, for sheet-stamping, forging, hot-stamping, casting shops, shops of steel shaped profiles.

In the formula of labor productivity, product Q can now be expressed quantitatively through its qualimetric equation

$$P_l = \frac{\sum_1^r m_i K_{q_i}}{W + \sum_1^n C_i} .$$

There is a definite correlation between the productive labor power and labor productivity. Considering this, it is possible to express the productive labor power with reference to the workplace $P_p = \varphi(M, P, E, O, \eta)$, where M – mechanical loading at the workplace; P – power loading of labor; E – electronic loading of labor; O – technological equipment of the workplace; η – Q-factor level of the workplace functioning, depending on the state of management emanating from the higher authority (ΔT) and the skill level and efficiency of the worker (ΔY_C).

Using the methods of mathematical statistics and expressing quantitatively each of the factors, one can obtain the production function that establishes the dependence of labor productivity on the factors that form the value of the productive force of labor at the given workplace, i.e., $P_l = f(P_p) = B \cdot \eta \cdot M^{\beta_1} \cdot P^{\beta_2} \cdot O^{\beta_3} \cdot E^{\beta_4}$, then

$$P_l = \frac{\sum_1^r m_i K_{q_i}}{W + \sum_1^n C_i} = B \cdot \eta \cdot M^{\beta_1} \cdot P^{\beta_2} \cdot O^{\beta_3} \cdot E^{\beta_4} ,$$

or

$$\frac{\sum_1^r \left[P_i \cdot \left(A \cdot b_1^{a_1} \cdot b_2^{a_2} \cdot \ldots \cdot b_m^{a_m} \right) \right]}{W + \sum_1^n C_i} = B \cdot \eta \cdot M^{\beta_1} \cdot P^{\beta_2} \cdot O^{\beta_3} \cdot E^{\beta_4} .$$

This equation, we believe, is the main conclusion from the whole previous study. It is a technical-economic-mathematical engineering-qualimetric model of the workplace and serves as the target function of ergonomic optimization of the workplace under the actual and project organization of labor, which we defined as a field of people's practical activity in designing and implementing projects of single labor processes and managing them to improve labor productivity.

To sum it up, the derived target function is only the concrete expression of the social target function applied to the workplace.

1. Qualimetrically calculated volume of products

$$Q=\sum_{1}^{r} P_i\left(A\cdot b_1^{a_1}\cdot b_2^{a_2}\cdot\ldots\cdot b_m^{a_m}\right).$$

2. Costs (expenditures) of living and past labor

$$L_c+T_{pr}=\mu(W+\sum_{1}^{n} C_i).$$

3. Resources of production (productive labor force)

$$P_F=B\cdot\eta\cdot M^{\beta_1}\cdot P^{\beta_2}\cdot O^{\beta_3}\cdot E^{\beta_4}.$$

4. Q-factor (efficiency) of production management

$$\eta=f(\Delta T,\ \Delta Y_C)=K_{lb}K_{td}K_{md}\ .$$

Consideration of these indexes in complex leads to the expression of the dependence of product output on resources and Q-factor in public system, i.e.,

$$Q=\eta P_F(L_c+T_{pr}).$$

If Q-factor equals zero (η=0), the product is zero. At P_F=0, also Q=0, i.e., without resources there is no product output and, moreover, from the production function of resources it is evident that the absence of one resource (one type of resource is zero) is sufficient, as the entire value of resources becomes zero. There must be all necessary resources! If the costs of living labor are zero, then the production functions only at the expense of past labor costs, which means full automation of the workplace. In the absence of the past labor costs, the products are manufactured only by living labor – completely manual labor.

Practical use of objective derived workplace function is in the next part of “Economic metrology. Part II. Labor process – a social “molecule”.

APPLIED ERGOMETRY

Chapter 9
Calculations of external mechanical work performed by a human body during its movements with labor tools in various types of labor activity

9.1. Walking without load

A man weighing 65 kg in the lightest clothes and sports shoes moves without load on a smooth road at speeds of 2, 3, 4, 5, 6, 7 km/h. It is necessary to calculate the mechanical work performed by the human body in 1 minute of walking.

We require the following additional conditions:

a) the weight of clothes and shoes is neglected, since their weight is insignificant in comparison with the weight of the human body;

b) the length of a person's leg – 0,94 m;

c) the step length is variable, it increases with increasing speed;

d) the relative weight of the individual parts and links of the human body:

head	– 0,0724	body+head	– 0,5114
body	– 0,4390	whole hand	– 0,0577
shoulder	– 0,0299	whole leg	– 0,1865
forearm	– 0,0205	head+body+	
thigh	– 0,1206	two arms	– 0,6268
wrist	– 0,0075	shin	– 0,0500
foot	– 0,0158		

The movement of the human body as a mechanical system consists of the following fixed states (Fig. 10):

• starting position: legs spaced by the length of the step and arms, respectively;

• position with the legs attached to each other;

• end position: legs spaced by the length of the step and arms, respectively.

The total kinetic energy consists of the sum:

a) kinetic energy of the leg movement by the length of the step, which can be calculated with practically sufficient accuracy by the pendulum swing formula

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2,$$

where m_l – mass of the leg in kg·s^2/m; φ_l – leg swing angle; c_l – distance from the swing axis to the center of gravity of the leg, m; t_1 – time during which the leg moves by 1 step, s;

b) kinetic energy of the body lifting (head+arms+body) to a certain height when passing from the initial position with legs set to the length of the step to the position with the legs attached to each other

$$A_2 = P_k h_k\,,$$

where P_k – bodyweight (head+hands+body), kg; P_k=0,63P (P – weight of the whole body); h_k – value of the body lifting, m;

c) kinetic energy of the body fall (head+arms+body) to a certain height during the transition from the intermediate position to the end position

$$A_3 = (P_k - m_k\, a)\, h_k\,,$$

where m_k – body weight (P_k), kg·s^2/m; a – acceleration of the body fall (P_k), approximately calculated by the formula

$$a = \frac{8h_k}{t_1^2}\,,$$

where h_k – height of the body, m; t_1 – time of one step, s;

d) kinetic energy of the translational horizontal body motion

$$A_4 = mv^2/2\,,$$

where m – mass of the whole body, kg·s^2/m; v – speed of translational motion of the center of gravity of the human body, m/s;

e) kinetic energy of the arms swing

$$A_5 = m_a \left(\frac{\varphi_a c_a}{t_1}\right)^2\,,$$

where m_a – mass of the arm, m_a=0,06 P/g, kgf^2/m; φ_a – angle of the arm swing; c_a – distance from the swing axis to the center of gravity of the arm, m; t_1 – time of one step, s.

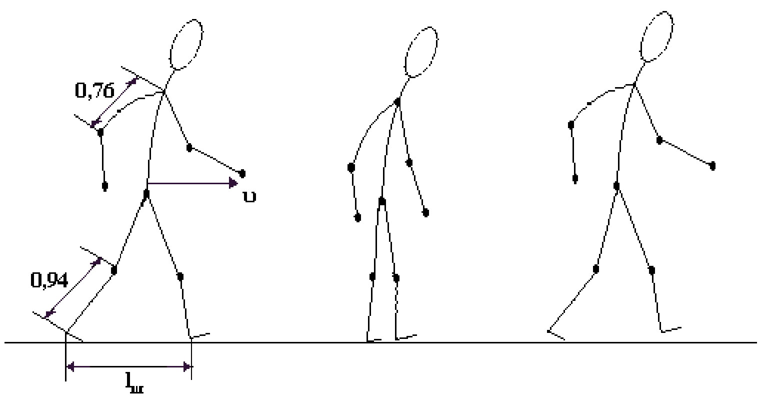
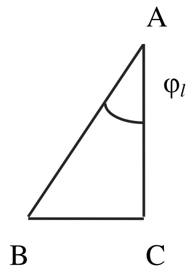


Fig.10. Walk scheme (1 step)

The speed of movement is 2 km/h. We take the step length l_{step}=0,46 m. Then the number of steps per minute n=72, the movement speed of the gravity center of the body horizontally v=0,56 m/s. Let us calculate the height of lifting the body:



Leg movement scheme

AB=0,94 m; $BC=l_{step}/2$=0,23 m;
$\sin\varphi_l$=0,23/0,94=0,25;
$2\varphi_l$=30°=0,52 rad;

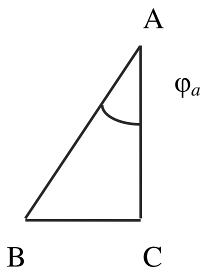
$$AC=\frac{BC}{\mathbf{tg}\varphi_l}=\frac{0{,}23}{0{,}27}=0{,}90 \text{ m};$$

h_k=0,94–0,90=0,04 m.

Angle of the arm swing:

$$\sin\varphi_a=\frac{BC}{AB}=\frac{0{,}23}{0{,}76}=0{,}3\ ;$$

$2\varphi_a$=35°=0,61 rad.
Time 1 step t_1=60/72≈0,8 s.



Arm movement scheme

Acceleration of the body fall

$$a=\frac{8h_k}{t_1^2}=\frac{8\cdot 0{,}04}{0{,}8^2}=0{,}5\ \frac{\text{m}}{\text{s}^2}.$$

$$A_1=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2=\frac{1{,}23}{2}\left(\frac{0{,}52\cdot 1{,}42}{0{,}4}\right)^2=0{,}18 \text{ kgm/step}.$$

$A_2=P_k\cdot h_k$=65·0,63·0,04=1,64 kgm/step.

$A_3=(P_k–m_k\cdot a)\cdot h_k$=(41–4,11·0,4)·0,04=1,55 kgm/step.

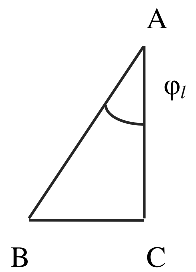
$A_4=m\cdot v^2/2$=65·0,56²/2·9,81=1,03·60=61,5 kgm/min.

$$A_5=m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2=\frac{0{,}06\cdot m}{9{,}81}\cdot\frac{(0{,}61\cdot 0{,}33)^2}{0{,}4^2}=\frac{0{,}06\cdot 65\cdot(0{,}61\cdot 0{,}33)^2}{9{,}81\cdot 0{,}16}=$$

=0,010 kgm/step.

A=(0,018+1,64+1,55+0,010) ·72+61,5=300 kgm/min.

The speed of movement is 3 km/h. We take the step length l_{step}=0,59 m. Then the number of steps in 1 minute is n=87 steps/min, the movement speed of the gravity center of the body horizontally v=0,83 m/s, the time of one step t_1=60/87=0,68 s. Let us calculate the height of the body lifting:

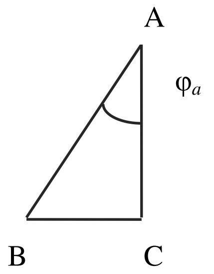


Leg movement scheme

AB=0,94 m; $BC=l_{step}/2$=0,295 m;
$\sin\varphi_l$=0,295/0,94=0,32;
$2\varphi_l$=37°=0,64 rad.;

$$AC=\frac{BC}{\mathbf{tg}\varphi_l}=\frac{0{,}295}{0{,}33}=0{,}89 \text{ m};$$

h_k=0,94–0,89=0,05 m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a = \frac{BC}{AB} = \frac{0{,}295}{0{,}6} = 0{,}37\ ;$$

$2\varphi_a$=35°=0,6 rad.

Acceleration of the body fall

$$a = \frac{8h_k}{t_1^2} = \frac{8\cdot 0{,}05}{0{,}68^2} = 0{,}65\ \frac{\text{m}}{\text{s}^2}\ .$$

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 = \frac{1{,}23}{2}\left(\frac{0{,}64\cdot 0{,}42}{0{,}34}\right)^2 = 0{,}39 \text{ kgm/step.}$$

$A_2 = P_k \cdot h_k$=65·0,63·0,05=2 kgm/step.

$A_3 = (P_k - m_k a)\ h_k$=(41–4,18·0,65)·0,05=1,8 kgm/step.

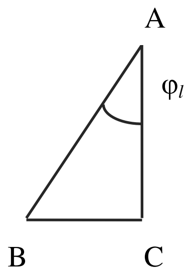
$A_4 = m\cdot v^2/2$=65·0,83²/2·9,81=140 kgm/step.

$$A_5 = m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2 = \frac{0{,}06\cdot m}{9{,}81}\cdot\frac{(0{,}68\cdot 0{,}33)^2}{0{,}68^2} = \frac{0{,}06\cdot 65\cdot(0{,}68\cdot 0{,}33)^2}{9{,}81\cdot 0{,}46^2} =$$

=0,032 kgm/step.

A=(0,39+1,8+2,00+0,032)·87+140=500 kgm/step.

The speed of movement is 4 km/h. We take the step length l_{step}=0,66 m. Then the number of steps in 1 minute is n=100 steps/min, the movement speed of the gravity center of the body horizontally v=1,11 m/s, the time of one step t_1=60/100=0,6 s. Let us calculate the height of the body lifting:



Leg movement scheme

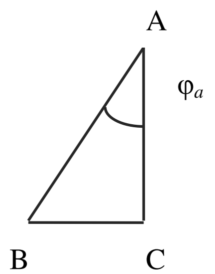
AB=0,94 m; $BC = l_{step}/2$=0,33 m;

$\sin\varphi_l$=0,33/0,94=0,35;

$2\varphi_l$=41°=0,71 rad.;

$$AC = \frac{BC}{\mathbf{tg}\varphi_l} = \frac{0{,}33}{0{,}37} = 0{,}885\ \text{m};$$

$h_k = AB - AC$=0,94–0,885=0,055 m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a = \frac{BC}{AB} = \frac{0{,}33}{0{,}76} = 0{,}4\ ;$$

$2\varphi_a$=45°=0,82 rad.

Time 1 step t_1=60/72≈0,8 s.

Acceleration of the body fall

$$a = \frac{8h_k}{t_1^2} = \frac{8\cdot 0{,}06}{0{,}6^2} = 1{,}20\ \ \frac{\text{m}}{\text{s}^2}\ .$$

$$A_1=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2=\frac{1{,}23}{2}\left(\frac{0{,}71\cdot 0{,}42}{0{,}6}\right)^2=0{,}15 \text{ kgm/step.}$$

$A_2=P_k h_k=65\cdot 0{,}63\cdot 0{,}055=2{,}25$ kgm/step.

$A_3=(P_k-m_k a)\ h_k=(41-4{,}28\cdot 1{,}20)\cdot 0{,}055=2{,}0$ kgm/step.

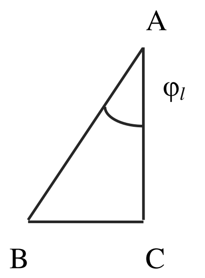
$A_4=mv^2/2=65\cdot 1{,}11^2/2\cdot 9{,}81\cdot 60=240$ kgm/step.

$$A_5=m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2=\frac{0{,}06\cdot 65}{9{,}81}\frac{(0{,}82\cdot 0{,}33)^2}{0{,}6^2}=\frac{0{,}06\cdot 65\cdot(0{,}82\cdot 0{,}33)^2}{9{,}81\cdot 0{,}36}=$$

$=0{,}1$ kgm/step.

$A=(0{,}15+2{,}25+2{,}00+0{,}1)\cdot 100+240=710$ kgm/min.

The speed of movement is 5 km/h. We take the step length $l_{step}=0{,}72$ m. Then the number of steps in 1 minute $n=115$ steps/min, the movement speed of the gravity center of the body horizontally $v=1{,}38$ m/s, the time of one step $t_1=60/115=0{,}52$ s. Let us calculate the height of the body lifting:



Leg movement scheme

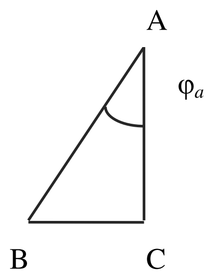
$AB=0{,}94$ m; $BC=l_{step}/2=0{,}36$ m;

$\sin\varphi_l=0{,}36/0{,}94=0{,}37$;

$2\varphi_l=44°=0{,}77$ rad.

$$AC=\frac{BC}{\mathrm{tg}\varphi_l}=\frac{0{,}36}{0{,}40}=0{,}89 \text{ m;}$$

$h_k=AB-AC=0{,}94-0{,}89=0{,}05$ m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a==\frac{BC}{AB}=\frac{0{,}36}{0{,}76}=0{,}47\ .$$

$2\varphi_a=56°=0{,}98$ rad.

Acceleration of the body fall

$$a=\frac{8h_k}{t_1^2}=\frac{8\cdot 0{,}5}{0{,}52^2}=1{,}47\ \frac{\text{m}}{\text{s}^2}\ .$$

$$A_1=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2=\frac{1{,}23}{2}\left(\frac{0{,}77\cdot 0{,}42}{0{,}52}\right)^2=0{,}25 \text{ kgm/step.}$$

$A_2=P_k h_k=65\cdot 0{,}63\cdot 0{,}05=2$ kgm/step.

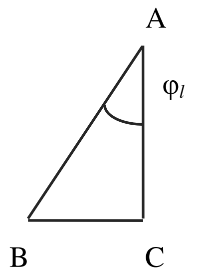
$A_3=(P_k-m_k a)\ h_k=(41-4{,}18\cdot 1{,}47)\cdot 0{,}05=1{,}75$ kgm/step.

$A_4=mv^2/2=65\cdot 1{,}38^2/2\cdot 9{,}81\cdot 60=380$ kgm/min.

$$A_5=m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2=\frac{0{,}06\cdot 65}{9{,}81}\frac{(0{,}77\cdot 0{,}33)^2}{0{,}52^2}=0{,}1 \text{ kgm/step.}$$

$A=(0{,}25+2{,}00+1{,}75+0{,}1)\cdot 115+380=850$ kgm/min.

The speed of movement is 6 km/h. We take the step length l_{step}=0,78 m. Then the number of steps per minute n=128 step/min, the movement speed of the gravity center of the body horizontally v=1,65 m/s, time of one step t_1=60/128=0,47 s. Let us calculate the height of the body lifting:



Leg movement scheme

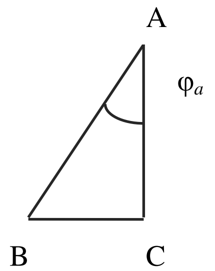
AB=0,94 m; $BC=l_{step}/2$=0,39 m;

$\sin\varphi_l$=0,39/0,94=0,415;

$2\varphi_l$=50°=0,88 rad.;

$$AC=\frac{BC}{\mathrm{tg}\varphi_l}=\frac{0{,}39}{0{,}457}=0{,}86 \text{ m};$$

$h_k=AB-AC$=0,94–0,866=0,08 m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a=\frac{BC}{AB}=\frac{0{,}39}{0{,}76}=0{,}515 .$$

$2\varphi_a$=62°=1,1 rad.

Acceleration of the body fall

$$a=\frac{8h_k}{t_1^2}=\frac{8\cdot 0{,}095}{0{,}47^2}=3{,}4 \ \ \frac{\text{m}}{\text{s}^2} .$$

$$A_1=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2=\frac{1{,}23}{2}\left(\frac{0{,}88\cdot 0{,}42}{0{,}47}\right)^2=0{,}36 \text{ kgm/step.}$$

$A_2=P_k h_k$=65·0,63·0,08=3,98 kgm/step.

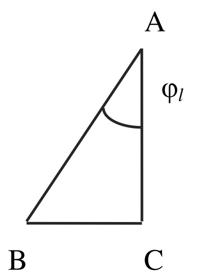
$A_3=(P_k-m_k a)\ h_k$=(41–4,18·3,4)·0,08=2,14 kgm/step.

$A_4=mv^2/2$=65·1,65^2/2·9,81·60=540 kgm/min.

$$A_5=m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2=\frac{0{,}06\cdot 65}{9{,}81}\frac{(0{,}88\cdot 0{,}33)^2}{0{,}47^2}=0{,}15 \text{ kgm/step.}$$

A=(0,36+3,28+2,14+0,15)·128+540=1300 kgm/min.

The speed of movement is 7 km/h. We take the step length l_{step}= =0,88 m.Then the number of steps per minute n=132 step/min, the movement speed of the gravity center of the body horizontally v=1,9 m/s, time of one step t_1=60/132=0,46 s. Let us calculate the height of the body lifting:



Leg movement scheme

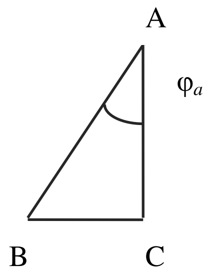
AB=0,94 m; $BC=l_{step}/2$=0,44 m;

$\sin\varphi_l$=0,44/0,94=0,468;

$2\varphi_l$=56°=0,98 rad.;

$$AC=\frac{BC}{\mathrm{tg}\varphi_n}=\frac{0{,}44}{0{,}53}=0{,}83 \text{ m};$$

$h_k=AB-AC$=0,94–0,83=0,11 m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a = \frac{BC}{AB} = \frac{0{,}44}{0{,}76} = 0{,}58 .$$

$2\varphi_a$=71°=1,25 rad.

Acceleration of the body fall

$$a = \frac{8h_k}{t_1^2} = \frac{8 \cdot 0{,}11}{0{,}46^2} = 4{,}8\ \frac{\text{m}}{\text{s}^2} .$$

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 = \frac{1{,}23}{2}\left(\frac{0{,}98 \cdot 0{,}42}{0{,}46}\right)^2 = 0{,}49 \text{ kgm/step.}$$

$A_2 = P_k h_k = 65 \cdot 0{,}63 \cdot 0{,}11 = 4{,}5$ kgm/step.

$A_3 = (P_k - m_k a)\, h_k = (41 - 4{,}18 \cdot 4{,}8) \cdot 0{,}11 = 2{,}3$ kgm/step.

$A_4 = mv^2/2 = 65 \cdot 1{,}9^2/2 \cdot 9{,}81 \cdot 60 = 710$ kgm/min.

$$A_5 = m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2 = \frac{0{,}06 \cdot 65}{9{,}81}\,\frac{(0{,}98 \cdot 0{,}33)^2}{0{,}46^2} = 0{,}2 \text{ kgm/step.}$$

$A = (0{,}49 + 4{,}5 + 2{,}3 + 0{,}2) \cdot 132 + 710 = 1700$ kgm/min.

The results of the calculations are summarized in Table 10.

Table 10

The results of calculating the work done during walking

v, km/h	l_{step}, m	n, step/min	v, m/s	t_1, s	h_k, m	a, m/s^2	A_1, kgm/step	A_2, kgm/step	A_3, kgm/step	A_4, kgm/step	A_5, kgm/step	A_{total}, kgm/step
2	0,46	72	0,56	0,8	0,04	0,5	0,18	1,64	1,55	61,5	0,01	300
3	0,59	87	0,83	0,68	0,05	0,65	0,39	2,00	1,80	140	0,032	500
4	0,66	100	1,11	0,6	0,055	1,20	0,15	2,55	2,00	240	0,10	710
4	0,72	115	1,38	0,52	0,05	1,47	0,25	2,00	1,75	380	0,10	850
6	0,78	128	1,65	0,47	0,095	3,4	0,36	3,90	2,50	540	0,15	430
7	0,88	132	1,9	0,46	0,11	4,8	0,49	4,5	2,30	710	0,20	1700

9.2. Walking with over-the-shoulder load

A man weighing 65 kg in the lightest clothes and sports shoes moves with over-the-shoulder load on a smooth solid road. The weight of the load and the speed vary:

Load, kg	10	30	50	75	100
Speed, km/h	4,0	4,0	3,5	3,0	

It is necessary to calculate the external mechanical work (power) performed by the human body taking into account the over-the-shoulder load for 1 minute.

Additional conditions are the same as for a case of walking without load.

The total kinetic energy consists of the sum:

a) kinetic energy of the leg movement by the length of the step, which can be calculated with practically sufficient accuracy by the pendulum swing formula

$$A_1=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 \text{ kgm/step;}$$

b) kinetic energy of the body lifting (head+arms+body) taking into account the over-the-shoulder load to a certain height when passing from the initial position with legs set to the length of the step to the position with the legs attached to each other $A_2=(P_k+P_g)h_k$, where P_g – weight of the over-the-shoulder load, kg;

c) kinetic energy of the body fall (head+arms+body) taking into account the over-the-shoulder load to a certain height when passing from the intermediate position to the end position $A_3=(P_k+P_g-m_k a-m_g a)h_k$, where m_g – load weight, kgs^2/m;

d) kinetic energy of the horizontal translational body motion

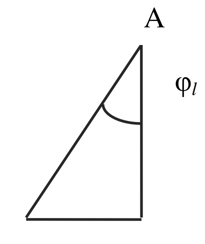
$$A_4=\frac{mv^2}{2} \ ,$$

where m – mass of the whole body+weight of the over-the-shoulder load;

e) kinetic energy of the swinging arms

$$A_5=m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2.$$

1. The load is 10 kg, the speed is 4 km/h. Let us take the step length l_{step}=0,6 m, then the number of steps per minute n=112, the movement speed of the gravity center of the body horizontally υ=1,11 m/s, the time of one step is t_1=0,535 s.



Leg movement scheme

Height of lifting the body with load:

$h_k=AB-AC$; AB=0,94 m;

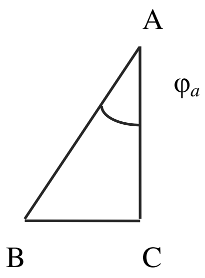
$BC=l_{step}/2$=0,3 m;

$\sin\varphi_l$=0,3/0,94=0,32;

$2\varphi_l$=37°=0,65 rad.;

$$AC=\frac{BC}{\mathrm{tg}\varphi_l}=\frac{0,3}{0,337}=0,89 \text{ m;}$$

$h_k=AB-AC$=0,94–0,89=0,05 m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a = \frac{BC}{AB} = \frac{0{,}3}{0{,}76} = 0{,}396;$$

$2\varphi_a$ =46°40'=0,816 rad.

Acceleration of the body fall

$$a = \frac{8h_k}{t_1^2} = \frac{8\cdot 0{,}05}{0{,}535^2} = 1{,}4 \ \frac{\text{m}}{\text{s}^2}.$$

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 = \frac{1{,}23}{2}\left(\frac{0{,}65\cdot 0{,}42}{0{,}535}\right)^2 = 0{,}16 \text{ kgm/step.}$$

$A_2=(P_k+P_g)\ h_k$=(41+40)·0,05=2,54 kgm/step.

$A_3=(P_k+P_g-m_k a-m_g a)\ h_k$=(41+10–4,18·1,4–1,02·1,4)·0,05=2,20 kgm/step.

$$A_4 = \frac{m\upsilon^2}{2} = \frac{(m_k+m_g)\cdot\upsilon^2}{2}\cdot 60 = \frac{7{,}67\cdot 1{,}11^2}{2}\cdot 60 = 276 \text{ kgm/min.}$$

$$A_5 = m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2 = \frac{0{,}06\cdot 65}{9{,}81}\frac{(0{,}816\cdot 0{,}33)^2}{0{,}536^2} = 0{,}12 \text{ kgm/step.}$$

A=(0,16+2,54+2,20+0,12)·112+276=840 kgm/min.

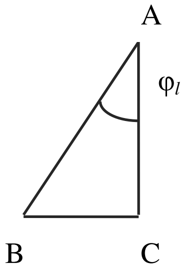
2. The load is 30 kg, the speed is 4 km/h. Let us take the step length l_{step}=0,6 m, then the number of steps in 1 minute n=112, the movement speed of the gravity center of the body horizontally υ=1,11 m/s, the time of one step t_1=0,535 s. The height of lifting the body with load h_k=0,05 m.

Leg swing angle $2\varphi_l$=37°=0,65 rad.;
arm swing angle $2\varphi_a$=46°40'=0,816 rad.;
acceleration of the body fall a=1,4 m/s^2.
A_1=0,16 kgm/step.
A_2=0,12 kgm/step.
$A_2=(P_k+P_g)\ h_k$=(41+30)·0,05=3,55 kgm/step.
$A_3=(P_k+P_g-m_k a-m_g a)\ h_k$=(41+30–4,18·1,4–3,07·1,4)·0,05=3,06 kgm/step.

$$A_4 = \frac{m\upsilon^2}{2} = \frac{(m_k+m_g)\upsilon^2}{2}\cdot 60 = \frac{6{,}65+3{,}07}{2}\cdot 1{,}11^2\cdot 60 = 350 \text{ kgm/min.}$$

A=(0,16+3,55+3,06+0,12)·112+350=1120 kgm/min.

3. The load is 50 kg, the speed is 4 km/h. Let us take the step length l_{step}=0,5 m, then the number of steps in 1 minute n=133, the movement speed of the gravity center of the body horizontally υ=1,11 m/s, the time of one step t_1=0,45 s.



Leg movement scheme

The height of lifting the body with load:

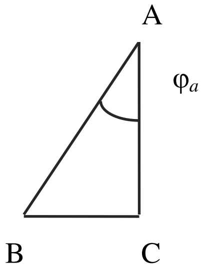
$h_k = AB - AC$; $AB = 0{,}94$ m; $BC = l_{step}/2 = 0{,}25$ m;

$\sin\varphi_l = 0{,}25/0{,}94 = 0{,}266$;

$2\varphi_l = 31° = 0{,}54$ rad.;

$$AC = \frac{BC}{\mathbf{tg}\varphi_n} = \frac{0{,}25}{0{,}277} = 0{,}905 \text{ m};$$

$h_k = AB - AC = 0{,}94 - 0{,}905 = 0{,}035$ m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a = \frac{BC}{AB} = \frac{0{,}25}{0{,}76} = 0{,}33.$$

$2\varphi_a = 38°40' = 0{,}68$ rad.

Acceleration of the body fall

$$a = \frac{8h_k}{t_1^2} = \frac{8 \cdot 0{,}035}{0{,}45^2} = 1{,}4 \ \frac{\text{m}}{\text{s}^2}.$$

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 = \frac{1{,}23}{2}\left(\frac{0{,}54 \cdot 0{,}42}{0{,}45}\right)^2 = 0{,}153 \text{ kgm/step}.$$

$A_2 = (P_k + P_g)\ h_k = (41+50) \cdot 0{,}035 = 3{,}19$ kgm/step.

$A_3 = (P_k + P_g - m_k a - m_g a) h_k = (41+50-4{,}18 \cdot 1{,}4 - 5{,}05 \cdot 1{,}4) \cdot 0{,}035 = 2{,}74$ kgm/step.

$$A_4 = \frac{m\upsilon^2}{2} = \frac{(m_k + m_g)\upsilon^2}{2} \cdot 60 = = \frac{6{,}65 + 5{,}10}{2} \cdot 1{,}11^2 \cdot 60 = 420 \text{ kgm/step}.$$

$$A_5 = m_a\left(\frac{\varphi_a - c_a}{t_1}\right)^2 = \frac{0{,}06 \cdot 65}{9{,}81}\frac{(0{,}68 \cdot 0{,}33)^2}{0{,}45^2} = 0{,}1 \text{ kgm/step}.$$

$A = (0{,}153 + 3{,}19 + 2{,}74 + 0{,}1) \cdot 133 + 420 = 1240$ kgm/min.

4. The load is 75 kg, the speed is 3,5 km/h. Let us take the step length $l_{step} = 0{,}5$ m, then the number of steps in 1 minute $n = 115$, the movement speed of the gravity center of the body horizontally $\upsilon = 0{,}97$ m/s, the time of one step $t_1 = 0{,}52$ s. The height of lifting the body with load $h_k = 0{,}035$ m.

Leg swing angle $2\varphi_l = 31° = 0{,}54$ rad.;

Arm swing angle $2\varphi_a = 38°40' = 0{,}868$ rad.;

Acceleration of the body fall $a = \frac{8 \cdot 0{,}035}{0{,}52^2} = 1{,}03 \frac{\text{m}}{\text{s}^2}$.

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 = \frac{1{,}23}{2}\left(\frac{0{,}54 \cdot 0{,}42}{0{,}52}\right)^2 = 0{,}115 \text{ kgm/step}.$$

$A_2 = (P_k + P_g)\ h_k = (41+75) \cdot 0{,}035 = 4{,}06$ kgm/step.

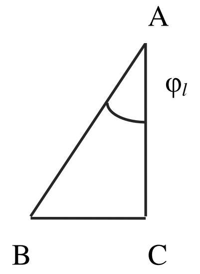
$A_3 = (P_k + P_g - m_k a - m_g a)\ h_k = (41+75-4{,}18 \cdot 1{,}03 - 7{,}70 \cdot 1{,}03) \cdot 0{,}035 =$
$= 3{,}63$ kgm/step.

$$A_4 = \frac{m\upsilon^2}{2} = \frac{(m_k + m_g)\upsilon^2}{2} \cdot 60 = \frac{6{,}65 + 7{,}70}{2} \cdot 0{,}97^2 \cdot 60 = 400 \text{ kgm/min} .$$

$$A_5 = m_a \left(\frac{\varphi_a c_a}{t_1}\right)^2 = \frac{0{,}06 \cdot 65}{9{,}81} \frac{(0{,}68 \cdot 0{,}33)^2}{0{,}5^2} = 0{,}4 \cdot 0{,}188 = 0{,}075 \text{ kgm/step.}$$

A=(0,115+4,06+3,63+0,075)·115+400=1300 kgm/min.

5. The load is 100 kg, the speed is 3,0 km/h. Let us take the step length l_{step}=0,4 m, then the number of steps in 1 minute n=125, the movement speed of the gravity center of the body horizontally υ=0,83 m/s, the time of one step t_1=0,48 s.



Leg movement scheme

The height of lifting the body with load:

$h_k = AB - AC$; AB=0,94 m;

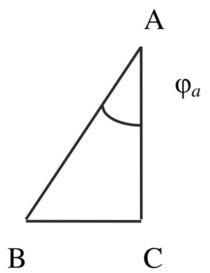
$BC = l_{step}/2$=0,20 m;

$\sin\varphi_l$=0,20/0,94=0,212;

$2\varphi_l$=25°=0,437 rad.;

$$AC = \frac{BC}{\mathbf{tg}\varphi_l} = \frac{0{,}20}{0{,}22} = 0{,}913 \text{ m};$$

$h_k = AB - AC$=0,94–0,913=0,027 m.



Arm movement scheme

Angle of the arm swing:

$$\sin\varphi_a = \frac{BC}{AB} = \frac{0{,}20}{0{,}76} = 0{,}264 .$$

$2\varphi_a$=30°40'=0,54 rad.

Acceleration of the body fall

$$a = \frac{8h_k}{t_1^2} = \frac{8 \cdot 0{,}027}{0{,}48^2} = 1{,}94 \ \frac{\text{m}}{\text{s}^2} .$$

$$A_1 = \frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2 = \frac{1{,}23}{2}\left(\frac{0{,}437 \cdot 0{,}42}{0{,}48}\right)^2 = 0{,}089 \text{ kgm/step.}$$

$A_2 = (P_k + P_g)\, h_k$=(41+100)·0,027=3,82 kgm/step.

$A_3 = (P_k + P_g - m_k a - m_g a)\, h_k$=(41+100–4,18·1,94–10,2·0,94)·0,027= =3,42 kgm/step.

$$A_4 = \frac{m\upsilon^2}{2} = \frac{(m_k + m_g)\upsilon^2}{2} \cdot 60 = \frac{6{,}65 + 10{,}2}{2} \cdot 0{,}83^2 \cdot 60 = 350 \text{ kgm/min.}$$

$$A_5 = m_a \left(\frac{\varphi_a c_a}{t_1}\right)^2 = \frac{0{,}06 \cdot 65}{9{,}81} \frac{(0{,}54 \cdot 0{,}33)^2}{0{,}48^2} = 0{,}055 \text{ kgm/step.}$$

A=(0,089+3,82+3,42+0,055)·125+350=1300 kgm/min.

The results of the calculations are summarized in Table 11.

Table 11

The results of calculating the work performed when walking with the over-the-shoulder load

P_g	v, km/h	l_{step}, m	n, step/min	v, m/s	t_1, s	h_k, m	a, m/s^2	A_1, kgm/step	A_2, kgm/step	A_3, kgm/step	A_4, kgm/step	A_5, kgm/step	A_{total}, kgm/step
10	4,0	0,6	112	1,11	0,535	0,05	1,4	0,16	2,54	2,20	276	0,12	840
30	4,0	0,6	112	1,11	0,535	0,05	1,4	0,16	3,55	3,06	350	0,12	1120
50	4,0	0,5	133	1,11	0,450	0,035	1,4	0,153	3,19	2,74	420	0,10	1240
75	3,5	0,5	115	0,97	0,52	0,035	1,03	0,115	4,06	3,63	400	0,075	1300
100	3,0	0,4	125	0,83	0,48	0,027	0,94	0,089	3,82	3,42	350	0,055	1300

9.3. Walking up an inclined plane

A person weighing 65 kg goes with the speed of 2,5 m/h along an inclined plane with varying parameters (Table 12):

It is necessary to calculate the external mechanical work performed by the human body taking into account the load in 1 minute. The weight of clothes and shoes is neglected. The length of the legs is 0,94 m, the length of the arms is 0,76 m. The relative weight of individual links of the human body is set forth in the task “Walking without load”.

Table 12

№	α, grad	υ, m/min	υ, m/s	Q, kg	Location of load	l_{step}, m
1	10	7,24	0,12	–	on the back	0,6
2	10	7,24	0,12	20	same	0,6
3	10	7,24	0,12	50	– " –	0,4
4	16	11,50	0,20	–	– " –	0,4
5	16	11,50	0,20	20	– " –	0,4
6	16	11,50	0,20	50	– " –	0,3
7	25	17,50	0,30	–	– " –	0,3
8	25	17,50	0,30	20	– " –	0,3
9	25	17,50	0,30	50	– " –	0,3

When analyzing the motion by one step, the following fixed states can be distinguished:

- initial position with legs spaced by the length of the step;
- leg straightening, which is in front and bent at the knee, with simultaneous body lifting by the value of the leg straightening;
- leg movement, which was in the initial position at the back of the body by the step value;
- swinging of the arms relative to the body;
- moving the center of gravity of the body horizontally according to the length of one step.

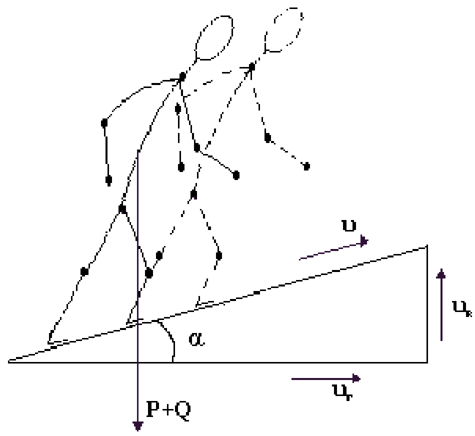


Fig.11. Scheme of walking up an inclined plane

1. Work of the body lifting: A_1=Ph and A_1=(P+Q)h, where P – weight of the body+head+arms+one arm; P=65–(65·0,15)=53 kg; Q – load weight, kg; h – value of the body lift, depending on the angle of surface inclination (α) and the step length (l_{step}). In addition, the human body when walking up is going by some additional height by the excess value of the gravity center from the usual initial position with legs set apart by the step length, i.e., $h=\Delta h_1+\Delta h_2$; $\Delta h_1=l_{step}\cdot$ $\cdot\sin\alpha$; Δh_2 take 0,02 m, then $h=l_{step}\cdot\sin\alpha+0{,}02$.

2. Work of moving the leg to the step length with sufficient accuracy for practice is determined by the pendulum swinging formula:

$$A_2=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2,$$

where m – weight of the leg, 1,23 kg·s^2/m; φ_l – angle of the leg swinging, rad; c_l – distance from the swinging axis of the leg to the gravity center of the leg, m; t_1 – time of the leg movement by 1 step, s.

3. Work done with the swinging of two arms:

$$A_2=m_a\left(\frac{\varphi_a c_a}{t_1}\right)^2,$$

where m_a – arm weight, 0,4 kg·s^2/m; φ_a – angle of the arm swinging when moving the body by 1 step, rad; c_a – distance from the axis of the arm swing to its center of gravity, m; t_1 – time of the arm movement when moving the body by 1 step, s.

4. Work of translational movement of the body center of gravity horizontally

$$A_4=\frac{mv^2}{2},$$

where m – mass of the whole human body, taking into account the weight of the carried load, kg·s^2/m; v_h – horizontal component of the movement speed of the body gravity center along the inclined surface, m/s.

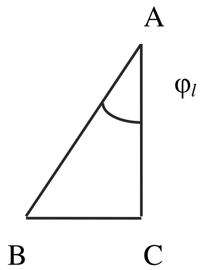
It should be noted that when the body moves from the initial position forward by 1 step, a slight lowering of the body from the extreme upper point takes place, which it has when moving. The lowering occurs as a result of bending the leg, thrown forward when moving by 1 step. When traveling on an inclined surface, the lowering of the body depends on the angle of surface inclination.

With an increase in the angle of inclination (α), the lowering value decreases with the increasing step length (l_{step}). However, the work done by the body with the load when lowering is very difficult to calculate. Therefore, its influence on the total result of the dynamic work is taken into account in the formula A_1 through the inclusion of the additional height Δh_2.

Table 13

Work of walking up the body with a load on an inclined surface

№	α, grad	l_{step}, m	sinα	h, m	P, kg	Q, kg	n, step/min	$A_1=(P+Q)hn$, kgm/min
1	10	0,6	0,174	0,124	53	–	70	460
2	10	0,6	0,174	0,124	53	20	70	635
3	10	0,4	0,174	0,090	53	50	100	930
4	16	0,4	0,274	0,129	53	–	100	680
5	16	0,4	0,274	0,129	53	20	100	940
6	16	0,3	0,274	0,102	53	50	140	1480
7	25	0,3	0,42	0,146	53	–	140	1080
8	25	0,3	0,42	0,146	53	20	140	1500
9	25	0,3	0,42	0,146	53	50	140	2100



Leg movement work:
AB=0,94 m; $BC=l_{\text{step}}/2$;
$\sin\varphi_l=BC/AB=l_{\text{step}}/2\cdot 0{,}94$;
$2\varphi_l$=grad/57°171 rad;
C_l=0,42 m.

Table 14

Work done when swinging the arms

№	l_{step}, m	m_n, kg·s²/m	φ_n, rad	t_1, s	n, step/min	$A_2=\frac{m_l}{2}\left(\frac{\varphi_l c_l}{t_1}\right)^2$, kgm/min
1	0,6	1,23	0,65	0,85	70	8
2	0,4	1,23	0,44	0,60	100	7
3	0,3	1,23	0,31	0,42	140	8

In view of its insignificant influence, it can be taken from the previously performed calculations – 5 kgm/min.

Table 15

Work of lowering the body with a load

№	P_k, kg	P_g, kg	m_k, kg·s²/m	m_k, kg·s²/m	t_1, s	h_k, m	a, m/s	n, step/min	$A_4=(P_k+P_g-m_k \cdot a-m_g a)h_k n$, kgm/min
1	41	–	4,20	–	0,85	0,05	0,47	70	137
2	41	20	4,20	2,04	0,85	0,05	0,47	70	200
3	41	50	4,20	5,10	0,60	0,05	0,67	100	420
4	41	–	4,20	–	0,60	0,05	0,67	100	190
5	41	20	4,20	2,04	0,60	0,05	0,67	100	290
6	41	50	4,20	5,10	0,42	0,05	0,95	140	580
7	41	–	4,20	–	0,42	0,05	0,95	140	260
8	41	20	4,20	2,04	0,42	0,05	0,95	140	390
9	41	50	4,20	5,10	0,42	0,05	0,95	140	365

Table 16

Work of horizontal translational movement

№	α, grad	cosα	υ, m/s	υ cosα	m, kg·s²/m	$A_4=\frac{m(\upsilon\cos\alpha)^2}{2}\cdot 60$, kgm/min
1	10	0,980	0,7	0,68	6,62	90
2	10	0,980	0,7	0,68	8,62	120
3	10	0,980	0,7	0,68	11,70	160
4	16	0,958	0,7	0,66	6,62	85
5	16	0,958	0,7	0,66	8,62	110
6	16	0,958	0,7	0,66	11,70	152
7	25	0,904	0,7	0,63	6,62	80
8	25	0,904	0,7	0,63	8,62	105
9	25	0,904	0,7	0,63	11,70	140

Table 17

Overall total work

№	α, grad	Q, kg	A_1	A_2	A_3	A_4	A_{total}, kgm/min
1	10	–	460	6	5	90	560
2	10	20	635	6	5	120	760
3	10	50	930	7	5	160	1100
4	16	–	680	7	5	85	780
5	16	20	940	7	5	110	1060
6	16	50	1480	8	5	152	1650
7	25	–	1080	8	5	80	1180
8	25	20	1500	8	5	105	1620
9	25	50	2100	8	5	140	2250

9.4. Climbing the stairs

A person weighing 65 kg climbs the stairs with a slope of 30,5°, the width of the steps – 29 cm, and the height – 17,2 cm. The climbing speed – 100 steps per minute or 17,2 m/min=0,28 m/s. The load is suspended from the belt side (on both sides).

The following cases are considered:

1) climbing without load;

2) climbing with the load of 20 kg;

3) climbing with the load of 50 kg.

The movement of the human body can be recorded in the following states:

1) initial position;

2) lifting one leg vertically upward by $h+\Delta h$,

where h – height of one step, Δh – elevation of the leg above the step height;

3) horizontal movement of the leg;

4) body lifting of a person and the second leg to the height of the step;

5) moving the body and the second leg horizontally;

6) initial position;

7) vibrational movement of the arm by 1 step.

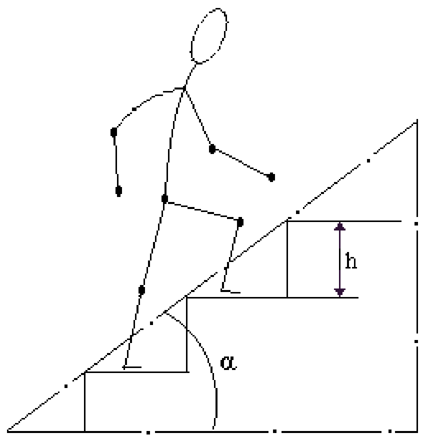


Fig.12. Scheme of climbing the stairs

Then all the movements are repeated with each step.

The components of the overall work are added up:

1. Work of the leg lifting:

$$A_1=P_l\cdot(h+\Delta h)\cdot n,$$

where P_l – weight of the leg, kg; n – number of steps on the stairs per minute.

2. Work of moving the body and the second leg in horizontal plane:

$$A_2 = \frac{m\ \upsilon^2}{2}\cdot 60,$$

where m_p – mass of 2 people; υ – speed of horizontal movement, m/s.

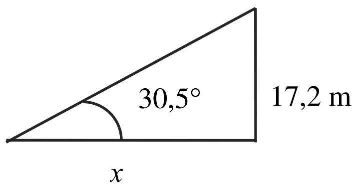
3. Work of lifting the body and the second leg to the height of the step:

$$A_3=(P_k+P_l)hn.$$

4. Work of lowering the leg by value Δh.

5. Swing motion of the arms can be neglected as a small value.

Climbing without load. The speed of horizontal movement of the body can be calculated according to the scheme:



$$x=\frac{17{,}2}{\mathrm{tg}30{,}5^{\circ}}=\frac{17{,}2}{0{,}58}=29\ \text{m};$$

$$\upsilon=\frac{29}{60}=0{,}48\ \text{m/s};$$

$$\upsilon^2=0{,}23\ \text{m}^2/\text{s}^2.$$

The time for lowering the leg by the value of Δh is taken as 0,05 s, based on the following considerations. The climbing time by 1 step is $\frac{60}{100}$ steps=0,6 s. The climbing is split into 6 states, therefore, assuming the uniform time distribution for all states, the time per 1 state will be $\frac{0{,}6}{6}$=0,1 s. Lowering the leg by Δh is only the part of lifting one leg by value $h+\Delta h$, so the time to lower the leg by Δh can be taken to be greater than half the time by 1 state, i.e., t=0,07 s or t^2=0,0049 s^2. We take Δh=0,03 m on the basis of experimental observations. The acceleration of lowering will be

$$a=\frac{\Delta h}{t^2}=\frac{0{,}03}{0{,}005}=6\ \frac{\text{m}}{\text{s}^2}.$$

$A_1=P_l(h+\Delta h)n$=12,12(0,172+0,03)100=245 kgm/min.

$A_2=\frac{m_g\upsilon^2}{2}\cdot 60$=6,62/2·0,23·60=46 kgm/min.

$A_3=(P_k+P_l)hn$=52,88·0,172·100=909 kgm/min.

$A_4=(P_l-m_la)\Delta hn$=(10,12–1,23·6)·0,03·100=20 kgm/min.

A_{total}=245+909+46+20=1220 kgm/min.

Climbing with load P_g=20 kg.

$A_1=P_l(h+\Delta h)n$=12,12 (0,172+0,03)100=245 kgm/min.

$A_2=\frac{(m_g+m_g)\upsilon^2}{2}\cdot 60$=8,65/2·0,23·60=60 kgm/min.

$A_3=(P_k+P_l+P_g)hn$=72,88·0,172·100=1250 kgm/min.

$A_4=(P_l-m_la)\Delta hn$=(10,12–1,23·6)·0,03·100=20 kgm/min.

A_{total}=245+60+1250+20=1575 kgm/min.

Climbing with load P_g=50 kg.

$A_1=P_l(h+\Delta h)n$=12,12(0,172+0,03)100=245 kgm/min.

$A_2=\frac{(m_g+m_g)\upsilon^2}{2}\cdot 60$=11,73/2·0,23·60=81 kgm/min.

$A_3=(P_k+P_l+P_g)hn$=102,88·0,172·100=1770 kgm/min.

$A_4=(P_l-m_l\cdot a)\Delta hn$=(12,12–1,23·5,54)·0,03·100=16 kgm/min.

A_{total}=245+81+1770+16=2111 kgm/min.

Climbing the ladder.

A person weighing 65 kg climbs the stairs with the distance between steps of 0,17 m with the climbing speed of 70 steps per minute with the following parameters (Table 18)

Table 18

No	Climbing type	Ladder angle, grad	Climbing speed, m/min	Losses of internal energy, kcal/min
1	Without load	50	9,12	6,6
2	With the load of 20 kg	50	9,12	8,4
3	With the load of 50 kg	50	9,12	13,2
4	Without load	70	11,12	8,00
5	With the load of 20 kg	70	11,12	10,2
6	With the load of 50 kg	70	11,12	16,0
7	Without load	90	11,90	10,4
8	With the load of 20 kg	90	11,90	13,5
9	With the load of 50 kg	90	11,90	24,3

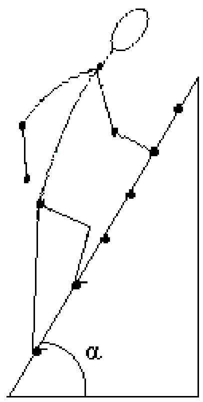


Fig.13. Scheme of climbing the ladder

The components of the overall work:

1. Work of lifting one arm and foot to the height of one step per minute (A_1);
2. Work of lowering the arm and leg by the value exceeding the height of the 1st Δh (A_2);
3. Body lifting by the height of one step (A_3);
4. Work of moving the body horizontally (A_4);
5. Total work (A_{total}).

$$A_1=[(P_l+P_a)(h\sin\alpha+\Delta h)]n ,$$

where P_l – weight of one leg, kg; P_a – weight of one arm, kg; h – height of one step, m; α – angle of the ladder inclination; Δh – height of one step, m; n – speed of climbing, steps per minute.

$$A_2=[(P_l+P_a)-(m_l+m_a)]\Delta hn ,$$

where m_l – leg weight, kg·s^2/m; m_a – arm weight, kg·s^2/m; a – acceleration of the arm and leg fall.

$$A_3 = P_k\, h \sin\alpha\, n,$$

where P_k – weight of the body, arm and legs combined, kg.

$$\grave{A}_4 = \frac{m_p \upsilon^2}{2} \cdot 60,$$

where m_p – weight of the human body, kg·s^2/m; υ – speed of horizontal movement, m/s.

$$A_{total} = A_1 + A_2 + A_3 + A_4 .$$

In cases of climbing with a load, the weight and mass of the load are added to formulas A_3 and A_4.

Constant values:

- arm weight P_a=3,76 kg;
- arm mass m_a=0,39 kg
- leg weight P_l=1212 kg;
- leg mass m_l=123 kg·s^2/m;
- Δh is taken based on the observations Δh=0,03 m;
- step height h=0,17 m;
- number of steps n=70;
- time of climbing by 1 step – 0,86 s;
- climbing and lowering time by the value Δh is taken equaling to 0,2 s;
- acceleration of the body fall by Δh

$$a = \frac{2\upsilon_v}{t},$$

where υ_v – vertical climbing speed is taken from the task setting;

- mass of the human body m_p=6,62 kg·s^2/m;
- weight of the body+legs+hands P_k=49,12 kg.

The results of the calculations are summarized in Table 19.

Table 19

The results of calculating the work performed while climbing the ladder

№	Type of climbing	α, grad	υ_v, m/s	a, m/s^2	sinα	Work, kgm/min				
						A_1	A_2	A_3	A_4	A_{total}
1	Without load	50	0,126	1,5	0,765	178	28	447	3,10	656
2	With the load of 20 kg	50	0,126	1,5	0,765	178	28	627	4,00	938
3	With the load of 50 kg	50	0,126	1,5	0,765	178	28	923	6,00	1213
4	Without load	70	0,07	2,3	0,937	211	26	550	1,00	788
5	With the load of 20 kg	70	0,07	2,3	0,937	211	26	774	1,30	1012
6	With the load of 50 kg	70	0,07	2,3	0,937	211	26	1110	1,76	1348
7	Without load	90	–	2,7	1,00	222	24	584	–	831
8	With the load of 20 kg	90	–	2,7	1,00	222	24	822	–	1069
9	With the load of 50 kg	90	–	2,7	1,00	222	24	1178	–	1425

9.5. Pushing and pulling trolley with load

1. A person weighing 65 kg pushes a trolley with load along the flat solid road with the handle height of 100 cm with a pushing force of 11,6 kg and 16,1 kg. It is necessary to find the mechanical work done by the system “person–trolley” in 1 minute at the speed of 3,6 km/h.

2. A person weighing 65 kg pulls a trolley with load having the handle height of 100 cm with the traction force of 11,6 kg and 16,1 kg. It is necessary to find the work done by the system “person-trolley” in 1 minute at the speed of 3,6 km/h.

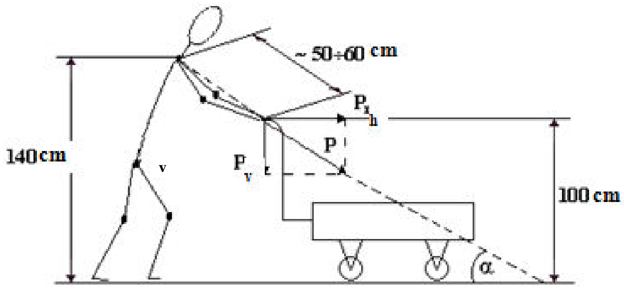


Fig.14. Scheme of pushing the trolley with load

Horizontal force P_h=Pcosα; where sinα=(140–100)/60=0,66; α=42°≈45°.

a) P_g=11,6·0,7=81 kg,

b) P_g=16,1·0,7=11,3 kg.

The total work can be represented as the sum of the work done by the trolley when it moves and the human body while walking at the speed of 3,6 km/h:

$$A_{total}=A_t+A_p,$$

where A_t – trolley work; A_p – work of the human body.

$$A_t=P_g\,S,$$

where P_g – horizontal component of the pushing force, kg; S – path traversed by the trolley in 1 min.

a) A_t=8,1·3600/60=485 kgm/min;

b) A_t=11,3·3600/60=680 kgm/min.

The work done by the human body in 1 minute while walking at the speed of 3,6 km/h, based on previously solved problems is A_p=570 kgm/min.

The total work:

a) A_{total}=485+570=1055 kgm/min;

b) A_{total}=680+570=1250 kgm/min.

Horizontal force P_g=Pcosα; where sinα=(140–100)/55=0,72; α≈45°.

a) P_g=11,6·0,7=81 kg,

b) P_g=16,1·0,7=11,3 kg.

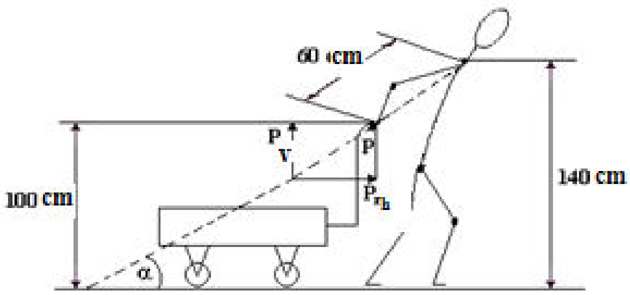


Fig.15. Scheme of pulling a trolley with load

Thus, during pushing and pulling the conditions of dynamic work are the same and the total work at pushing equals the total work of pulling, i.e.

a) A_{total}=1055 kgm/min;

b) A_{total}=1250 kgm/min.

9.6. Working with a hammer

A man weighing 65 kg, 170 cm high, produces with full force two-handed hammer hits at the rate of 15 beats per minute with the following changing parameters:

Table 20

No	Type of hit	Hammer weight, kg	Energy costs, kcal/min	Notes
1	From above	4,4	7,3	
2	Circular	4,4	6,7	
3	From above	10,6	8,2	
4	Circular	10,6	7,3	

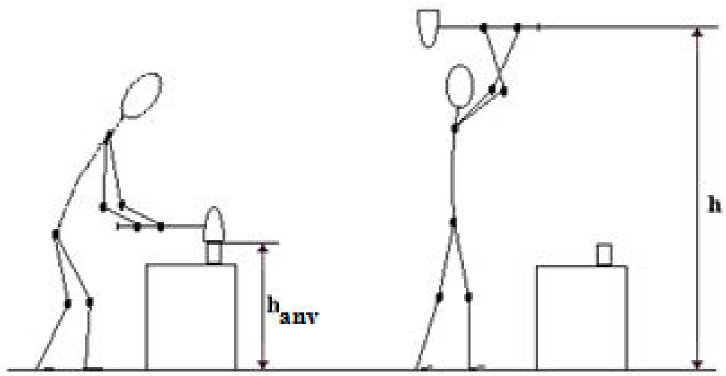


Fig.16. Scheme of working with a hammer

Let us set the following additional parameters:

• work is performed on an anvil with the height of h_{anv}=0,5 m;

• length of the hammer handle l_h=0,4 m;

• delay time of the hammer on the anvil between two successive hits will be 0,8 s;

• hammer lifting height from the ground h=2,0 m.

In the movement of the human body and hammer the following fixed states can be noted:

1. initial position – a man stands with his legs apart, a hammer is in his h a n d ;

2. hammer is raised above the head;

3. hammer is on the anvil, the legs are bent at the knees.

The total work done by the system “person-hammer” is determined by the formula

$$A_1=(P_a+P_h)(h-h_{anv})\, n\ ,$$

where P_a – arm weight, P_a=7,5 kg; h – hammer lifting height from the ground; h_{anv} – height of the anvil; P_h – hammer weight.

The work of lifting body+head+hand+hammer by the value of straightening the legs and body:

$$A_2=(P_t+P_h)\, h_1 n\ ,$$

where P_t – weight of body+head+hand, P_t=41 kg; h_1 – lifting height approximately (based on measurements) 0,15 m; n – number of hits per minute.

The work of lowering the hammer from the upper position to the anvil is accomplished with the acceleration greater than the acceleration of gravity:

$$A_3=(m_a+m_h)\, a'\, (h-h_{anv})\, n\ ,$$

where m_a – arm weight; m_h – hammer weight; a' – acceleration of hammer fall exceeding the acceleration of gravity; h – hammer lifting height; h_{anv} – anvil height; n – number of hits per minute.

$$a'=a-g\ ,$$

where a – general acceleration developed by the falling hammer and arms; g – 9,8 m/s^2.

If the hammer is given a free fall, then it will fall to the height of 1,5 m in time $t=\sqrt{\dfrac{2h}{g}}=\sqrt{\dfrac{2\cdot 1{,}5}{9{,}8}}=0{,}6$ s.

Let us assume that with the hammer weight of 4,4 kg and speed of 15 hits per minute, the time to lower the hammer will be 0,4 s. Then

$$a=\frac{2h}{t^2}=\frac{2\cdot 1{,}5}{0{,}4^2}=18{,}7\ \text{m/s}^2\ .$$

The work of braking the falling body

$$A_4=(P_b-m_b\cdot a)(h-h_h)n\ ,$$

where P_b – weight of the body, P_b=29 kg; m_b – mass of the body, m_b=3,0 kg·s^2/m; a – deceleration acceleration, which can be calculated by assuming the deceleration time t=0,8+0,3≈1,0 s.

$$a=\frac{2(h-h_h)}{t^2}=\frac{2\cdot 1{,}5}{0{,}4^2}=3\ \text{m/s}^2\ .$$

Total work $A_{total}=A_1+A_2+A_3+A_4$.

The hit is from above, the hammer weight is 4,4 kg.

$A_1=(P_a+P_h)(h-h_{anv})\ n=11{,}9\cdot1{,}5\cdot15=270$ kgm/min.

$A_2=(P_a+P_h)\ h_1 n=(41+4{,}4)\cdot1{,}5\cdot15=100$ kgm/min.

$A_3=(m_a+m_h)\ a'\ (h-h_l)n=1{,}2\cdot(18{,}8-9{,}8)\cdot1{,}5\cdot15=250$ kgm/min.

$A_4=(P_b-m_b\cdot a)(h-h_h)n=(29-3{,}0\cdot3)\cdot1{,}5\cdot15=450$ kgm/min.

$A_{total}=270+100+250+450=1070$ kgm/min.

The hit is from above, the hammer weight – 10,6 kg.

The greater the weight of the hammer, the less acceleration a person can give to it when lowering from the upper position to the anvil. Let us take for this case the time for lowering the hammer equaling to 0,45 s;

$$a = \frac{2h}{t^2} = \frac{2\cdot1{,}5}{0{,}45^2} = 15\,\text{m/s}^2;$$

$$a'=a-g=15-9{,}8=5{,}2\ \text{m/s}^2.$$

$A_1=(P_a+P_h)(h-h_{anv})n=(7{,}5+10{,}6)(2-0{,}5)\cdot15=400$ kgm/min.

$A_2=(P_b+P_h)h_1\ n=(41+10{,}6)\cdot0{,}15\cdot15=117$ kgm/min.

$A_3=(m_a+m_h)\cdot a'\cdot(h-h_{anv})\cdot n=1{,}85\cdot5{,}2\cdot1{,}5\cdot15=220$ kgm/min.

$A_4=(P_b-m_b\cdot a)\cdot(h-h_h)\cdot n=(29-3{,}0\cdot3)\cdot1{,}5\cdot15=450$ kgm/min.

$A_{total}=400+117+220+450=1187$ kgm/min.

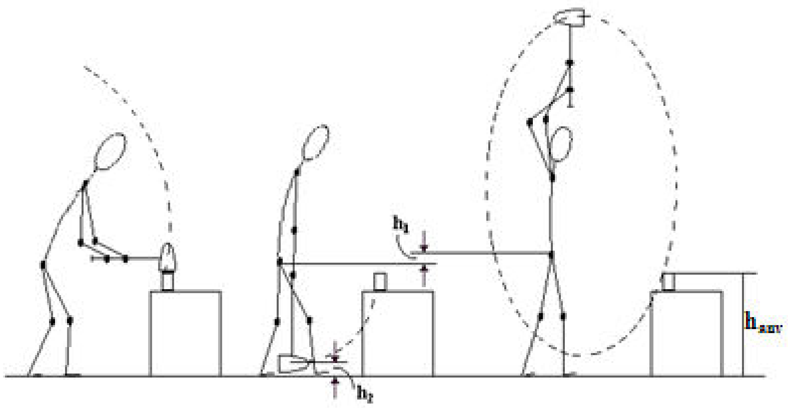


Fig.17. Scheme of work with a hammer in a circular way

The circular hit has some differences from the above hit. Let us assume that the hit force on the anvil in both cases is the same. The hammer height above the head h=20 m, lifting and lowering of the body h_{anv}=0,5 m. However, it is known from practice that a person makes circular hits easier. The same is evident from the initial conditions, since the losses of internal energy in circular impacts are less. A person would always use circular hits if their accuracy were ensured. The hit from the top is more precise, but it is also more strained for the muscles because of the large static loads when the hammer is fixed in the upper position and when the inertia force of rest at the beginning of lowering is overcome. In the case of circular hits, the hammer is not fixed in the upper position and the inertia force of the free fall of the hammer from the anvil to the lowest position h_2 is used to overcome the inertia forces of rest. Some increase in the hammer lifting height can be neglected when the total work of the system "human-hammer" will equal the mechanical work when hitting from above:

P_h=4,4 kg A_{total}=1000 kgm/min

P_h=10,6 kg A_{total}=1180 kgm/min.

9.7. Filing of iron

Unfortunately, in the description of this activity, G. Lehmann [22] did not give data about the file. The number of file movements is only indicated. We will take the coarse file with the cut angle of 30°. Based on the survey of experienced locksmiths (5 people), it turned out that the force applied to the file is, in the average, 14 kg. This coincides with the data given by S.A. Kosilov [20]. The components of the total work:

1. Work on overcoming the resistance force of metal

$$A_1=Ps,$$

where P – resistance force, kg; s – way to overcome the resistance of the force P;

2. Work of moving the body and arms (kinetic energy of moving the body and arms), which can be calculated with sufficient accuracy

$$A_2 = \frac{m\upsilon^2}{2} \cdot 60$$

where m – mass of the body+hands+file.

The weight of the file P_f=0,5 kg.

The weight of the arms P_a=3,76·2=7,52 kg.

The weight of the body P_b=33 kg.

$$m=(0,5+7,52+33)/9,8=4,2 \text{ kg·s}^2/\text{m}.$$

The speed of moving the body in the forward and backward directions is taken to be $\upsilon = \frac{s}{t}$ for s=0,3 m (based on observations).

The time t can be determined from the specified conditions (42, 60, 80 movements of file per minute):

t_1=60/42·2=0,71 s;

t_2=60/60·2=0,5 s;

t_3=60/80·2=0,37 s.

Then

$$\upsilon_1 = \frac{s}{t_1} = \frac{0,3}{0,71} = 0,42 \text{ m/s};$$

$$\upsilon_2 = \frac{s}{t_2} = \frac{0,3}{0,5} = 0,6 \text{ m/s};$$

$$\upsilon_3 = \frac{s}{t_3} = \frac{0,3}{0,37} = 0,8 \text{ m/s};$$

Table 21

The results of calculating the work performed during filing

№	Number of movements per minute	Energy losses, kcal/min	A_1, kgm/min	A_2, kgm/min	A_{total}, kgm/min
1	42	2,0	176	20	200
2	60	2,5	250	45	300
3	80	4,2	335	80	415

9.8. Working with a shovel

A man weighing 65 kg throws sand with a shovel with 8 kg of sand loaded onto it in one throw. It is necessary to determine the amount of mechanical work done by the system "man-shovel-sand" per cycle of one throw and per 1 minute of work with the following changing parameters:

1. Length of throw is 1 m:
a) throw height is 0,5 m, 15 throws per minute;
b) throw height is 1,0 m, 12 throws per minute;
c) throw height is 1,5 m, 12 throws per minute;
d) throw height is 2,0 m, 12 throws per minute.

2. Length of throw is 2 m:
a) throw height is 0,5 m, 12 throws per minute;
b) throw height is 1,0 m, 10 throws per minute;
c) throw height is 1,5 m, 10 throws per minute;
d) throw height is 2,0 m, 10 throws per minute.

3. Length of throw is 3 m:
a) throw height is 1,0 m, 10 throws per minute;
b) throw height is 1,5 m, 10 throws per minute;
d) throw height is 2,0 m, 10 throws per minute.

We require the following additional conditions:
a) weight of clothing is neglected;
b) length of a person's legs is 0,9 m;
c) length of a person's arms is 0,7 m;
d) step length in the position with the legs apart is 0,6 m;
e) shovel weight is 2 kg;
f) loose sand with porosity above 40%, with specific resistance coefficient of pressure of 2 kg/cm^2;
g) in determining the kinetic energy of throwing sand in order to simplify the calculations, we will use the laws of swinging the mathematical pendulum and the laws of motion of a body thrown up at an angle to the horizon.

In the movements of the human body, shovel and sand as a mechanical system, the following fixed states can be distinguished:

1. Initial position – legs and arms are placed at the length of the step, approximately. The shovel is in hands.

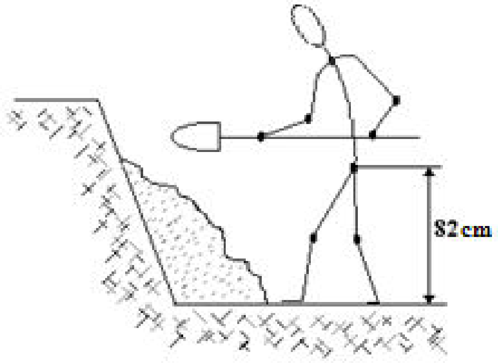


Fig.18. Scheme (position 1)

2. Position with bent knees, the body is perpendicular to the horizon. The body lowers from its initial position by 20 cm.

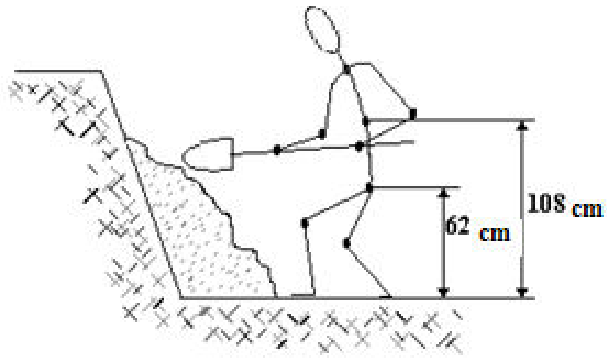


Fig.19. Scheme (position 2)

3. Position with bent knees and lowered body. The hands with the shovel are laid back 90 cm from the surface of the sand pile.

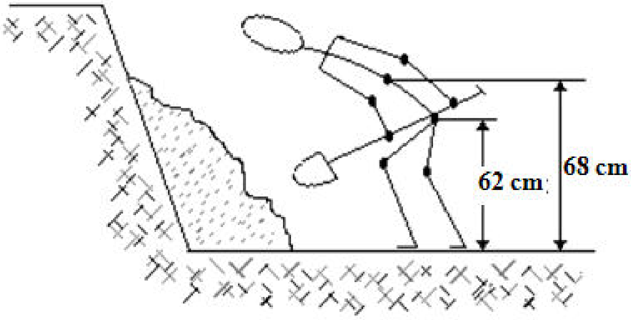


Fig.20. Scheme (position 3)

4. Position with bent knees and lowered body. The hands with the shovel are advanced forward by 70 cm from position 3. The shovel is stuck in the sand for 30 cm.

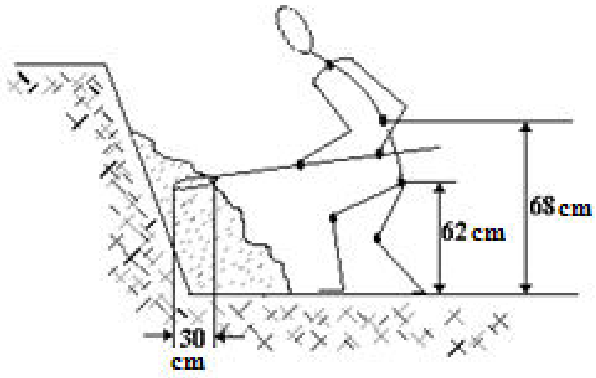


Fig.21. Scheme (position 4)

5. Position with knees straightened and lowered body. The shovel is stuck in the sand, the position of the hands corresponds to position 3.

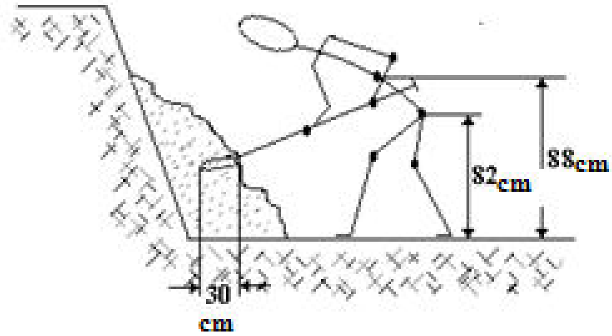


Fig.22. Scheme (position 5)

6. The person stands with the straightened body. The position corresponds to the initial one with the shovel loaded with sand. When moving from position 5 to position 6, the work is done on the body lifting (sand throwing) and shovels with sand.

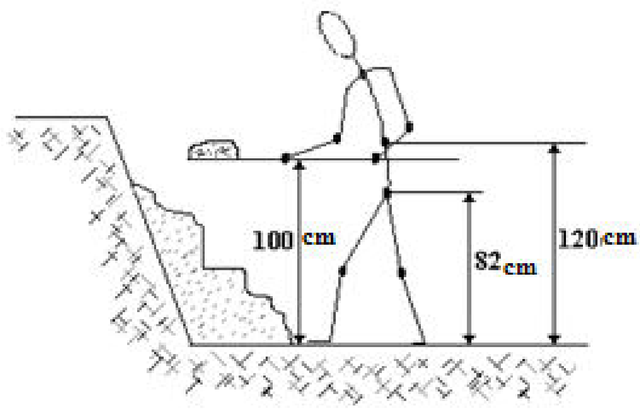


Fig.23. Scheme (position 6)

7. The ready position for throwing the sand. The hands with the loaded shovel are retracted 40 cm from position 6.

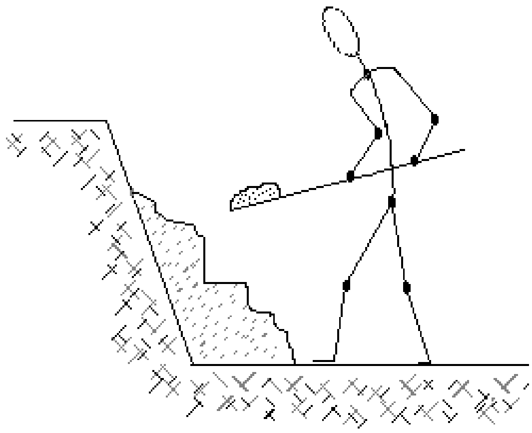


Fig.24. Scheme

8. The sand throwing. The hands with sand-loaded shovel are moved forward. The minimum distance – 40 cm, the maximum distance – 125 cm, depending on the height and length of the sand throw. The throwing is made at the angle of 45° to the horizon.

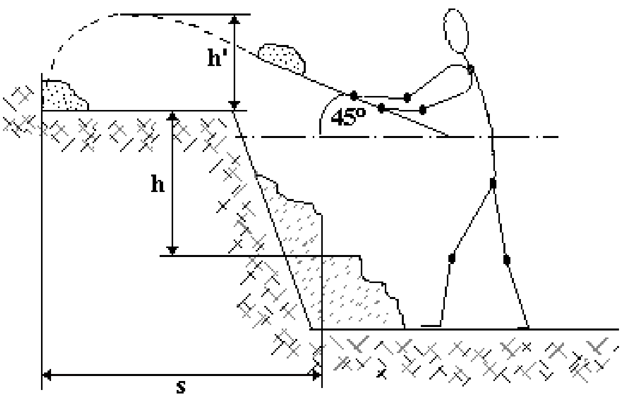


Fig.25. Scheme

9. Return to the initial position. The sand is thrown off the shovel. The hands with the shovel return to the initial position for the next cycle.

The time for the work cycle of sand throwing of 1 shovel:

a) at 15 throws per minute – 4 s;

b) at 12 throws per minute – 5 s;

c) at 10 throws per minute – 6 s.

The transition from position 2 to position 3 occurs simultaneously with the transition from position 1 to position 2. Actions 3 and 4 can be considered as one action with two phases: the transition from position 3 to position 4 and then from position 4 to position 5. Then action 6 takes place combined with action 7, the subsequent action 8 – sand throwing and 9 – return to the initial position. For the sake of some simplification of calculations, the duration of all actions is the same, that is $t_{1,2,3}=t_4=t_5=t_6=t_7=t_8=t_9$.

Thus, it is expedient for the calculations to identify 7 actions. In addition, out of the total time for the throw cycle of 1 sand shovel, it is necessary to distinguish the delay time of the shovel in the sand pile, approximately 0,8 s. The average time per action will be:

a) at 15 throws per minute $\frac{4-0{,}8}{7}=0{,}46$ s;

b) at 12 throws per minute $\frac{5-0{,}8}{7}=0{,}6$ s;

c) at 10 throws per minute $\frac{6-0{,}8}{7}=0{,}74$ s.

The work of transition from the initial position to the position with bent knees:

$$A_1=(P_b+P_{sh}-m_b a_1)\Delta h \text{ kgm/throw},$$

where P_b – body weight (41 kg); P_{sh} – shovel weight (2 kg); $m_b=\frac{m_b+m_{sh}}{9{,}8}=\frac{43}{9{,}8}=4{,}4$ kg·s^2/m – mass of the body and shovel; a_1 – acceleration of braking when the body is lowered from position 1 to position 2; $a_1=\frac{23}{t^2}=\frac{2\cdot 0{,}2}{0{,}46^2}=1{,}9$ m/s^2;

$s=\Delta h=0{,}2$ m;

$A_1=(43-4{,}4\cdot 1{,}9)\cdot 0{,}2=7$ kgm/throw.

This amount of work will be the same for all variations of the number of throws, length and height of the throw.

The work of lowering the body when it is bent in position 3:

$A_2=(P_b+P_{sh}-m_b a_1)\,\Delta h_1$;

$\Delta h_1=108-68=40$ cm;

$A_2=(43-4{,}4\cdot 1{,}9)\cdot 0{,}4=14$ kgm/throw.

The work of hands with the shovel, while drawing them back in position 3, can be neglected as the value that does not significantly affect the overall amount of work. The value of A_2 can also be taken to be the same for all variations.

The work done by the arm with the shovel when putting it into the sand pile,

$$A_3=\frac{m_a \upsilon^2}{2}+qFsn,$$

where m_a – mass of the arm and shovel, kg·s^2/m; υ – speed of the arm movement with the shovel m/s; q – specific resistance to pressure in sand with the porosity of up to 40% – 2 kg/cm^2 (Smirnov. Calculation of the foundation base); F – cross-section of the shovel, 4 cm^2; n – number of throws per minute; s – length of the shovel, m.

$$\upsilon=s/t=1/0{,}5=2 \text{ m/s}.$$

For n=15 throws

$$A_3=9{,}5\cdot2^2\cdot\frac{60}{2}\cdot9{,}8+2\cdot4\cdot0{,}3\cdot15=160 \text{ kgm/min}.$$

For n=12 throws

$$A_3=9{,}5\cdot2^2\cdot\frac{60}{2}\cdot9{,}8+2\cdot4\cdot0{,}3\cdot12=150 \text{ kgm/min}.$$

For n=10 throws

$$A_3=9{,}5\cdot2^2\cdot\frac{60}{2}\cdot9{,}8+2\cdot4\cdot0{,}3\cdot10=144 \text{ kgm/min}.$$

The work done when lifting the body+hands+shovel with sand by 0,6 m when moving from position 4 to position 6,

$$A_4=(P_b+P_{sh}+P_s)\ \Delta h_2\,;$$

where P_b – body+hands weight (41 kg); P_{sh} – shovel weight (2 kg); P_s – sand weight (8 kg);

Δh_2 – lifting height (0,6 m).

A_4=(41+2+8)·0,6=30 kgm/throw.

The work done with the removal of hands+shovels with sand at the distance of 0,4 m,

$$A_5=\frac{(m_a+m_{sh})\upsilon^2}{2}\cdot60,$$

where m_a – arm weight, kg·s^2/m; m_{sh} – weight of shovel with sand, kg·s^2/m; υ – arm pull speed with shovel; $\upsilon=\frac{s}{t}=0{,}4/0{,}5=0{,}8$ m/s.

$$A_5=[(7{,}5+10)\cdot0{,}8^2/2\cdot9{,}8]\cdot60=35 \text{ kgm/min}.$$

To throw the sand by length s and height h, it is necessary to initiate create such initial speed for the sand at which the kinetic energy could move sand in the air by length s. According to the laws of body motion thrown up at an angle without air resistance, you can determine:

a) distance of flight $s=\dfrac{\sin 2\alpha\cdot\upsilon_0^2}{g}$;

the maximum value of s will be at α=45°;

b) altitude of flight $h=\dfrac{\sin^2\alpha\cdot\upsilon_0^2}{2g}$;

c) free fall work $A_P=P\,h$;

d) work of translational motion with constant speed $A_G=\dfrac{mv^2}{2}$.

For s=1 m and α=45°

$\upsilon_0^2 = s\,g = 1{,}0 \cdot 9{,}81 = 9{,}81$ m²/s²;

$\upsilon_0 = 3{,}14$ m/s.

Therefore, in order for the sand to reach the distance of 1 m, it is necessary to reach the speed at a drop from the shovel of 3,14 m/s.

For s=2 m and α=45°

$\upsilon_0 = 4{,}44$ m/s.

For s=3 m and α=45°

$\upsilon_0 = 5{,}42$ m/s.

Additional lifting height: $h' = \dfrac{\sin^2\alpha \cdot \upsilon_0^2}{2g}$;

For s=1 m $\quad h' = \dfrac{0{,}49 \cdot 9{,}81}{2 \cdot 9{,}81} = 0{,}25$ m;

s=2 m $\quad h' = \dfrac{0{,}49 \cdot 19{,}62}{2 \cdot 9{,}81} = 0{,}49$ m;

s=3 m $\quad h' = \dfrac{0{,}49 \cdot 29{,}43}{2 \cdot 9{,}81} = 0{,}73$ m.

The work done with the movement of hands with a shovel loaded with sand can be determined from the condition that it (work) equals the work that free-moving sand makes after its discharge from the shovel. From here

$$A_6 = \frac{m_s \upsilon_0^2}{2} \cdot 60 + m_s\left(h' + h - 0{,}9\right)n \ ,$$

where m_s – mass of sand (0,82 kg·s²/m); υ_0 – initial speed of sand, depends on s and h; P_s – weight of sand, 8 kg; h' – additional height of the sand rise, depending on the distance of throwing; h – height of the sand throwing; 0,9 – height, in which the shovel with sand is in position 7; n – amount of throws per minute. The results of the reports are summarized in Table 22.

Table 22

The results of calculating the work done when working with a shovel

№	s, m	h, m	n, throws/min	h', m	υ_0^2, m²/s²	$\frac{m\upsilon_0^2}{2} \cdot 60$, kgm/min	$P_s = (h' + h - 0{,}9)n$, kgm/min	A_6, kgm/min
1	1,0	0,5	15	0,25	9,81	240	–	240
2	1,0	1,0	12	0,25	9,81	240	34	274
3	1,0	1,5	12	0,25	9,81	240	82	320
4	1,0	2,0	12	0,25	9,81	240	130	370
5	2,0	0,5	12	0,49	19,62	480	–	480
6	2,0	1,0	10	0,49	19,62	480	28	508
7	2,0	1,5	10	0,49	19,62	480	68	548
8	2,0	2,0	10	0,49	19,62	480	108	588
9	3,0	1,0	10	0,73	29,43	720	28	748
10	3,0	1,5	10	0,73	29,43	720	68	788
11	3,0	2,0	10	0,73	29,43	720	108	828

The work done by the falling arm with the empty shovel depends on its initial position in height. With sufficient accuracy for practice, we can calculate

$$A_7=(P_a+P_{sh}-m_{ash}\,a)\ \Delta hn\ ,$$

where P_a – arm weight (7,5 kg); P_{sh} – shovel weight (2 kg); a – acceleration of braking, depends on the number of throws per minute, therefore, can be calculated approximately from the formula $a=\frac{2\cdot\Delta h_3}{t^2}$;

t=0,46 s (for 15 throws);
t=0,60 s (for 12 throws);
t=0,74 s (for 10 throws).

Δh_3 – height of fall, m;

for h=0,5 Δh_3=0; a=0 m^2/s^2;
for h=1,0 Δh_3=0,01; a=0 m^2/s^2;
for h=1,5 Δh_3=0,6; a=3,5 m^2/s^2;
for h=2,0 Δh_3=1,0; a=4,0 m^2/s^2.

For h=0,5 m A_7=(9,5–0,97·0)·0=0.
For h=1,0 m A_7=0.
For h=1,5 m A_7=(9,5–0,97·3,5)·0,6=4,0 kgm/throw.
For h=2,0 m A_7=(9,5–0,97·4,0)·1,0=6,0 kgm/throw.

The results of the work done with throws are summarized in Table 23.

Table 23

The results of calculating the work done during throws

№	h, m	n, throws/min	a, m^2/s^2	Δh_3, m	A_7, kgm
1	0,5	15	–	–	–
2	1,0	12	–	0,1	12
3	1,5	12	3,5	0,6	48
4	2,0	12	4,0	1,0	72
5	0,5	12	–	–	–
6	1,0	10	–	0,1	9,5
7	1,5	10	3,5	0,6	40
8	2,0	10	4,0	1,0	60
9	1,0	10	–	0,1	9,5
10	1,5	10	3,5	0,6	40
11	2,0	10	4,0	1,0	60

Table 24

The summary table of the results of work calculations

№	*s*, m	*h*, m	*n*, throws/ min	A_1, kgm/ min	A_2 kgm/ min	A_3, kgm/ min	A_4, kgm/ min	A_5, kgm/ min	A_6, kgm/ min	A_7, kgm/ min	A_{total} kgm/ min
1	1	0,5	15	105	210	160	450	35	240	–	1200
2	1	1,0	12	84	170	150	360	35	274	12	1085
3	1	1,5	12	84	170	150	360	35	320	48	1170
4	1	2,0	12	84	170	150	360	35	370	72	1240
5	2	0,5	12	84	170	150	360	35	480	–	1280
6	2	1,0	10	70	140	144	300	35	508	9	1200
7	2	1,5	10	70	140	144	300	35	548	40	1280
8	2	2,0	10	70	140	144	300	35	588	60	1340
9	3	1,0	10	70	140	144	300	35	748	9	1450
10	3	1,5	10	70	140	144	300	35	788	40	1520
11	3	2,0	10	70	140	144	300	35	828	60	1580

The summary table 24 shows the results of calculating the shovel work, discussed in paragraph 9.8.

The performed calculations of the mechanical work done with different types of physical labor processes make it possible to compile a consolidated list of ergometric parameters (Table 25).

In the summary Table 25 the results of the calculation are brought into line with the International Metric System. The values of work done in various activities are given in joules. In addition, it presents the calculated data of the moments of force that arise during the performance of labor movements. The calculation of the moments of force is given in Chapter 10.

Table 25

Ergonomic parameters of work processes

Types of work	m, kg	υ, km/h	n, 1/ min	T_{tc}, s	Mechanical work per cycle, A, joules	Static moment per cycle, M, Nm·s	Energy consumption per cycle, E, kcal	Mechanical power, N_A, joules/min	Static power, N_M, Nm·s/min	Energy power, N_E, kcal/min
1	2	3	4	5	6	7	8	9	10	11
Walking without load	–	2	66	0,9	69,5	154	0,018	4590,9	10174	1,2
2.Same	–	4	94	0,6	238,0	129	0,022	22379,1	12136	2,1
3.Same	–	7	126	0,48	683,2	144	0,043	86086,0	18095	5,4
Walking with load 4. cargo on the back	10	4	94	0,6	302,8	167	0,038	33915,1	15679	3,6
5. cargo on the back	50	4	94	0,6	432,5	414	0,086	4887905	38950	8,1
Work with shovel 6. S=1 m h=0,5 m	–	–	15	4,0	785	1437	0,42	11772	21554	6,3
7. S=1 m h=1 m	–	–	12	5,0	887	1812	0,55	10644	21752	6,6
8. S=1 m h=1,5 m	–	–	12	5,0	956	1814	0,67	11478	21768	8,0
9. S=1 m h=2m	–	–	12	5,0	1014	1921	0,74	12164	23052	8,9
10. S=2m h=0,5 m	–	–	12	5,0	1046	1891	0,6	12557	22692	7,2
11. S=2 m h=1m	–	–	10	6,0	1177	2315	0,78	11772	23150	7,8
12. S=2 m h=1,5 m	–	–	10	6,0	1256	2344	0,9	12557	23440	9,0
13. S=2 m h=2m	–	–	10	6,0	1314	2248	1,0	13145	22480	10
14. S=3 m h=1m	–	–	10	6,0	1422	2290	0,88	14224	22900	8,8
15. S=3 m h=1,5 m	–	–	10	6,0	1491	2259	0,95	14911	22590	9,5
16. S=3 m h=2 m	–	–	10	6,0	1550	2167	1,04	15500	21670	10,4
17.Pushing the trolley	11,6	3,6	85	0,7	289,5	204	0,09	24611,4	17376	7,7
18.Same	16,1	3,6	85	0,7	311,3	228	0,12	26464,4	19402	10,6
19.Pulling the trolley	11,6	3,6	85	0,7	289,5	183	0,1	24611,4	15603	8,5
20.Same	16,1	3,6	85	0,7	311,3	207	0,13	26464,4	17629	10,9

Continuation of Table 25

Types of work	m, kg	υ, km/h	n, 1/min	T_{tc}, s	Mechanical work per cycle, A, joules	Static moment per cycle, M, Nm·s	Energy consumption per cycle, E, kcal	Mechanical power, N_A, joules/min	Static power, N_M, Nm·s/min	Energy power, N_E, kcal/min
1	2	3	4	5	6	7	8	9	10	11
Climbing up the inclined plane										
Incline 10°										
21. load	–	0,43	70	0,85	256,2	113	0,07	17935,8	7910	4,9
22. on	20	0,43	70	0,85	334,8	146	0,087	23439,8	10220	6,1
23. the back	50	0,43	100	0,6	269,3	277	0,092	26938,6	27700	9,2
Incline 25°										
24. cargo	–	1,05	140	0,43	131,1	119	0,095	18365,5	16660	13,3
25. on	20	1,05	140	0,43	171,3	258	0,12	23987,5	36120	17,2
26. the back	50	1,05	140	0,43	231,5	454	0,19	32420,2	63560	26,3
Climbing the stairs										
Incline 30,5°										
27. load	–	1,03	100	0,6	190,0	133	0,137	19001,8	13290	13,7
28.	20	1,03	100	0,6	237,2	185	0,184	23725,8	18540	18,4
29. on the side	50	1,03	100	0,6	308,1	278	0,263	30811,8	27770	26,3
Climbing the ladder										
Incline 50°										
30. load	–	0,55	70	0,85	121,7	238	0,09	8523,2	16677	6,6
31. on	20	0,55	70	0,85	148,1	366	0,12	10372,1	25620	8,4
32. the back	50	0,55	70	0,85	187,7	577	0,188	13145,4	40390	13,2
Incline 70°										
33. load	–	0,67	70	0,85	142,7	240	0,114	9992,8	16800	8,0
34. on	20	0,67	70	0,85	174,3	325	0,146	12203,9	22750	10,2
35. the back	50	0,67	70	0,85	221,7	453	0,23	15520,5	31710	16,0

End of Table 25

Types of work	m, kg	υ, km/h	n, 1/min	T_{tc}, s	Mechanical work per cycle, A, joules	Static moment per cycle, M, Nm·s	Energy consumption per cycle, E, kcal	Mechanical power, N_A, joules/min	Static power, N_M, Nm·s/min	Energy power, N_E, kcal/min
Incline 90° 36. load	–	0,71	70	0,85	149,9	400	0,15	10495,0	28000	10,4
37. on	20	0,71	70	0,85	183,2	585	0,19	12829,8	40950	13,5
38. the back	50	0,71	70	0,85	233,3	863	0,35	16332,0	60410	24,3
Working with a hammer 39. hit from above	4,4	–	15	4,0	700	1116	0,49	10497	16740	7,3
40. circular hit	4,4	–	15	4,0	654	1100	0,45	9810	16500	6,7
41. hit from above	10,6	–	15	4,0	776	1498	0,55	11644	22470	8,2
42. circular hit	10,6	–	15	4,0	772	1414	0,49	11576	21210	7,3
43. **Filing of iron**		–	42	1,4	46,7	242	0,05	2034	10148	2,0
44.Same		–	60	1,0	49	173	0,04	3338	10378	2,5
45.Same		–	80	0,75	50,9	124	0,05	5386	9902	4,2

Note. The calculation is made for a man weighing 65 kg 170 cm high.
$M \approx 154$ Nm·s/step; $A \approx 300$ Joules/step; $\upsilon = 4{,}5$ km/h

Chapter 10
Practical methods for determining the labor hardness at workplaces

10.1. Once again on the concept of "hardness" of labor process

By the present time, there has been no generally accepted point of view on the definition of the concept "labor "hardness", although several approaches to the disclosure of the content of this concept can be singled out.

Supporters of one of them understand the labor "hardness" as the energy costs of the human body in the labor process, quantitatively determining them as the difference between the total metabolic capacity of the organism and the basic metabolism [2, 22, 44]. In this case, the hardness is determined by the reaction not of the whole organism as one unit, but of the system of its energy exchange being changed under the influence of the load.

Other authors consider the hardness as the impact degree of the combination of the labor process factors on the human body, which manifests itself in the formation of three different functional states: normal, borderline and pathological [13, 37] . Moreover, each of these functional states is determined by a set of performance indicators of a number of organism systems (cardiorespiratory, central nervous system, musculoskeletal system and others). Here, I. M. Sechenov's effect is the criterion for classifying the labor process as a class of hardness or category of hardness, manifested in the rapid restoration of efficiency when switching to another kind of work. It should be borne in mind that ultimately all the authors imply the "hardness" of work as its physiological value for the human body, but in the first case, the leading indicators are selected indicators of energy exchange, in the second – a wider set of characteristics of the overall organism reaction to the load, arising during the labor process performance.

Supporters of the third approach suggest understanding the hardness in a narrower sense, implying the physical load formed during the work performance under this category. They emphasize the transformation of energy by the subject in the labor process, whereas, according to the authors, the information load characterizes the labor process complexity [25, 40, 59].

The most fruitful in this regard, in our opinion, is the point of view of Yu. S. Perevoshchikov [40]. He proceeds from the assumption that the labor subject (man) is an active, creative labor factor, while other factors are passive, they counteract man in the performance of particular work. Therefore, the labor subject strains his body to overcome the passive factors of the labor process. The higher the hardness of counteraction, the higher the level of strain of the human body.

Consequently, “strain is a concept attributed only to the subject of labor” [40, P.25]. At the same time, in the process of work performance, the human organism can be strained in two ways: on the one hand, the musculoskeletal system tends to overcome physical counteracting forces, on the other hand – the central nervous system for perceiving, processing information, developing an action program and transferring this program to executive organs. One kind of strain does not exist without the other one, because it is a common process of a unified system. However, for analysis (scientific only), it is expedient to dismember the total strain into physical and intellectual ones. In this sense, the actual labor processes are divided into two types: with pronounced physical strain (physical labor) and with pronounced intellectual strain (mental labor) [40, P.25]. We give the formula for the functional dependence between the human organism strain (H) and labor hardness (τ)

$$H=\mathrm{f}(\tau)\ .$$

Thus, in this case, the labor “hardness” is understood as the organism strain that arises under the action of physical load. In other words, “... the labor intensity is a function of the hardness of the material and information conditions of its process at the workplace” [40, P.25].

Actually, we believe that the concept of labor “hardness” should be attributed to the very labor process, to the physical load that it forms. In response to the hardness of a particular labor process, a certain amount of physical strain of the organism arises, characterizing the physiological value of this work for a person. Therefore, this approach takes into account both the amount of physical load (for example, mechanical work to move the links of the musculoskeletal system), and the body response to this load, in particular, the change in its energy exchange. Moreover, this point of view allows one to relate physical load and physical strain quantitatively to one another, and also to reveal the mechanical effectiveness of the human body work when performing the labor process.

The problem of relationship between the concepts of labor “hardness” and “physical working capacity” is extremely important, too. By now, this issue has not been practically developed, except for some fragmentary data [13, 37], which do not have sufficient theoretical and experimental justification. Therefore, we would like to present a number of our own views on this matter.

First of all, it was previously established [25] that physical performance is a category that includes two sides: physical load (work hardness) and generalized response of the organism to this load (physical strain of the organism).

Therefore, we can write $P=\mathrm{f}(\tau, H)$, where P – amount of physical working capacity; τ – work hardness; H – physical strain of the organism.

It would seem that the value of working capacity can be described quantitatively by a complex of parameters characterizing both of its above-mentioned components. However, it seems that physical performance is not only a combination of its two components. Indeed, during the working shift a person can perform a variety of technological operations, each of which forms both the specific physical load and corresponding physiological value of this load for the organism, i.e., it is necessary to keep in mind the time aspect, the dynamics of the change in hardness and physical strain during the working day. Moreover, each operation (work method or labor action) is a certain "quantum" of work, having its own time duration. At the same time, this "portion" of work carries a certain physical load (hardness), which can change during the transition from quantum to quantum in the same way as the physical strain can also change in response to this load. Consequently, the physical working capacity of the organism is a complex of "instantaneous" values of hardness and strain that varies with time. Therefore, in the most general form, it is possible to express physical performance in the form $P=\mathrm{f}[\tau(t), H(t)]$, where hardness ($\tau$) and physical strain ($H$) are no longer arguments, but complex functions that depend on time.

Thus, we believe that the work hardness is a part of the working capacity associated with the physical load and reflects the performance quantitatively, which, surely, changes with time. So, we can say that hardness is a kind of "instantaneous" physical working capacity.

We would like to draw attention to one more aspect of this relationship. In most cases, when performing labor processes, a person does not fully mobilize his working capacity, but uses only a certain part of it. In our opinion, the hardness reflects this part of the overall physical working capacity of the organism quantitatively and precisely, i.e., the so-called "demanded" part of working capacity related to the amount of physical activity.

Therefore, in the final analysis, it seems expedient to determine the work "hardness" as an element ("quantum") of the demanded physical working capacity, attributed to that side of it that is related to the physical load that occurs when performing various labor processes.

All the existing methods for quantifying the hardness of labor processes are either reduced to scoring the degree of physical strain of the human body (methodology of Moscow Research Institute of Labor [37], or the range of energy costs of an organism is set for certain works. As a rule, there is no single standard reference point in such classifications on work hardness; therefore, first, the quantity of hardness is not measured quantitatively and directly, but its range is indicated, and, second, these methods of hardness estimation do not allow differentiating different technological operations that cause the same reaction of the organism approximately, and, therefore, equal hardness values, differing in the effectiveness of performance, which is also necessary in determining the work hardness.

10.2. Substantiation of the reference point for the hardness of labor processes on the basis of their ergometric characteristics

In our opinion, it seems expedient to choose as a benchmark the labor process, which can be performed for a long time without fatigue, namely: walking at the speed of 4–4,5 km/h. This choice is due to the optimal ratio of ergometric parameters of the given labor process.

It is manifested primarily in the fact that for the indicated range of speeds the energy expenditures of the human body per unit of distance traveled is minimal [56, 57, 58]. We obtained similar results on the basis of the data given in the manual by G. Lehmann [22]. Indeed, out of all walking options the minimum energy expenditures of the organism fell at the speeds close to 4 km/h, and in our case they were 33 kcal/m (Table 26).

In addition, it was found that in the range of average walking speeds of 3–6 km/h, the efficiency of human physical activity is of the greatest importance [22, 40, 57]. The calculation of the coefficient of mechanical efficiency (CME) for walking at different speeds demonstrated that the maximum CME lies in the region of speeds close to 4 km/h and is about 2,29 J/cal.

In a certain way, the static load parameters of the human musculoskeletal system change depending on the body movement speed. In particular, the value of the total static moment (TSM) gradually decreases with increasing average movement speed. Such changes in the TSM are due to the dependence of the aggregate static moment (ASM) on the step length when walking at different speeds. If we consider changes in the static moment in the ankle joint, which is an integral part of the ASM, then it can be noted that the areas bounded by the curves of the functions “static moment – duration” and time axis increase with increasing step length while walking, i.e., with a decrease in the average movement speed. If the TSM is in fact an integral of the function “ASM – step duration” at the final speed interval (from 2 to 8 km/h), then its changes from the speed of travel are fully explained by corresponding changes in the value of this integral.

When calculating the mechanical power developed by the human musculoskeletal system when walking, it is necessary to perform the mechanical work done by the links and the whole body in one step divided by its duration. If we perform the same operation with the TSM value, we get the so-called average static moment (AVSM), which reflects a kind of “static power”. Our calculations have established that the AVSM had a well-defined maximum in the range of average speeds from 4 to 5 km/h. If we compare the changes in the TSM in relation to the walking speed and the functional dependence of “step length – movement speed”, we can understand why this maximum appeared. Indeed, the AVSM is the ratio of the TSM to the duration of the step and depends on their mutual variation and on the average walking speed. At first, the TSM dropped slightly, while the step time decreased rapidly enough, i.e., the denominator decreased faster than the numerator, so that the AVSM value increased with the speed value of 4–5 km/h, then reached a maximum in this range, then again dropped due to a steeper drop in the value of the numerator (TSM) on the background of a smoother slight decrease in the denominator (step duration).

Table 26

Ergometric walking parameters (according to G. Lehmann [22] and own data)

Average walking speed, km/h	Object weight, kg	Mechanical work, J/step	Energy expenditures (without basic metabolism), cal/step	Energy expenditure per 1 m of the way, cal/m	Metabolic capacity (without basic metabolism), kcal/min	Mechanical power, J/min	CME, J/cal
2	0	28,4	18	36	1,2	1874	1,56
4	0	51,1	22	33	2,1	5110	2,29
7	0	89,6	43	50	5,4	11290	2,0
4	10	53,5	38	58,5	3,6	5029	1,4
4	50	75,9	86	132,3	8,1	7229	0,89

Thus, the conducted studies showed that the value of AVSM had, as for mechanical work, a pronounced optimum in the same range of body travel speeds.

We tried to find the relationship between the ergometric indicators of physical load and energy exchange parameters of the human body and to determine the optimum by the movement speed proceeding from the established regularities. At the same time, we relied on the data of experimental studies on the heat exchange of the human body with the environment [11, 42, 43]. According to the basic heat balance equation [11], the heat content in the organism is determined according to the formula $Q=M \pm C \pm R-E$, where Q – heat load on the organism; M – metabolic heat, which is 67–75% of the energy consumption level; C – convection heat exchange of the organism and the surrounding air; R – radiant heat exchange of the organism with the environment; E – heat recovery by evaporation. At the same time, only 15 to 50% of the energy spent goes directly to the continuous renewal of the organism structural elements, synthesis of ATP and other organic compounds, movement of ions against the concentration gradient, contraction of myocardium, respiratory muscles, etc. The rest of the energy is converted into heat, 60–70% of the energy consumed [14]. Thus, a part of the metabolic capacity goes to "useful" work, and some of it acts as free metabolic heat in the human body. It should be borne in mind that both components, productive energy expenditures and metabolic heat, increase with increasing physical exertion, and the load exerts a significantly greater influence on the growth of the body heat content than the ambient temperature [42, 43].

If we subtract the energy expenditure for performing mechanical work while walking at the speed of 4–4,5 km/h out of the metabolic capacity of the organism (without basic metabolism), then as, a result, we get 2,1–1,22= =0,88 kcal/min. According to a number of data [3, 22, 40], the energy spent by a person to maintain a standing posture is from 0,7 to 1,2 kcal/min. Therefore, it can be assumed that when walking at such speed, the remaining part of the metabolic capacity of the organism (0,88 kcal/min) is used to make static work by the body muscles to maintain the appropriate posture, and the heat balance of the body is close to its comfortable value, i.e. to zero, under optimal environmental conditions (temperature, air speed and humidity). The increase in the physical work intensity compared with the same for walking at the speed of 4–4,5 km/h should lead, therefore, to an increase in both the energy expenditure for performing mechanical work and the body heat content in the form of residual metabolic energy, so that it found its reflection in the calculation results of ergometric parameters of a number of labor processes.

Apart from the established patterns of changes in metabolic power components, depending on the physical load intensity, we also found that from the whole set of labor processes considered walking at the speed of 4–4,5 km/h is the most mechanically effective from the point of static load. If we subtract the energy expenditures to perform mechanical work by the locomotor system of a person in the labor process out of the metabolic capacity of the organism (without the basic metabolism) and then divide the AVSM value by the obtained value, we get a kind of mechanical efficiency of the static work. Our calculations showed that the maximum mechanical efficiency of the static work was inherent in the same energetically favorable labor process – walking at the speed of 4–5 km/h – and amounted to 442 N/kcal/min. Later, this value of the mechanical efficiency of the static strain served as a kind of thermal equivalent of the static work for the labor processes considered, i.e., the value of the static load in the scale of hardness was calculated from the indicated value of “static” cost per 1 kcal/min of the metabolic energy.

After revealing the relationship between the ergometric parameters of walking at different speeds, the problem of correct choice of the reference point for the average movement speed arose, since the changes in the two indicators of physical load (mechanical work and static moment) can be multidirectional, and in this case, the position of the optimum of energy expenditures depends on the combinatorial effect of both parameters.

For this purpose, the position of the optimal average walking speed was determined on the basis of revealing the empirical dependencies of ergometric parameters of the given labor process. The optimization was carried out at the previously mentioned point of 4–4,5 km/h, when the metabolic capacity of the organism per unit distance is minimal. The general form of the optimized function can be expressed as

$$f(\upsilon)=\frac{E(\upsilon)}{lm(\upsilon)}=\frac{E_A(\upsilon)+M_{av}(\upsilon)/\eta\mu(\upsilon)}{lm(\upsilon)} \quad ,$$

where f(υ) – optimized function; $E(\upsilon)$ – function of metabolic power dependence on the movement speed when walking; $E_A(\upsilon)$ – function of dependence of a part of metabolic power, spent on performing mechanical work, on walking speed; $M_{av}(\upsilon)$ – function of dependence of the AVSM on walking speed; $\eta\mu(\upsilon)$ – function of dependence of mechanical efficiency of static work on walking speed.

Thus, it was found that the function is complex, it contains four basic ergometric dependencies. The calculations carried out according to the information model of walking made it possible to reveal empirical expressions for each of the four indicated functions (Table 27). Finding the derivative f(υ) and equating it to 0, we obtained the differential equation, whose solution gave the value $\upsilon \approx 3{,}9$ km/h. Thus, the reference point for minimum energy consumption per distance unit for walking was chosen correctly, and it is in a region close to the speed of 4 km/h according to our calculations.

10.3. Measuring the value of hardness of labor processes

The next stage after determining the location of the hardness reference point was the solution of the problem of measuring the hardness of labor processes on the basis of revealing the relationships between their ergometric indicators. In this case, under measurement we mean a quantitative assessment of the hardness of single labor processes or, more broadly, the definition of the reflection of empirically established quantitative relationships of ergometric parameters of labor processes in the theoretical hardness model (finding specific correspondence rules in P. Blagush's terminology [4]).

In the process of developing the methodology for quantifying the labor hardness, four conditions of the "measurement" level according to K. Burke (cited from [4]) were used as the main criteria for the completeness of measurement:

1. Finding the corresponding transitive empirical interpretation of numerical relationships (Table 28).

2. Possibility to solve the problem of these relations for any two empirical objects or any two motor achievements, for example, the achievements of various individuals in this moving task (Table 27).

3. Definition of the empirical relation in the arithmetic operation of addition: for example, the running time at maximum speed (moving start) is empirically "additive" in a certain range.

4. Establishment of constant measurement units.

A numerical visualization, i.e., a representation of numbers that fits the first two so-called topological conditions, serves to simply order the

Table 27

Ratio of energy indicators of labor processes

Types of work	Total energy consumption, kcal/min	Expenditures for mechanical. work, kcal/min	Expenditures for static work, kcal/min	Residual energy consumption, kcal/min	Mechanical efficiency of static work, Nm/kcal/min
Walking without load at the speed of:					
– 2 km/h	1,2	0,45	0,63	0,12	375
– 4 km/h	2,1	1,22	0,88	0,00	442
– 7 km/h	5,4	2,7	0,76	1,94	124
Walking at a distance with cargo:					
– 10 kg	3,6	1,2	0,96	1,44	176
– 50 kg	8,1	1,73	1,55	4,82	109
Work with a shovel: throwing length – 1 m; height of throw – 1,5 m; tempo – 12 throws per minute	8,0	2,74	0,98	4,28	82,7
Walking on an inclined plane: inclination angle – 25°, without cargo, walking speed – 17,6 m/min	13,3	4,38	0,71	8,21	35,3
Climbing the stairs: slope – 30,5°, without cargo	13,7	4,53	0,61	8,56	29,2
Climbing the ladder: inclination – 90°, without cargo, climbing speed – 17,2 m/min	10,4	2,5	1,12	6,78	62,5
Work with a hammer: hit from above, weight of the hammer – 4,4 kg, work tempo – 15 hits per minute	7,3	2,5	0,78	4,02	71,4
Filing of iron, frequency of movements – 60 per minute	2,5	0,70	0,52	1,28	127,2

achievements on the rank scale. This type of assessment is referred to as scaling. Only a numerical visualization that fulfills all four conditions – the so-called metric visualization – enables measurement in the actual sense [6, 8].

Table 28

Empirical dependencies of the components of the optimized function on walking speed and their derivatives

Designation of functions	Empirical forms of communication	Derived functions
$E_A(\upsilon)$	$0{,}194\ \upsilon^{1{,}338}$	$0{,}26\upsilon^{0{,}338}$
$M_{av}(\upsilon)$	$153{,}7+99\upsilon-11{,}1\upsilon^2$	$99-22{,}2\upsilon$
$\eta\mu(\upsilon)$	$311{,}4\upsilon-165{,}7-40{,}1\upsilon^2$	$311{,}4-80{,}2\upsilon$
$\mathrm{lm}(\upsilon)$	$0{,}072\upsilon+0{,}363$	$0{,}072$

In the conducted studies, an attempt was made to metrically visualize the work hardness on the basis of biomechanical analysis of single labor processes.

The development of empirical interpretation of the hardness value had, as a basis, the proposition that hardness should be determined by the ratio of energy expenditure by the human organism when performing a specific labor process to that of an optimal labor process – walking at the speed of 4 to 4,5 km/h. Thus, walking at the specified speed, or rather, the level of energy exchange during its implementation was a kind of "standard" of the scale of hardness due to the optimal ratio of ergometric parameters, as indicated earlier. Proceeding from this, we can write down that

$$H = \frac{E}{E_w}, \tag{54}$$

where H – hardness of a single labor process; E – metabolic capacity of the organism (without basic metabolism) when performing the studied labor process, kcal/min; E_w – metabolic capacity when walking at the speed of 4–4,5 km/h.

The value E_w of an average person (a man 170 cm tall, weighing 70 kg) is approximately constant [5] for a fixed walking speed and has the average value of 2,1 kcal/min. The exponent E is rather complicated function, which, in our opinion, is determined by three components

$$E=\mathrm{f}(E_A, E_M, \Delta E), \tag{55}$$

where E_A – part of metabolic capacity that was spent to perform mechanical work, kcal/min; E_M – part of metabolic capacity used to compensate for the arising static moments, kcal/min; ΔE – residual heat in the organism, one part of which was spent on maintaining the active state of supporting systems (respiratory, circulatory) and regulatory (nervous, endocrine), and the other was either emitted into the external space or formed the body heat content, kcal/min.

The first two components of the total energy exchange can be represented in the form of relations

$$E_A = \frac{A}{A_E} \text{ and } E_M = \frac{M_{av}}{M_E} , \qquad (56), (57)$$

where A – mechanical power developed by the musculoskeletal system of a person during the labor process performance, J/min; A_E – mechanical equivalent of heat equaling to 4189 J/kcal; M_{av} – average static moment developed during the labor process performance, Nm; M_E – maximum mechanical efficiency of the static work equaling to 442 Nm/kcal/min (empirically established thermal equivalent of the AVSM for walking at the speed of 4 km/h).

Thus, the development of the dependencies E_A and E on the value of ergometric parameters was carried out in the form of similarity scales [6, 7, 8], where the mechanical power and the AVSM values were compared with the reference values (A_E and M_E). The numerical ranking of these empirical relationships is given in Table 28. It should be noted that as parameters of hardness only those ergometric parameters were selected that revealed significant correlation links (correlation coefficient not less than 0,7) between themselves and metabolic capacity value.

Later, the form of communication between the total physical load (static and dynamic) and residual energy expenditure of the organism (ΔE_0) for one cycle was determined. It turned out that this kind of dependence is power-mode and is expressed by the formula

$$\Delta E_0 = 3 \cdot 10^{-5} \cdot S_i^{2,199}, \qquad (58)$$

where E_0– residual heat in the organism per one movement or their cycle, cal; S_i – total physical load of the organism, Nm.

In future it is possible to move from the residual heat of the organism per one movement or their cycle to the expression of this value in one minute:

$$\Delta E = \frac{\Delta E_0}{t_0} 60 , \qquad (59)$$

where all the parameters, except t_0, were described above; t_0 – duration of the labor process, sec. Formula (59) leads to the expression ΔE in kcal/min. To translate the dimension of this parameter in kcal/min, we divide the entire expression by 1000 and finally for a given value we obtain

$$\Delta E_0 = \frac{0,06 \Delta E_0}{t_0} .$$

Thus, the general empirical dependence for the hardness value will take the form

$$H = \frac{A}{E_w}\left(\frac{A}{A_E} + \frac{M_{av}}{M_E} + \Delta E\right) , \qquad (60)$$

where all parameters and intermediate transformations were considered earlier.

In the final form, the numerical interpretation of empirical relations of hardness parameters will be expressed in the form of an interval scale of discrete values of hardness of a number of labor processes studied.

The calculations establish the reliability of the forecast of the hardness of labor processes on the basis of a generalized theoretical curve in comparison with discrete values obtained on the basis of empirical dependence. It turned out that the coefficient of linear correlation between these two series of data was 0,86, which indicates a high degree of reproducibility of the results of the calculating hardness in the theoretical conceptual model in relation to the experimental one and observing the first condition.

To satisfy the second condition of the correctness of applying the proposed empirical relations of ergometric parameters, an individual variability, depending on anthropometric characteristics of human body, was estimated as a measuring instrument for the hardness of labor processes.

The third condition concerning the complementarity of ergometric parameters in the evaluation of hardness has been taken into account in two ways. First, the value of mechanical work and mechanical power are additive and can be added based on the energy conservation law, and second, the very value of hardness is defined as a certain sum of three components, each of which is complementary to another two for each labor process.

In addition, in the empirical relations of ergometric indicators used for the quantitative evaluation of the hardness of labor processes, the interrelations of dimensionalities of physical magnitudes in the hardness formula are strictly observed. Therefore, the final, the fourth condition for the completeness and accuracy of the hardness measurement is also observed – the unification of measurement units.

Consequently, the developed methodology for quantifying the hardness of single labor processes satisfies the conditions of the metric visualization of the investigated quantity and can be used to measure the hardness of the work performed.

The above method for measuring the hardness of single labor processes was used then to determine this indicator of a number of technological operations of metalworking, assembly, and operations of blank production, which ultimately allowed us to calculate the labor costs for these operations and then use them in the standardization of labor. The calculation of the hardness of a single labor process (technological operation) is carried out in the sequence indicated below.

10.4. Practical methods for calculating the hardness of a single labor process

A microelement analysis of the labor process is carried out according to the methods described in the manuals [24, 38]. Then, from the tables of ergometric parameters of labor movements given in the supplement to this work, time (t_i), mechanical work (A_i) and static moments (M_i) are determined for each of the microelements.

When calculating M_i for each manual movement, excluding large ("body") movements, a correction is introduced to maintain the posture in two stages.

1) The instantaneous value of the posture moment (M_0) is calculated:

- for the "standing" posture

$$M_0=((150+6{,}2\sqrt{\varphi^2+m^2})^2+(150{,}2+11{,}2m)^2)^{1/2};$$

- for the "sitting" posture

$$M_0=((54{,}0+2{,}3\sqrt{\varphi^2+m^2})^2+(51{,}8+8{,}05m)^2)^{1/2};$$

where M_0 – posture moment, Nm; φ – arm (arms) inclination angle when performing the technological operation, grad; m – mass of the object held, kg.

2) M_i is determined for each manual movement adjusted for posture:

$$M_i=M_0t_i+M_a,$$

where M_a – static moment of the arm microelement taken from the tables of ergometric indicators of labor movements (Table 10.6), Nms.

Then, the total values of the above three parameters are calculated for the entire labor process.

We determine the total time of the operation (t_0), which acts mostly as an auxiliary time in practice, therefore, to get the "net" operational time, the main (machine) time is added to it:

$$t_0=\sum_{i=1}^{n}t_i,$$

where t_0 – total operation time (auxiliary), s; t_i – time of the i-th microelement, s.

Also it should be borne in mind that in the process of time summation of labor movements in the presence of microelements (overlapping movements carried out simultaneously) combined, the time of the largest one by duration is selected.

We find the total mechanical work:

$$A_0=\sum_{i=1}^{n}A_i,$$

where A_0 – total mechanical work, J; A_i – mechanical work when performing the i-th microelement, J.

We calculate the total static moment (M_t) per operation, Nms:

$$M_t=\sum_{i=1}^{n}M_i,$$

where M_i – static moment for the i-th microelement, Nms; and for manual movements the static moment with the correction for maintaining the appropriate posture is already taken into account.

For overlapping motions, as in the case of microelements, a larger static moment is selected when summing them up.

Then, we find the mechanical power of the human musculoskeletal system when performing this technological operation (A), J/min:

$$A=\frac{A_0}{t_0}\cdot 60,$$

where A_0, t_0 – total mechanical work and total operation time, respectively.

Let us determine the average static moment (M_{av}), Nm:

$$M_{av}=\frac{M_t}{t_0}\ .$$

We calculate the total physical load of the human body when performing a single labor process (S_i), Nm:

$$S_i=A_0+M_{av}\,,$$

Then we calculate the residual energy consumption (ΔE_0), cal:

$$\Delta E_0=5{,}12(S_i-440)^{0{,}53}.$$

If we have $S_i < 440$ as a result of calculation at the previous stage, then we take S_i=440 Nm and ΔE_0=0.

We determine the hardness value of the labor process:

$$T=0{,}476\left(\frac{A}{4189}+\frac{M_{av}}{442}+\frac{0{,}06\Delta E_0}{\mathrm{t}_0}\right)\ ,$$

where T – hardness of the technological operation, the dimensionless (relative) value.

10.5. Examples of calculating the hardness of technological operations

1. It is necessary to calculate the value of hardness of technological operation "Grinding of base surface of the bracket BrAZH-9-3L on the surface grinding machine 3GT1". 19 parts are processed simultaneously, the weight of one piece is 0,02 kg, the pieces are fixed on magnetic plate with special device. We split this operation into separate procedures and labor movements, as indicated in the chart of the labor process analysis. We note that the operation actually includes 3 main methods of work: installation of the workpiece on magnetic plate; control of the workpiece dimensions with the help of measuring clamp; taking the workpiece off the machine. Further, we detail the microelemental composition of a single labor process, noting labor movements – overlapping, non-overlapping and combined. We write down the algorithm of the labor process, where we state: symbols (codes) of the incoming microelements, quantitative and qualitative factors that affect their duration, logical conditions for the transition from one movement to another (indicated in the algorithm by arrows with numbers), overlapping movements (in the algorithm they are highlighted by frames).

In the BSM system, the algorithm of this operation is written down as follows:

↓ШС1 (S400); ПТ1(φ90); ПР2(S400) (ОС1; К1); В2 (1100);
ПТ1(90); П2В(S100; Р 038); П2В(S100; Р 0,38; 1100) (ОС1; К1);
ШС1(S400); ШС2(S400); П2Н(S400) (ОС1; К1); ОТ2; $\overset{1}{\uparrow}\overset{2}{\downarrow}$
ПР1(S100) (ОС1; К2); УП1(Р 0,02; 133); $\overset{2}{\uparrow}\overset{3}{\downarrow}$ ПР1(S100) (ОС1; К2);
УП1(РО602;133); $\overset{3}{\uparrow}\overset{4}{\downarrow}\overset{3}{\uparrow}$ПР2Н(S600) (ОС1; К3); НРС1;
ПР1В(S600) (ОС1; К2); ПР1Г(S700) (ОС1; К2) В1; В1;
П1Г(S400; Р 0,02; 133) (ОС1; К2); П1Г(S500; Р 0,1; 1100) (ОС1;К2);
УОС1Г(РО,1; 1100; L10); $\overset{4}{\uparrow}$ПОВ1(РО,02;φ180) (ОС1);
УОС1Г(РО, 1; 1100; L10); $\overset{5}{\uparrow}$РС1(Р 0,1; 1100; L10);
П1Н(S200);Р 0,02; 1100) (ОС1; К1); П1Г(S500; Р 0,1; 1100)
(ОС1; К1); ОТ1; ОТ1; ПР1Г(S500) (ОС1; К1); В2; П2В(S100; Р 0, 38;
1100) (ОС1; К1); ШС1(S400).

The algorithm recording for the same operation in the MTM-1 system is as follows:

$\overset{1}{\uparrow}$ШС1; ПК2; Пр1(2) 0,4; В1(2); ПК2; 0,38 $П_в$(2) 0,1; ШС1; ШС2;
0,38 По (2) 0,4; ОГ(2); $\overset{1}{\uparrow}\overset{2}{\downarrow}$ Пр 1 0,1; $У_{1ПЛ}$; Пр1 0,1; $У_{1ПЛ}$; $\overset{3}{\uparrow}\overset{4}{\downarrow}\overset{5}{\uparrow}$; Пр1(2) 0,75;
Н; Пр1 0,05; Н; Пр1 0,1; Н; Пр1 0,6; Пр1 0,75; В1; В2; 0,02 Пг 0,4;
0,1 Пг 0,5; $У_{1ПЛ}$; $\overset{4}{\downarrow}$ПГ; $У_{1ПЛ}$; $\overset{5}{\downarrow}Р_{1Л}$; 0,02 По 0,2; 0,1 Пг 0,5; Ог; Пр1 0,5;
В1 (2); 0,38 Пв 0,1; ШС1;ПК2; Ог.

From the tables of ergometric parameters (item 10.6. or manual [38] of working movements, we find the values of biomechanical indexes of every microelement. We state them in the “The labor process chart”, and then calculate:

- total operation time (t_0), s;
- general mechanical work (A_0), J;
- total static moment (M_m), Nms.

They are determined by the summation of the corresponding values of every microelement. In our case, the addition gives the following values: operation time (t_0) – 27,3 s; total mechanical work (A_0) – 244,05 J; total static moment (M_m) – 1311 Nms. We should pay attention to the fact that time t_0 is not “net” operational time, but the auxiliary time, therefore, to get the actual operation time it is necessary to add the basic (machine) time to it.

Next, we find the mechanical power developed by the musculoskeletal apparatus of a person when performing this operation A=244,05/27,3·60= =536,37 J/min.

We calculate the average static moment maintained during the operation M_{av}=1311/273=48033 Nm (J).

We estimate the total (static and dynamic) physical load of the body: $S_i=$ $=244{,}05+480{,}33=724{,}38$ J.

Using the formula (58) and knowing the value of S_i, we find the residual energy expenditure per operation: $\Delta E_0=3\cdot10^{-5}\cdot72438^{2{,}198}=57{,}99$ kcal.

We substitute the obtained values A, M_{av}, ΔE_0 in the hardness formula (54) and get $T=1/2{,}1(536{,}37/4189+480{,}33/442+0{,}06\cdot57{,}99/27{,}3)=0{,}64$.

Consequently, the hardness value of the operation “Grinding of base surface of the bracket BrAZH-9-3L on the surface grinding machine 3GT1” is 0,64.

2. We calculate the hardness value of the milling-centering operation for machining the output shaft weighing 14,4 kg of the gearbox RCD-350. We write down the algorithm of the single labor process. In the BSM system it is as follows:

ПР1В(S400); НPS1; ПР1В(S100); НРС1; ПР1Н(S400); В2; РС2В (Р14,4; 1412; L10); П2Г(S500; Р14,4); ШС 2(S400); ПТ(φ180); ПР1(S500); НП В2 П2В(S500; Р14,4); ВНП; П2Г(S500; Р14,4); ПТ (φ180; Р14,4); П2Н(S100; Р14,4); УП2;

$\overset{1}{\downarrow}$ПР1 (S500); НРС1 $\overset{1}{\uparrow}$; $\overset{2}{\downarrow}$ПР1 (S100); НРС1; $\overset{2}{\uparrow}$П1Г (S300; Р 0,1); П1Н (S400); УОП1Г (Р 0,1; 1100; L10); $\overset{3}{\downarrow}$РП1Г (Р 0,1; 1100; L10); $\overset{3}{\uparrow}$; РП1Г (Р 0,1; 1100; L10); П1Г (S400; Р 0,1); ОТ1; ПР1 (S300); В1; П2Г (S500; Р 14,4); ПОТ2G (S600; Р 14,4); ШС2 (S400).

The same operation in the MTM-1 system will be recorded as

Пр1 0,4; Н; Пр$_1$ 0,1; Н; Пр$_1$ 0,4; В$_2$; Р$_{1с}$; 14,4 Пг 0,5; Ог; ШС$_2$ ПК$_2$; Пр$_1$ 0,5; На$_2$; В$_2$; 14,4П$_в$ 0,5; Вна$_2$; 14,4 Пг 0,5; ПК$_2$;

14,4 По 0,1; У$_{1с}$$\overset{1}{\downarrow}$; Пр$_1$ 0,5; Н; $\overset{1}{\uparrow}$; $\overset{2}{\downarrow}$Пр$_1$ 0,1; Н;

$\overset{2}{\uparrow}$0,1 Пг 0,3; 0,1 По 0,4; У$_{1с}$; $\overset{3}{\downarrow}$Р$_{1с}$; $\overset{3}{\uparrow}$0,1 По 0,4; У$_{1п}$; $\overset{3}{\uparrow}$; Р$_1$; 0,1 Пг 0,4; Ог; Пр$_1$ 0,3; В$_1$; 14,4 Пг 0,5; Ог; ШС$_1$.

The summation of three basic parameters of each of the microelements gave the generalized initial data:

- total operation time $t_0=27{,}8$ s;
- total mechanical work $A_0=848{,}9$ J;
- total static moment $M_m=16242{,}6$ Nms.

We find the mechanical power developed by the musculoskeletal apparatus of a person when performing this operation: $A=848{,}9/27{,}8\cdot60=$ $=1832{,}2$ J/min.

We estimate the average static moment maintained during the operation: $M_{av}=16242{,}6/27{,}8=584{,}3$ Nm.

We calculate the aggregate (static and dynamic) physical load of the organism: $S_i=848{,}9+584{,}3=1433{,}2$ Nm.

We find the residual energy consumption of the organism for the operation of the supporting systems: $\Delta E_0=5{,}12(1433{,}2–440)^{0{,}53}=198{,}5$ cal.

Eventually, we find the operation hardness: T=0,476(1832,3/4189+ +584,3/442+0,06·198,5/27,8)=1,04.

3. Let us find the hardness of the labor process, characterized by high physical load when performing it. As an example, we consider the work with a shovel on throwing viscous soil from a trench. Let the weight of the shovel be 2 kg, and the weight of the one-time thrown soil – 8 kg. Thus, the total weight of the moving object with the load is 10 kg.

Let us compose the algorithm of the labor process under study in the BSM system:

П2В(200; Р2,0); НП(φ90; Р2,0); С(h0,7; Р2,0); П2Н(S500; П2,0); ПОТ 2V(S400); П2В(S200; Р10,0); ВНП(φ90); ВС(h0,7; Р10,0); П2Г(S600; Р10,0); П2В(S200; Р10,0) П2Н(S200; Р2,0); ВНК(φ10; Р2,0); ВС(h0,7; Р2,0); П2В(S200; Р2,0)

The same labor process described with the codes of microelements of the MTM-1 system is as follows:

2Пв 0,2; На$_2$; С; 2По 0,5; 2Пв 0,4; Н; 10Пв 0,2; Вна$_2$;Вс; 10пГ 0,6; 10 Пг 0,6; 10Пв 0,2; На$_1$; С; 10Пв 0,7; Н; 2По0,2; Вна$_1$; Вс; 2Пв 0,2

Let us calculate the hardness of the process being studied. First, on the basis of microelement analysis we determine three main common indicators:

- total operation time t_0=6,22 s;
- total mechanical work A_0=816,2 J;
- total static moment M_m=5248,6 Nm.

We determine the mechanical power of the human musculoskeletal system used in this process:

A=816,2/6,22·60=7873,3 J/min.

We find the average static moment for the operation:

M_{av}=5248,6/6,22=843,8 Nm.

We reveal the total physical load:

S_i=816,2+843,8=1660 Nm (J).

The residual energy consumption of the body is:

ΔE_0=5,12(1660–440)^{0,53}=221,3 cal.

The required hardness of this labor process is:

T=0,476(7873,3/4189+843,8/442+0,06·221,3/6,22)=2,82.

4. The following labor process combines labor movements of manipulative and locomotive type. Let us calculate the hardness of loading stone into a dump truck body, when it is known that the stone weight is, on average, 5 kg, and for bringing it to the truck, the loader makes about 10 steps.

We perform a microelement analysis of this labor process in two basic systems of microelement time standards: BSM and MTM-1:

a) algorithm for loading the stone in the symbols of the BSM has the following form:

НП(φ90); ПР2(S500); В2 ВНП(φ90); П2В(S300; Р5,0); ПК2; ШС1;
10·Х(Р 5,0); НК(φ10); П2Г(S200; Р5,0); ВНК(φ10); ПОТ2V(S700; Р 5,0); ПР2(S500);

b) same labor process in the MTM-1 system can be expressed as

На$_2$; Пр$_2$ 0,5; В$_1$; Вна$_2$; 5Пв 0,3; Пк$_2$; ШС$_1$; 10·Х; На$_1$; 5Пг 0,2; Вна$_1$; 5Пв 0,7; Н; Пр$_1$ 0,5.

We determine the basic generalized ergometric indicators of the labor process "Loading stone into a dump truck body":

- total time of the labor process (operation) t_0=11,21 s;
- total mechanical work A_0=3306,7 J;
- total static moment M_m=6610,8 Nms.

We calculate the mechanical power developed by the musculoskeletal apparatus of a person when performing this technological operation:

A=3306,7/11,21·60=17698,7 J/min

We find the average static moment:

M_{av}=6610,8/11,21=589,7 Nm.

We estimate the total physical load:

S_i=3306,7+589,7=3896,4 Nm.

We detect the residual energy expenditure of the organism:

$\Delta E_0=5{,}12(3896{,}4–440)^{0{,}53}=384{,}4$ cal.

Finally we have:

T=0,476(17698,7/4189+589,7/442+0,06·384,4/11,21)=3,63.

5. Let us consider the labor process, which is characterized by significant physical load (both by its volume and intensity). It is about working with a hammer. Let us take the weight of the hit with a hammer from above as 10,6 kg. We will determine the hardness of this labor process per one cycle "raising and lowering the hammer".

This operation is split into a number of microelements (labor movements).

In the BSM system:

П2В(S1000; Р10,6; 1 600); ВНП(φ90; Р10,6); ВС(h0,7; Р10,6;
ПОТ 2V (S1000); НП(φ90; Р10,6); С(0,7; Р10,6). ;

In the MTM-1 system:

10,6 Пв 1,0; ВН$_2$; ВС; 10,6 По 1,0; Н; С.

The summed up indicators of the labor process are as follows:

- total operation time t_0=2,514 s;
- total mechanical work A_0=776 J;
- total static moment M_m=1844,2 Nms.

We find the value of mechanical power:

A=776/2,514·60=18520 J/min.

We find the average static moment:

M_{av}=1844,2/2,514=733,6 Nm.

We calculate the aggregate (static and dynamic) physical load:

S_i=776+733,6=1509,6 Nm.

We determine the residual power consumption:

ΔE_0=5,12(1509,6–440)^{0,53}=206,4 cal.

Finally we have:

T=0,476(18520/4189+733,6/442+0,06·206,4/2,514)=5,2.

6. Work with a file in a "standing" position. The weight of the file is 500 g. The hardness is calculated in the cycle of "forward-backward" movements.

The algorithm in the BSM system:

НК (φ5); | НРУ; П2Г (S300; Р 0,5); | ВНК (φ5); П2Г (S300; Р 0,5. |

The algorithm in the MTM-1 system:

$На_1$; | Н; 0,5 Пг 0,3; | $ВНа_1$; 0,5 Пг 0,3 |

The selection of ergometric parameters of labor movements according to the tables from the Supplements and their summation gives the following values of the common indicators:

- total cycle time t_0=1,572 s;
- total mechanical work A_0=45,54 J;
- total static moment M_m=641,9 Nm.

We calculate the value of mechanical power:

A=45,54/1,572·60=1738,2 J/min.

We find the average static moment:

M_{av}=641,9/1,572=408,3 Nm.

We find the total physical load:

S_i=45,54+408,3=453,9 Nm.

We estimate residual energy consumption:

ΔE_0=5,12(453,9–440)^{0,53}=20,6 cal.

Finally we have:

T=0,476(1738,2/4189+408,3/442+0,06·20,6/1,572)=1,02.

7. Work with a file in the "sitting" position. For this labor process, it is characteristic that it differs from the previous one only by a static load. We consider how it affects the hardness value. The algorithms of the labor process in both systems of microelements are identical to the ones from the previous labor process.

We have that t_0=1,572 s; A_0=45,54 J; M_m=398,1 Nms.

Successively calculating the hardness, we obtain:

$$A=45,54/1,572·60=1738,2 \text{ J/min.}$$

$$M_{av}=398,1/1,572=253,2 \text{ Nm.}$$

$$S_i=45,54+253,2=298,8 \text{ Nm.}$$

Since S_i < 440 Nm, we take ΔE_0=0.

Then T=0,476(1738,2/4189+253,2/442+0)=0,47.

Thus, the change in working posture significantly affected the hardness value, namely: in the "sitting" position, it is significantly less in comparison with the "standing" position.

Table 28

10.6. Tables of ergometric indexes of labor movements
To stretch an arm– SA

Movement type	Code	Movement distance, S, mm, not more											
		170		300		435		530		640		750	
Stretch an arm automatically without vision	Sa_1	The standard values of time, t, s											
		0,3		0,385		0,465		0,492		0,532		0,583	
		Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
		3,2	0,78	4,03	2,28	4,81	4,46	5,25	7,23	5,7	11,4	6,4	16,6
Stretch an arm under control of vision to the object whose location is known	Sa_2	Standard values of time, t, s											
		0,3		0,385		0,465		0,492		0,532		0,583	
		Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
		4,1	0,61	5,4	1,7	6,5	3,3	7,3	5,2	8,1	8,0	9,1	11,7

Notes. 1. The values of mechanical work are given for moving the arm vertically upwards. When moving the arm down, the amount of mechanical work from the table should be reduced in 2 times, while moving horizontally – in 9 times. The values of static moment and time for motion performance remain unchanged in any direction of the arm movement.

2. In case of moving two arms simultaneously, the amount of mechanical work and static moment should be doubled.

Table 29

To move an object in space with one arm– M1

Weight, P, kg, not more	Movement distance, S, mm, not more											
	75		160		340		510		620		750	
1,0	Standard values of time, t, s											
	0,468		0,684		1,00		1,21		1,34		1,47	
	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
	10,7	3,8	16,3	8,3	22,6	8,9	27,3	12,1	30,3	15,9	34,0	22,0
3,0	Standard values of time, t, s											
	0,3		0,385		0,465		0,492		0,532		0,583	
	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
	24,2	7,3	36,7	16,1	51,3	17,2	61,9	24,7	68,7	30,9	76,6	37,6
10,1	Standard values of time, t, s											
	0,564		0,828		1,218		1,47		1,62		1,776	
	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
	73,7	17,4	111,6	38,5	158,6	43,2	191,6	59,4	211,6	73,9	233,3	86,9

Note. The values of mechanical work are given in the table for moving the load vertically upwards. When moving the object down, the amount of mechanical work should be reduced in 2 times, while moving it horizontally – in 9 times. The values of static moment and time for motion performance remain unchanged with any arm movements.

Table 30

To move an object in space with both arms– M2

Weight, P, kg, not more	Movement distance, S, mm, not more											
	110		230		340		510		620		750	
	Standard values of time, t, s											
2,0	0,36		0,396		0,576		1,02		1,122		1,236	
	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
	14,2	4,3	15,1	10,4	21,9	16,5	39,2	27,4	44,6	36,4	47,6	49,4
10,0	0,396		0,576		0,846		1,122		1,236		1,362	
	30,1	9,2	43,2	21,3	62,9	31,1	84,0	48,5	94,7	58,8	101,9	79,7
30,0	0,576		0,846		1,02		1,236		1,362		1,494	
	118,5	23,2	172,6	52,2	207,3	70,0	250,0	111,8	282,9	131,6	302,2	176,2

Table 31

To rotate a hand with a load – RL

Weight, *P*, kg, not more											
0,3		1,5		3,5		5,0		8,0		10,0	
Size of the largest object side, *l*, mm, up to											
1100		1200		1200		1200		1200		1400	
Standard values of time, *t*, s											
0,318		0,462		0,558		0,618		0,678		0,744	
Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J	Stat, moment, Nms	Mech, work, J
3,8	22,7	9,9	29,1	20,9	40,2	30,5	45,1	49,7	58,0	66,4	80,1

Notes. 1. If the size of the largest object side and angle of its rotation are different from the table (angle of rotation for tabular data is 180°), then it is necessary to apply correction Δ_x in the values of movement time and mechanical work performance according to the formula:

$$\Delta_x = \left(\frac{0{,}125 m_G l + 0{,}057}{0{,}125 m_G l_T + 0{,}057}\right)\frac{\varphi}{180},$$

where m_G – weight of load, kg; l – size of the largest object side rotated at the workplace, mm; l_T – size of the largest object side taken from the table, mm; φ – angle of the object rotation at the workplace, grad. Further, the values of time (t) and mechanical work (A) are found: $t = t_T \cdot \Delta_x$; $A = A_T \cdot \Delta_x$, where t_T – tabular time, A_T – tabular mechanical work, and Δ_x – above correction.

2. Static moments remain unchanged.

Table 32

To rotate a handle – RH

Diameter of the handle, D, mm, not more	Angle of rotation, φ, grad, up to									
	45		105		180		245		360	
	Standard values of time, t, s									
	0,354		0,432		0,474		0,522		0,576	
	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J
60	3,9	0,74	4,9	1,9	5,5	3,0	6,1	3,73	6,6	5,5
	0,432		0,522		0,576		0,63		0,696	
120	4,4	1,0	5,5	2,6	6,2	4,3	7,0	5,4	7,5	8,0
	0,522		0,63		0,696		0,762		0,84	
235	3,99	0,90	5,5	3,1	6,5	6,1	7,5	8,1	7,7	12,9
	0,804		0,972		1,07		1,176		1,29	
370	4,0	0,41	6,2	4,6	8,1	6,8	9,7	10,9	9,4	17,2
	0,882		1,068		1,176		1,29		1,41	
	4,0	2,0	7,0	5,9	8,9	12,9	10,2	21,0	11,8	38,8

Notes. 1. At several rotations of a flywheel the mechanical work for intermediate rotations: $A=0,2 \cdot A_T$, where A_T – tabulated value of work, J.

2. Static moment is determined by the formula $M=0,7 \cdot M_T$, where M – static moment of the arm for intermediate rotations, Nms; M_T – tabular moment, Nms.

3. Values of mechanical work and static moment for the first and last rotations are taken from the table, the corresponding corrections to the work and moment for the intermediate rotations are added to them and, as a result, we have the required values.

4. When the handles are rotated with two arms, the mechanical work should be increased in 1,54 times, and the static moments in 2,3 times. The time of movement performance remains unchanged.

Table 33

To take – T

Movement characteristics	Micro-element code	Time, s	Stat. moment, Nms	Mech. work, J
1. Take a single easily grasped object	T_1	0,072	1,81	0,01
2. Take a single hard-to-grasp object	T_2	0,131	3,29	0,012
3. Intercept or transfer an object from one hand to another	T_3	0,202	5,3	0,42

Note. If this movement is performed with two arms, then the values of static moment and mechanical work increase in 2 times, and movement time remains unchanged.

Table 34

To press – P

Movement characteristics	Conditions of fulfillment	Micro-element code	Time, s	Stat. moment, Nms	Mech. work, J
Press with a hand	Without effort	P_1	0,16	2,23	0,01
	With effort	P_2	0,53	7,53	0,42
Press with hands	Without effort	P_1	0,16	4,45	0,02
	With effort	P_2	0,53	14,8	0,84

Note. Microelement P means the influence on the controls of equipment, buttons, shaped nuts, grip handles, wrenches.

Table 35

To set up – SU

Movement characteristics		Micro-element code	Conditions of movement fulfillment					
			easy			hard		
connection density	symmetry of parts		Time, s	Stat. moment, Nms	Mech. work, J	Time, s	Stat. moment, Nms	Mech. work, J
Free, without pressure	Total	SU_1	0,2	2,65	0,05	0,4	4,77	0,05
	Partial		0,33	3,86	0,05	0,53	6,63	0,04
	Not available		0,37	4,77	0,05	0,58	7,45	0,04
Tight, light pressure	Total	SU_2	0,58	7,0	0,04	0,79	10,72	0,04
	Partial		0,71	8,7	0,04	0,91	11,4	0,04
	Not available		0,76	9,31	0,04	0,96	12,0	0,04
Dense, strong pressure	Total	SU_3	1,55	18,7	0,04	1,75	22,3	0,04
	Partial		1,67	20,8	0,04	1,88	23,5	0,04
	Not available		1,72	22,1	0,04	1,92	24,3	0,04

Note. If this movement is performed with two arms, then the values of static moment and mechanical work increase in 2 times. The movement time remains unchanged.

Table 36

To disconnect – D

Connection density	Micro-element code	Conditions of movement fulfillment					
		easy			hard		
		Time, s	Stat. moment, Nms	Mech. work, J	Time, s	Stat. moment, Nms	Mech. work, J
Free, without pressure	D_1	0,14	1,86	0,05	0,21	2,79	0,05
Tight, light pressure	D_2	0,27	3,59	0,05	0,43	5,72	0,05
Dense, strong pressure	D_3	0,82	10,9	0,04	1,25	16,6	0,04

Note. If this movement is performed with two arms, then the values of static moment and mechanical work increase in 2 times. The movement time remains unchanged.

Table 37

To turn a body – TB

Position	Angle of rotation, grad, not more	Micro-element code	Object weight, kg, not more	Time, s	Stat. moment, Nms	Mech. work, J
Standing	45	TB_1	1 10 20	0,38 0,50 0,61	67,8 169,8 339,5	13,5 20,3 32,8
	90	TB_2	1 10 20	0,58 0,63 0,81	93,5 302,8 645,5	27,2 68,3 120
Sitting	45	TB_1	1 10 20	0,38 0,41 0,46	22,3 66,5 133,1	8,3 8,9 16,6
	90	TB_2	1 10 20	0,58 0,58 0,61	37,5 88,5 176,9	18,1 20,0

Table 38

To walk –W

Object weight, kg, not more	Walking speed, km/h	Step length, m, not more	Step time, s	Stat. moment, Nms/step	Mech. work, J/step
0	4,0	0,66	0,64	202,0	236,4
10	3,9	0,65	0,63	327,7	269,1
20	3,8	0,64	0,62	446,8	313,2
30	3,8	0,64	0,62	568,2	431,1
40	3,8	0,64	0,62	690,3	577,3
50	3,8	0,64	0,62	812,7	755,3

Note. The values of static moments and mechanical work are given in the table per 1 step. If the worker makes more steps, it is necessary to multiply the table values of static moments and mechanical works by this number in order to obtain real values of the moments and works.

Table 39

Step to the side – SS

Movement type	Code	Step length, m, not more	Step time, s	Object weight, kg, not more											
				0		10		20		30		40		50	
				Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J
To leave a leg	SS_1	0,3	0,6	137,6	13,7	218,2	19,7	301,0	27,2	384,8	36,5	468,9	47,7	553,2	61,1
		0,4	0,68	159,5	20,2	250,4	28,8	344,0	39,7	438,7	53,0	533,7	69,1	629,1	88,2
		0,5	0,76	182,7	29,3	284,0	41,6	388,3	57,0	493,9	75,9	600,0	98,7	706,3	125,6
		0,6	0,85	209,2	36,8	322,1	51,8	438,5	70,6	538,2	93,5	674,6	121,3	793,4	153,8
		0,7	0,93	233,8	42,4	357,0	53,9	484,1	80,3	612,7	105,9	742,0	136,6	871,5	172,8
To close a leg	SS_2	0,3	1,2	278,5	10,5	437,9	14,3	602,2	18,9	768,2	24,3	934,9	30,5	1102	37,6
		0,4	1,28	306,2	18,1	475,8	24,7	650,7	32,5	827,4	41,7	1005,1	52,5	1183,5	64,2
		0,5	1,36	336,3	27,7	516,0	37,7	701,4	49,5	888,9	63,2	1077	79,0	1266	97,0
		0,6	1,45	368,5	39,3	559,5	53,3	756,7	69,8	956,4	89,0	1157	111,0	1358	136,0
		0,7	1,53	399,8	52,9	600,8	71,6	808,6	93,6	1018	119,2	1230	148,4	1442,8	181,5

Table 40

To bend forward – Bf

Movement character	Code	Time, s	Angle of bent, grad, not more	Object weight, kg, not more											
				0		10		20		30		40		50	
				Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J
To bend slightly	Bf_1	0,42	10	73,3	10,7	134,0	13,4	195,3	16,2	256,5	19,1	316,8	21,9	379,5	24,8
			20	80,9	25,8	144,0	32,5	207,3	39,3	270,6	46,3	333,2	53,3	397,8	60,4
			30	89,7	45,1	154,6	56,8	219,9	68,9	285,0	81,2	349,2	93,6	415,5	106,1
			45	102,8	81,4	169,7	102,8	237,2	124,8	304,7	147,2	371,4	169,8	440,3	192,6
To bend low	Bf_2	0,882	80	263,8	84,3	406,7	106,4	551,4	124,1	696,3	146,2	840,6	174,6	987,6	200,3
			90	272,9	91,0	415,2	114,8	560,0	139,2	705,0	164,0	849,2	189,1	996,2	214,3
			100	278,6	101,8	420,4	128,5	564,2	156,0	708,5	182,8	852,3	212,0	997,7	340,3

Table 41

Straighten from the position “to bend” – SBf

Movement character	Code	Time, s	Angle of straigh-tening, grad, not more	Object weight, kg, not more											
				0		10		20		30		40		50	
				Stat. mo-ment, Nms	Mech. work, J	Stat. mo-ment, Nms	Mech. work, J	Stat. mo-ment, Nms	Mech. work, J	Stat. mo-ment, Nms	Mech. work, J	Stat. mo-ment, Nms	Mech. work, J	Stat. mo-ment, Nms	Mech. work, J
Straighten from the position “to bend slightly”	SBf_1	0,54	10	96,5	24,6	175,0	33,1	254,3	40,0	333,4	46,9	411,8	53,9	492,6	60,9
			20	110,1	54,9	192,1	68,9	274,7	83,2	357,1	97,7	438,7	112,2	522,9	126,8
			30	125,1	84,3	210,1	106,5	295,5	128,6	380,8	151,0	465,5	173,6	552,2	196,2
			45	147,7	130,5	235,6	164,1	324,7	198,4	413,7	233,1	501,6	268,1	592,6	303,3
Straighten from the position “to bend low”	SBf_2	1,02	80	341,4	168,2	507,6	211,2	646,5	255,2	846,1	299,6	1014,6	344,4	1186,5	389,4
			90	351,7	177,4	516,9	222,9	684,9	269,3	853,5	316,4	1021,9	363,8	1192,9	411,4
			100	357,2	187,4	520,5	235,5	686,3	284,8	853,5	334,6	1021,9	384,8	1192,5	435,3

Table 42

To kneel – KN

Movement characteristics	Code	Time, s	Object weight, kg, not more	Stat. moment, Nms	Mech. work, J
Get down on one knee	KN_1	1,04	0	225,0	177,9
			10	365,0	236,4
			20	510,2	306,5
			30	602,3	392,3
			40	858,7	482,4
			50	946,1	508,3
Get down on both knees	KN_2	2,5	0	240,3	296,1
			10	380,5	387,3
			20	593,5	496,4
			30	643,7	605,0
			40	883,7	714,8
			50	1005,7	843,8

Table 43

Get up from knees – GKN

Movement characteristics	Code	Time, s	Object weight, kg, not more	Stat. moment, Nms	Mech. work, J
Get up from one knee	GKN_1	1,15	0	250,0	267,6
			10	405,2	355,7
			20	566,1	443,8
			30	668,6	531,9
			40	953,2	620,0
			50	1050,2	708,3
Get up from both knees	GKN_2	2,76	0	259,9	383,4
			10	395,7	525,6
			20	617,2	667,8
			30	669,4	810,0
			40	919,0	952,2
			50	1156,8	1094,4

Table 44

To sit – S

Time, s	Height of the seat above the floor level	Object weight, kg, not more											
		0		10		20		30		40		50	
		Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J
1,3	0,7	204,0	50,9	362,3	63,1	522,6	75,5	682,7	88,1	843,1	100,7	1003,6	113,3
	0,6	224,0	117,9	366,6	139,3	512,0	160,4	658,2	181,4	806,1	202,1	953,9	222,7
	0,5	226,7	117,9	368,0	207,7	512,1	236,8	657,2	265,4	803,5	293,7	905,6	321,7
	0,4	230,0	241,3	369,8	279,7	512,3	317,0	656,1	353,6	800,9	389,6	996,1	425,2
	0,3	225,5	292,0	364,8	337,2	507,2	381,3	652,9	424,3	800,9	466,6	946,1	508,3

Table 45

To sit – S

Time, s	Height of the seat above the floor level	Object weight, kg, not more											
		0		10		20		30		40		50	
		Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J	Stat. moment, Nms	Mech. work, J
1,6	0,7	190,8	52,9	285,4	72,7	390,3	94,8	499,9	117,9	611,7	140,9	724,8	162,7
	0,6	299,1	146,0	382,2	186,1	476,9	225,6	578,7	264,7	683,6	303,4	792,8	340,4
	0,5	327,3	224,9	412,3	278,9	508,0	331,3	610,6	383,1	697,8	434,5	825,9	484,1
	0,4	351,3	313,0	438,1	381,5	535,0	448,1	638,6	514,1	744,6	579,6	855,8	642,9
	0,3	344,3	380,6	431,7	460,1	529,1	537,6	633,0	614,3	739,5	690,4	850,5	764,4

Table 46

Movement of a foot – MF

Movement characteristics	Time, s	Stat. moment, Nms	Mech. work, J
Without efforts	0,24	4,48	1,44
With effort	0,40	7,35	2,35

Table 47

Movement of a leg – ML

Movement characteristics	Time, s	Stat. moment, Nms	Mech. work, J
Without efforts	0,24	12,5	9,52
With effort	0,40	20,5	15,3

Table 48

To put down a load – Pl

Movement characteristics	Time, s	Stat. moment, Nms	Mech. work, J
To put down solid and soft objects	0,072	0,9	0,03
To put down fragile objects	0,138	1,74	0,01

Note. When the object is lowered with two arms, the values of mechanical work and static moment are doubled. The microelement time remains unchanged.

Table 49

Microelements performed with the help of eyes

To look closer – Z_1

The microelement time is 0,26 s. This movement does not cause any noticeable changes in the mechanical energy of human body, so the static moment for it equals the posture one, i.e., the moment to maintain the appropriate posture, and the mechanical work is taken as zero.

End of Table 49

To shift the gaze – Z_2

For this microelement, the same considerations as for the movement "To look closer" are characteristic. However, when performing this microelement with the help of turning the head, it is necessary to take into account the mechanical work.

Time, s	The angle of head turning, grad, up to	Mech. work, J
0,54	60	1,4
	120	5,6
	180	12,6

Table 50

Correction of the static moment to maintain the posture

Character of work posture	Formulas of the work correction	Parameters included into the formula
Standing	$M_0=[(150+6{,}2\cdot\sqrt{\varphi^2+m^2})^2+(150{,}2+11{,}2m)^2]^{1/2}$	M_0 – posture moment, Nm; φ – angle of arms inclination to the frontal plane of the joint, grad; m – weight of the object being moved, kg
Sitting	$M_0=[(54+2{,}3\sqrt{\varphi^2+m^2})^2+(51{,}8+8{,}05m)^2]^{1/2}$	

Note. For working movements: Step to the side (SS); to bend slightly (Bf_1); to bend low (Bf_2); to straighten out from the position “to bend slightly” (SBf_1); to straighten out from the position “to bend low” (SBf_2); to down on one knee (KN_1), to get down on both knees (KN_2); to get up from one knee (GKN_1); get up from both knees (GKN_2), to sit (S); to get out of the “sitting” position (GS); to turn the body (TB),the maintenance corrections are omitted, because they were taken into account earlier, when calculating the ergonomic parameters for these microelements.

Analysis chart of labor process

Name of the process	Movements of the left arm	Designa-tions	Logical bonds	Mech. work, J	Stat. mo-ment, Nms	MKE time		Stat. moment, Nms	Mech. work, J	Logical bonds	Designa-tions	Movements of the right arm
						Over-lapping	Non-over-lapping					
	2	3	4	5	6	7	8	9	10	11	12	13
To set up work-pieces							0,68	159,0	20,2	$\overset{1}{\rightarrow}$	ШС1	To packing
							0,6	105,1	31,3		ПР1	To workpieces
											(φ90)	
							0,624	314,7	1,8		ПР2	To workpieces
											(S400)	
											(ОС1; К1)	
							0,279	147,7	–		В2	Workpieces
	To transfer	П2В (S100; Р0,38; ОС1; К1)					0,6	105,1	31,3		ПТ1 (φ90; Р0,38)	With workpieces
							0,68	159,5	20,2		ШС1	To plate
							1,28	306,5	18,1		ШС2	To plate

Analysis chart of labor process

1	2	3	4	5	6	7	8	9	10	11	12	13
To set up workpieces	To move	П2Н (S400; P0,38; ОС1; К1)		18,1	553,7		1,02					
	To release	ОТ2		0,06	38,2		0,072					
	All workpieces?	ly	[1] →									
	To preset	ПР1 (S100;ОС1; К2)									ПР1 (S100;ОС1; К2)	To workpiece
	To set up	УП1 (P0,02; 133)		011	55,8	0,108	0,108	55,8	0,11		УП1 (P0,02; 133)	To set up
	Is it set up correctly?	ly	[2] →							[3] ←	ly	Is it set up correctly?
							0,756	389,6	6,6	[4] → [5] →	ПР2Н (S600; ОС1;К3)	To control panel

Analysis chart of labor process

1	2	3	4	5	6	7	8	9	10	11	12	13
To set up workpieces	To "On" switch	НРС1		0,01	82,9		0,16					
	To "Start" button	ПР1 (S50; ОС1; К3)		0,45	190,1		0,39					
	"Start" button	НРС1		0,01	82,9		0,16					
							0,39	204,5	1,22		ПР2В (S100; ОС1; К2)	To control panel
Size control	"Stop" button	НРС1		0,01	82,9		0,16					
	To the part	ПР1В (S600; ОС1; К2)		8	388,7	0,756	0,828	388,2	1,9		ПР1Г (S750; ОС1; К2)	To clamp
	Part	В1		–	77,7	0,147	77,7	–			В1	Clamp
	To move	П1Г (S400; Р0,02) (ОС1; К2)		0,61	1019	1,22	1,22	1019	0,61		П1Г (S500; Р0,1) (ОС1; К2)	To move

Analysis chart of labor process

1	2	3	4	5	6	7	8	9	10	11	12	13
Size control							0,99	508,6	0,03		УОС1Г (P0,1; L10)	To set up
										← 4	ly	Is it machined enough?
							0,726	374	–		РС1Г (P01; 1100; L10)	To separate
	To turn part	ПОВ1 (P0,2; φ180) (OC1)		0,76	228,5		0,444					
							0,99	508,6	0,03		УОС1Г (P0,1; 1100; L10)	To set up
										← 5	ly	Is it machined enough?

Analysis chart of labor process

1	2	3	4	5	6	7	8	9	10	11	12	13
Size control							0,726	374	–		РС1Г (Р0,1; 1100; L10)	To separate
	To move	П1Н (S200; Р0,02)		6,2	527	1,0	1,22	637,3	4,3		П1Г (S500; Р0,1)	To postpone
		(ОС1; К1)									(ОС1; К1)	
	To release	ОТ1		0,03	38,2	0,072	0,072	38,2	0,03		ОТ1	To release
							0,684	350,4	0,83		ПР1Г (S500; ОС1; К1)	To parts
	Parts	В2		–	747,7		0,279					
							0,36	530	4,3		П2В (S100;Р0,38) (ОС1; К1)	To move

Analysis chart of labor process

1	2	3	4	5	6	7	8	9	10	11	12	13
Part removal							0,68	159,5	20,2		ШС1	To packing
							0,6	105,1	31,3		ПТ1	With parts
											(φ90; Р0,38)	
							0,072	38,2	0,06		ОТ2	To release
				t_0	=	$\sum_{i=1}^{u} t_i$	=	27,3	s			
				A_0	=	$\sum_{i=1}^{u} A_i$	=	244,05	J			
				M_0	=	$\sum_{i=1}^{u} M_i$	=	13112,6	Nms			

Correction factors for microclimate C_m for works, performed in the room (V=0,2 m/s, γ≡50÷70%)

Air temperature in the work zone, °C	Work hardness groups									Characteristics of work hardness groups for v=0,2 m/s, γ=50÷70% and temperature, corresponding to the comfort zone	
	light works		medium severity		hard			very hard			
0	1,15	1,08	1,05	1,03	1,00	1,00	1,00	1,00	1,00	hardness group	coefficient of physical labor intensity C_{pi}
10	1,07	1,05	1,03	1,00	1,00	1,07	1,09	1,10	1,10		
12	1,05	1,02	1,00	1,00	1,06	1,09	1,11	1,12	1,12		
15	1,02	1,00	1,00	1,07	1,09	1,10	1,12	1,15	1,15	I	0,5
18	1,00	1,00	1,07	1,09	1,10	1,12	1,15	1,20	1,20	II	0,51–1,0
20	1,00	1,07	1,09	1,10	1,12	1,15	1,20	1,25	1,25	III	1,01–1,70
25	1,00	1,09	1,10	1,12	1,15	1,20	1,25	1,30	1,30	IV	1,71–2,50
30	1,03	1,10	1,12	1,15	1,20	1,25	1,30	1,35	1,35	V	2,51–3,00
35	1,08	1,12	1,15	1,20	1,25	1,30	1,35	1,39	1,39	VI	3,01–3,50
40	1,12	1,15	1,20	1,25	1,30	1,35	1,39	1,42	1,42	VII	3,51–4,00
45	1,15	1,20	1,25	1,30	1,35	1,39	1,42	1,45	1,45	VIII	4,01–4,50
50	1,20	1,25	1,30	1,35	1,39	1,42	1,45	1,48	1,50	IX	4,51–5,00

Supplement 2

Calculation results of mechanical work

Name of work types	Internal energy consumption excluding basic metabolism	Mech. work performed by the system "human-tool-labor object", kgm/min	Ratio of mech.work to internal energy consumption, kgm/kcal	Estimated coefficient of the ratio between static and dynamic load on muscles (*a*)
1	2	3	4	5
Sitting still without movement	0,3			
Sitting still without movement	0,7			
Walking without load, speed – 2 km/h	1,2	300	250	0,84
>> – 3 >>	1,7	500	294	1,00
>> – 4 >>	2,1	710	337	1,00
>> – 5 >>	2,8	850	304	1,23
>> – 6 >>	3,8	1300	330	1,19
>> – 7 >>	5,4	1700	314	1,38
Walking with 10 kg load, speed – 2 km/h	3,6	840	235	1,73
>> 30 kg >> 4,0 >>	5,3	1120	212	2,05
>> 50 kg >> 4,0 >>	8,1	1240	153	3,00
>> 75 kg >> 3,5 >>	11,7	1300	110	4,24
>> 100 kg >> 3,0 >>	15,0	1300	87	5,50
Working with shovel:				
s=1,0 m; h=1,0 m; n=15 throws	6,3	1200	190	2,34
s=1,0 m; h=1,0 m; n=15 throws	6,6	1085	184	2,72
s=1,0 m; h=1,0 m; n=15 throws	8,0	1170	146	3,06

1	2	3	4	5
Working with shovel:				
s=1,0 m; h=2,0 m; n=12 throws	8,9	1240	139	3,30
s=2,0 m; h=0,5 m; n=12 throws	7,2	1280	178	2,54
s=2,0 m; h=1,0 m; n=10 throws	7,8	1200	153	2,96
s=2,0 m; h=1,5 m; n=10 throws	9,0	1280	142	3,24
s=2,0 m; h=2,0 m; n=10 throws	10,0	1340	134	3,47
s=3,0 m; h=1,0 m; n=10 throws	8,8	1450	165	2,80
s=3,0 m; h=1,5 m; n=10 throws	9,5	1520	174	2,90
s=3,0 m; h=2,0 m; n=10 throws	10,4	1580	152	3,07
Pushing the cart:				
v=3,6 km/h; F=11,6 kg	7,7	1055	136	3,30
v=3,6 km/h; F=16,1 kg	10,6	1250	117	3,96
Pulling the cart: v=3,6 km/h; F=11,6 kg	8,5	1055	123	3,70
v=3,6 km/h; F=16,1 kg	10,9	1250	114	4,08
Walking up along the plane inclined at 10°, v=7,24 m/min without load	4,9	560	115	3,74
The same with shoulder load of 20 kg	6,1	760	125	3,56
>> 50 kg	9,2	1100	120	3,86
Inclination of 25°, v=17,6 m/min without load	13,3	1180	89	5,35
The same with load 20 kg	17,2	1620	94	5,10
>> 50 kg	26,3	2250	86	5,70
Walking up the stairs inclined at 30,5°, steps: width – 29 cm, height – 17,2 cm, 100 steps, velocity – 17,2 m/min, without load	13,7	1220	89	5,35
The same with load 20 kg	18,4	1575	85	5,62
>> 50 kg	26,3	2111	80	6,00

End of Supplement 2

1	2	3	4	5
Climbing the ladder, distance between the steps – 17 cm,70 steps per minute, load on the back, inclination – 50°, climbing speed – 9,12 m/min, without load	6,6	656	84	4,50
The same with load 20 kg	8,4	938	110	4,10
>> 50 kg	13,2	1213	93	5,15
Ladder inclination – 70°, climbing speed – 11,2 m/min, without load	8,0	788	94	4,62
The same with load 20 kg	10,2	1012	100	4,69
>> 50 kg	16,0	1348	84	5,65
Ladder inclination – 90°, climbing speed – 11,9 m/min, without load	10,4	831	82	5,83
The same with load 20 kg	13,5	1069	79	6,00
>> 50 kg	24,3	1425	58	8,27
Working with hammer, two-handed impact work with the full force, hammer weight – 4,4 kg, 15 hits per minute, hit from above.	7,9	1070	147	3,06
The same, circular hit	6,7	1187	178	2,53
The same, hammer weight 10,6 kg, hit from above	8,2	1000	122	3,76
The same, circular hit	7,3	1180	162	2,80
Iron filing, 42 file movements per minute	2,0	200	100	3,26
The same, 60 movements per minute	2,5	300	120	3,00
The same, 80 movements per minute	4,2	415	99	4,20

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