Editorial board

Editorial board

Editorial board

Editorial board

Editorial board

Vladimir Shapovalov

(Material science)

Professor, D.Sc. in engineering,

MER Corporation

Arizona, USA

Sergiy Belodedenko

(Engineering design)

D.Sc. in engineering, professor

National Metallurgical Academy of Ukraine

Dnipropetrovsk, Ukraine

Valeriy Balakin

(Material sciense, Constructional design)

D.Sc. in engineering, professor

National Metallurgical Academy of Ukraine

Dnipropetrovsk, Ukraine

Algorithmic software of the automatic risk management system on offshore drilling platform with a high level of automation

Zhilenkov A. A.

Associate Professor of Department of Control Systems and Informatics,
Candidate of Technical Sciences
Saint Petersburg National Research University
of Information Technologies, Mechanics and Optics
Saint-Petersburg, Russia
zhilenkovanton@gmail.com

Abstract
Offshore drilling platform is a complex object that includes an integrated automation system, each element of which is the source of the risk of emergency situations occurrence. These elements include primary transducers such as sensors, actuating devices and the systems of automatic control and regulation, due to their potential possibility of incorrect response to emerging operating conditions. Implementation of these risks can lead to catastrophic consequences. An algorithm for risk management as an add-on centralized automatic management system of the drilling platform was proposed to minimize the risks and their consequences. The algorithm includes the identification of risks, their analysis, prioritization, risk management planning, the process of managing and monitoring the risk metrics, according to which the assessment of the quality and effectiveness of risk management is carried out. Planning of risk management includes the processes determining ways to manage, search for ways to reduce the risks, risk documenting and risk metrics. The algorithm is based on the analysis of scientific publications dedicated to the description of emergency situations on drilling platforms: their causes, course and consequences; database of design offices, as well as the author's own research conducted at several drilling platforms operating in the Black Sea shelf.
Key words: OFFSHORE DRILLING PLATFORM, AUTOMATIC CONTROL SYSTEM, TECHNOLOGICAL PROCESS, RISKS, SYSTEM ANALYSIS, PROACTIVE CONTROL, IDENTIFICATION

Introduction

The appearance of an emergency on an offshore drilling platform with a high degree of probability can lead to catastrophic consequences. Over the last thirty years the history counts about fifteen largest in scale accidents on offshore drilling. It is referred to the tragedies in which the number of human casualties has reached several hundred and the amount of oil poured into the ocean has reached to tens of thousands barrels and contaminated surface area has been thousands of square kilometers. So, 168 people from 224-men team died due to an accident on «OccidentalPetroleum'sPiperAlpha» platform in 1988. In 1979, as a result of the accident on a platform near the coast of Mexico about 30,000 barrels of oil were thrown out in the sea. In 2009, the accident at the «Seadrill'sWestAtlas» platform led to the contamination of 2300 square miles of the sea area near the coast of Indonesia. And these are only the most serious accidents the damage from which was calculated in each case by billions of US dollars. This article reflects some of the results obtained in the course of work on the study of risk management problems on offshore drilling platforms.

The concept of risk implies the possibility of a different kind of losses or damage that will occur as a result of the continuation of a current action or script of the process development. Risk is a function of two parameters: the probability of an undesired event occurrence and the scale of the consequences caused by it (damage). The losses include financial damage, loss of time (simple), loss of productivity, etc. The risk is a kind of harbinger of the problem, its reminder, the probability that in a given point of time of system functioning the set goals may not be met by existing resources and operations. In a complex system reducing the risk to zero is impossible, but it is possible to manage it.

Sources of risk in the automation system of drilling platforms

Modern offshore drilling platforms are completely self-contained objects, which from the automation point of view consist of many complex subsystems that have their own local and central management for the entire system. In fact, each of these subsystems, starting from elementary sensors and ending with central control units, is a set of critical components or potential sources of unwanted scenarios of processes in the system and its defects.

Management systems of modern drilling platform are interlinked and have the Control Center:

- drilling operator chair with monitoring tools and manipulators;
- place of the remote control and management, located in the office of the drilling platform-owning company;
- place of the remote control and management, located in the office of the manufacturer of the automation system company installed by the customer on this drilling platform.

All major subsystems are interconnected by a computer network. The subsystems themselves have local software and ensure the implementation of control over drilling platforms elements by algorithms embedded in programmable logic controllers.

Operator working in a chair of a drilling operator or at one of the remote control places in the coastal offices has access to the settings and monitoring the status of each of the subsystems. For example, Fig. 1 shows a window for monitoring the state of the drilling mud control subsystems. By clicking on one of the displayed items the detalization window appears displaying the status of the elements of the selected subsystem.

Figure 1. Software window of status monitoring of the drilling mud control subsystems

Presented software interface was shown for the possibility of estimation the amount of information on the automation subsystems status that must be controlled by the operator during drilling, in addition to monitoring the parameters of the drilling process and the effective management of this process. The settings window shown in Fig. 1 describes only subsystem 1. Each subsystem has the similar individual subsystem settings in general and the plurality of its components in particular.

Risks associated with incorrect settings of systems

The analysis has shown that one of the most frequent causes implementation scenarios of risk zone is the process of setting up the subsystems and their components by the operator, engineer and according to control and measuring apparatus and automation or by other members of supervisors staff. Moreover, a specific reason can be distinguished, i.e. the deliberate removal of warnings or alarms provided by the software. In the process of drilling rig operation, a lot of emerging warning messages are related to the necessity of various types of sensors testing. Some sensors break down; the other part requires periodic calibration. The automatic control system generates reports for each of the sensors in the general registry of errors and warnings, and further indicates a fault in the appropriate system control window, where the problematic sensor is installed.

Modern control systems are used in the drilling platforms due to its flexibility, implying the possibility of upgrading the drilling rig hardware. They allow setting of all alarm threshold set values.

Under these circumstances, risk of emergency conditions is associated with reaching the alarm value of certain controllable parameter. But, as practice shows, the risk is transformed into a real emergency situation when the staff intentionally removes the signaling (in some cases, automatically blocking certain operations of drilling to eliminate the causes of the alarm), changes (overestimates) of the alarm set values so that signaling is no longer triggered without eliminating the cause.

The second typical reason of risk increasing is a forcing of the sensor readings. When, in response to the warning about the incorrect functioning of a particular sensor, the staff forcibly changes the value of its output signal in the program settings producing a kind of false calibration. The process is similar to described above process, but it corrects the value of the controlled variable instead of the set values.

These actions are not always deliberate. History provides the disaster on drilling platforms, caused by an error of sensor calibration.

Risks associated with the incorrect response to the warning

The authors have carried out the analysis of a large volume of reports on identified errors and warnings generated by the centralized management system for a number of eight-hour shifts of drilling operator. On the basis of the analysis the following conclusions were made:

- generated reports on error and warnings on all studied offshore drilling platforms do not meet the requirements of the industry standard [1] in terms of the frequency of warnings on the operator's screen;
- the prioritization when warnings is absent;
- the warnings are excessive and mostly uninformative.

Analysis has shown that the main problem in terms of prevention of the unwanted scenarios for the processes development in a complex control system of the drilling platform is a large amount of warnings provided to operator by the software. Every 10-12 seconds the operator receives a new error warning. Taking into account that the operator during this time controls processes related to well drilling by carrying out the monitoring of numerous parameters and deciding on further action, to assess adequately the continuous stream of warnings is impossible. Moreover, to identify in dozens of minor warnings the only error that can lead to catastrophic consequences is also impossible. Studies have shown that even explicit in its critical level errors in the stream of warnings of such intensity are elementary lost without reaching the operator's attention [2-5].

Considering that during one shift a number of warnings provided to the operator amounts in thousands, to find warnings indirectly indicating the risk of a critical error is virtually impossible.

This situation is compounded by the fact that out of all available options for sorting of the accumulated warnings is not possible to sort errors and warnings according to the priority.

Thus, firstly the risks of adverse scenarios occurrence as a result of "lost" warnings in excess information should be defined.

Further, studies have shown that the majority of alarms noticed by staff are actually ignored. In the existing control and monitoring systems the alarm signal may be delayed or the operator can confirm that he has received a signal.

Thus, the operator can confirm the receipt of an alarm signal, but does not take measures to eliminate its causes. Often this is due to the unawareness of the causes of the alarm and, as a consequence, it is impossible to predict possible catastrophic consequences in the case of ignoring its causes.

Risk management

In the larger systems, it is impossible to predict all the possible options for the processes development. But it is possible to name the main reasons for the development or actualization of risks: lack of information, lack of time and mismanagement.

According to the objectives considered by the authors, risk management requires the establishment around the target system at risk of proactive or reactive environment (but with higher reaction rate) of decision-making, which is able to continuous identify (predict) in real time the possibility of occurrence under these scenarios conditions of the events leading the process into error.

Further, it is necessary to determine which of the identified risks have the highest priority. Based on the assigned priorities, it is necessary to implement the decision-making according to on undertaken measures capable to prevent the identified undesirable scenario of possible course of events.

The task of creating a risk management system brings us to the problem of risk management strategies development, determination of risk management processes and, consequently, the development of methods, techniques and data support tools on the risk management processes.

The difference of mentioned proactive risk management from reactive is that when the reactive management fighting with erroneous scenario begins at its culmination, which can be compared with the methods of firefighting, unlike the methods of fire occurrence prevention methods corresponding to proactively control philosophy. When proactive management special focus is not only on the development of plans for prevention of the emerging undesirable scenarios, but also on the methods of early identification of the latter and their effective prevention by all means available prior to the scenario has begun to develop, and its consequences have begun to acquire the critical scale. Therefore, the proactive nature reaction is more desirable.

Figure 2 shows the structure of the risk management process. It consists of five main functions:

- identification of risks;
- analysis of risk;
- prioritization of risks;
- planning of measures to reduce or prevent the risks development;
- implementation of measures to reduce or prevent risks;
- control of measures taken and the monitoring of the system state subjected to preventable risk (tracking for risks metrics).

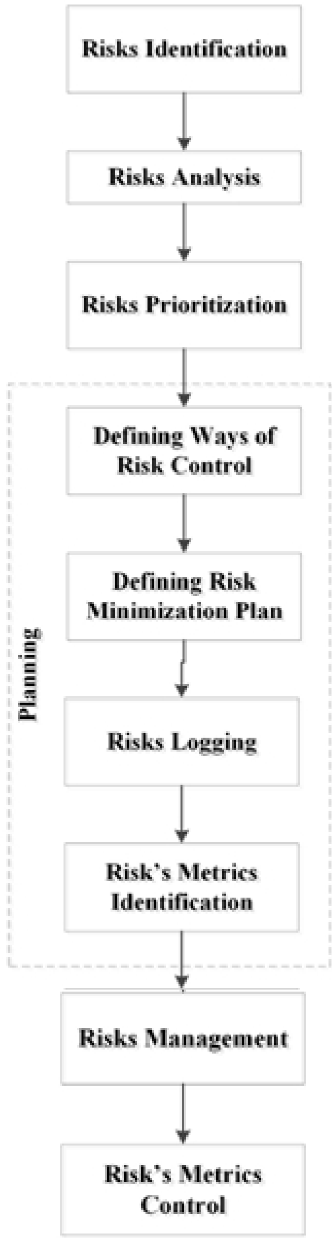


Figure 2. Structure of the risk management process

Identification of risks

For the effective risk management, firstly, it is necessary to ensure their identification. During proactive risk management, the identification should be performed prior to actualization of unwanted development scenario of the risk identified, i.e. at an early stage.

In the present study, a main class of considered risks was industrial risks, namely the risks of violations of technological processes. In turn, according to the results given above, these risks can be classified by the following main components [6-9]:

- risks associated with the human factor, i.e. with incorrect management, equipment and software setting;

- instrumental risks (hardware and software) are the risks that are associated with the occurrence of incorrect operation of the software or hardware (usually sensors);

- technological risks are risks associated with the occurrence of incorrect reaction of the management system (automatic or human operator) to the changed conditions.

Since the structure of the system, which risks are supposed to control is known, and its normal functioning criteria are determined quite definitely [10; 11], it is possible to create a basis for risks characteristic at the stage of its design complementing it during the system operation by unaccounted but arise in its work and identified risks.

Conclusions

On the basis of the proposed algorithm it is possible to create a supervisor -system integrated with a central drilling rig management system that will not only minimize the influence of the human factor in the control of warning signals and processes of information confirmation about emergency conditions, but also to identify the risks created under the given conditions in various subsystems of equipment and, consequently, to control them.

References

1. ISA 18.2: Management of Alarm Systems for the Process Industries, Int'l Soc. Automation, 2009.
2. Pereyra Marcelo (2016) A Survey of Stochastic Simulation and Optimization Methods in Signal Processing . *IEEE Journal of Selected Topics in Signal Processing*. No 10 (2). p.p. 224-241.
3. Renders J.M., Flasse S.P. (1996) Hybrid methods using genetic algorithms for global optimization. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*. No26 (2), p.p. 243-258. DOI: 10.1109/3477.485836
4. Guilherme Bergmann Borges Vieira (2015) The Rationalization of Port Logistics Activities: A Study at Port of Santos (Brazil). *International Journal of e-Navigation and Maritime Economy*. No2. p. p. 73-86.
5. Zhilenkov A., Chernyi S. (2015) Investigation performance of marine equipment with specialized information technology. *Procedia Engineering*. Vol. 100. p.p. 1247–1252.
6. Jensen R., Shen Q. (2008) *Computational intelligence and feature selection: rough and fuzzy approaches*. Hoboken: John Wiley & Song. 339 p.
7. Chaudhuri A., Stenger H. (2005) *Survey sampling theory and methods*. New York: chapman & Hall. 416 p.
8. Lavrakas P.J. (2008) *Encyclopedia of survey research methods*. Thousand Oaks: Sage Publications. Vol. 1-2. 968 p.
9. Shchokin V. (2015) Neuro-fuzzy activation sub-system of effective control channels in adaptive control system of agglomerative process. *Metallurgical and Mining Industry*. No 3, p.p. 6-14.
10. Shchokin V. (2014) Automation agglomeration production on based application neuro-fuzzy regulation of lower level. *Metallurgical and Mining Industry*. No 6, p.p. 32-39.

Automatic control of the ore suspension solid phase parameters

Andrey Kupin

D.Sc. in engineering, Professor, head of Computer networks and installations department, Kryvyi Rih National University, Kryvyi Rih, Ukraine

Natalia Morkun

PhD, Associate professor of Economic Cybernetics and Project Management Department Kryvyi Rih National University, Ukraine

Abstract
Method of automatic control of ore suspension solid phase parameters, which comprise the forming of gamma rays and low-frequency volume ultrasonic waves in the ore material suspension flow, measurement of the intensity of gamma radiation and low frequency volume ultrasonic waves, is presented.
Keywords. ULTRASOUND, AUTOMATIC CONTROL, ORE, SUSPENSION, SOLID PHASE, GAMMA RAYS

The invention relates to acoustic measurements and can be used for automatic control of the main characteristics of the ore solids in suspension, in particular the concentration of solids, its size distribution and the useful component disclosure degree. The closest technical solution, which is selected as a prototype, is a method of automatic control of the ore suspension solid phase parameters [1]. The disadvantage of this method is that the Love waves intensity in the measuring chamber wall, which contacts with the controlled medium flow varies according to condition of the metal film on the measuring chamber wall, which is in constant contact with the ore suspension abrasive medium. Wear and removing of the metal film leads to ambiguity of measured values, which are determined according to the parameters of the ore suspension solid phase. Thus, the known method requires constant monitoring and determining the state of metal film on the wall of the measuring chamber, and is impossible in the existing production. This fact leads to errors and, consequently, reduces the stability and reliability of measurement results. The object of the invention is to improve a method of ore suspension parameters automatic control by increasing the stability and reliability of measurement results [2-4].

The problem is solved by the method of automatic control of the ore suspension solid phase parameters, which comprise the forming of ore suspension material flow and the reference fluid in the measuring chamber, periodic influence of ultrasonic vibrations on suspension flow, formation of high frequency volume ultrasonic waves in the ore suspension flow, intensity measurement of high frequency volume ultrasonic waves, which have passed a fixed distance in the presence of reference liquid and ore suspension flow in the measuring chamber in the periods of ultrasonic oscillations influence on suspension flow, and in case of its absence, and calculation of measured values ratios, according to which the parameters of ore suspension solid phase are determined [5-9]. According to the invention, gamma radiation and low frequency volume ultrasonic waves in the flow of ore material slurry are formed, the intensity of gamma radiation and low-frequency volume ultrasonic waves is measured.

The method is implemented as follows [10-11]. Firstly, the reference liquid (water) is fed into the measuring chamber. Gamma radiation in the measuring chamber is formed, and passes a fixed distance in it. The obtained result is attenuation of the gamma radiation intensity. This result is reference (basic). In operation condition, the ore material suspension flow in the measuring chamber is formed. Gamma radiation, which passes a fixed distance in the measurement chamber in the presence of ore material suspension flow, is formed. The attenuation coefficient of gamma radiation, which passed a fixed distance in ore suspension material flow, is determined by expression

$$\mu = (1-W)\rho_W \mu_W + W\rho_S \mu_S \quad (1)$$

where μ_w and μ_s are the mass attenuation coefficients of water and suspension ore material respectively; p_w and p_s are the density of water and suspension ore material particles respectively; W is the volume fraction of ore particles in suspension.

The intensity of gamma radiation, which passed a distance l in ore suspension material flow, can be presented as follows

$$I = I_0 \exp\{-[(1-W)\rho_W \mu_W + W\rho_S \mu_S]l\}, \quad (2)$$

where I_0 – is the intensity of gamma radiation in the absence of ore material slurry in measurement chamber.

If water is present in the measuring chamber, the intensity of gamma radiation will be determined by the formula

$$I^* = I_0 \exp(-\rho_W \mu_W l)\ . \quad (3)$$

Considering (2) and (3), the intensity of gamma radiation can be represented as

$$I = I^* \exp\{-W[\rho_T \mu_T - \rho_W \mu_W]l\}. \quad (4)$$

This value does not depend on the particle size of solid phase i.e. ore slurry material, and is determined only by the slurry solid phase concentration and its particles density. According to the proposed method, the value S_r for the gamma radiation is formed

$$S_\gamma = \ln\frac{I^*}{I} = AW[(\rho_S \mu_S - \rho_W \mu_W)l], \quad (5)$$

where A – is the proportionality coefficient.

This expression shows that the density of the controlled medium, which depends on the ore suspension solid phase concentration and its particle density is determined by logarithm of intensity ratio of the gamma radiation in the presence of water flow and ore suspension in measuring chamber. Similarly, the value S_1 is determined for high frequency and S_2 for low frequency volume ultrasonic waves, which passed a fixed distance through the flow of water and ore suspension. Accordingly, the value S_1 is determined by

$$S_1 = \ln\frac{I_{w1}^{vol}}{< I_{v1}(z) >} \quad (6)$$

where I_{w1}^{vol} - is the intensity of high frequency volume ultrasound waves, which have passed a fixed distance z through the flow of water; and $< I_{v1}(z) >$ - for ore suspension flow. Thus, the value S_1 is determined by the logarithm of intensity ratio of high frequency volume ultrasound waves, which have passed a fixed distance z through the flow of water and ore suspension.

For this

$$< I_{v1}(z) > = I_{w1}^{vol} \exp\left(-\frac{Wz}{\aleph}\int_0^{r_m} \sigma(v_1, r)F(r)dr\right), \quad (7)$$

where $\aleph = \int_0^{r_m} \frac{4\pi r^3}{3} F(r)dr$; $F(r)$ – is the function of the solid phase particle size distribution in the ore suspension r; r_m – is the maximum solid phase particle size in the ore suspension; $\sigma(v_1 r)$ – is the cross section of high frequency volume ultrasonic wave attenuation of frequency v on the particle of size r.

The value σ (v,r) for any frequency volume ultrasonic waves is determined by the sum of the absorption cross-sections σ_s (v,r) and scattering σ_c (v,r) of ultrasound

$$\sigma(v,r)=\sigma_c(v,r)+\sigma_s\left(v,r\right) \quad (8)$$

In high frequency region ($v_1 \geq 5\cdot 10^6$) the ultrasound attenuation is caused mainly by scattering of ultrasonic waves on the solid phase particles: $\sigma_1(v,r) \approx \sigma_c(v_1,r)$. Therefore, the signal, which is generated at frequency $v_1 \geq 5\cdot 10^6$ Hz will be determined by the size and concentration of ore slurry solid phase particles. Thus, value S_1 depends on the ore suspension solid phase particle size and its concentration W

$$S_1=\frac{Wz}{\aleph}\int_0^{r_m}\sigma(v_1,r)F(r)dr \quad (9)$$

In the low-frequency region $v_2 \geq 5\cdot 10^5$ Hz the ultrasound attenuation is caused by viscous inertial effects: $\sigma(v_2,r) \approx \sigma_s(v_2,r)$. Therefore, the signal, which is generated at a frequency $v_2 \geq 5\cdot 10^5$ Hz will be proportional to the concentration of the ore suspension solid phase and independent of its particle size.

Accordingly, the value S_2 is determined by the expression

$$S_2=\ln\frac{I_{w2}^{vol}}{<I_{v2}(z)>} \quad (10)$$

For this

$$<I_{v2}(z)>=I_{w2}^{vol}\exp\left(-\frac{Wz}{\aleph}\int_0^{r_m}\sigma(v_2,r)F(r)dr\right), \quad (11)$$

Thus the value S_2 depends on the concentration W of ore suspension solid phase and does not depend on its particle size:

$$S_2=\frac{Wz}{\aleph}\int_0^{r_m}\sigma(v_2,r)F(r)dr\,. \quad (12)$$

If we divide (6) by (10), we can obtain a value S, which depends on the ore suspension particle size

$$S=\frac{S_1}{S_2}\,. \quad (13)$$

Measurement of the useful component content can be reduced to the determination of specific weight (density) of solid phase particles, which are located in the ore suspension. In the measuring chamber section, where the value S is determined, the flow of enriched material suspension is periodically exposed to high intensity ultrasonic waves. Due to the radiation pressure and acoustic flows, there is a displacement of ore suspension solid phase particles from the trajectory of their normal movement in the flow in the direction of high-intensity ultrasonic oscillations influence. Displacement of ore suspension solid phase particles leads to their redistribution by size and concentration in the high intensity ultrasonic oscillations influence zone. The value of this redistribution for the same particle size is determined only by the mineral composition (the ratio of the useful component and gangue) and specific weight (density) of each component. For solid phase particles of the same size, which are crushed to a particle size of useful component inclusions, the value of the displacement is proportional only to their specific weight. Thus, the change value of S parameter under the high intensity ultrasonic oscillations influence depends on the useful component content in the ore suspension solid phase fractions of various size. According to the proposed method the value S_r is determined as

$$S_r=k_1\frac{S_B-S_0}{S_B} \quad (14)$$

where S_B – is the measured value S in the presence of high intensity ultrasonic oscillations influence; S_0 - is the measured value S in the absence of this influence; k_1 - is the proportionality coefficient.

To obtain a signal which depends on the useful component content of ore suspension solid phase fractions of corresponding size, i.e. disclosure of useful component, the ratio of S_K is calculated

$$S_K=k_2\frac{S_\gamma}{S_r} \quad (15)$$

All or only certain size classes of the crushed material i.e. a certain solid phase size fraction can be displaced in the measurement zone by increasing the intensity of ultrasonic oscillations from zero to a certain value and with ore suspension constant flow rate.

$$F(r)=\left(\int_0^{r_1}f(r)r^3dr+\int_{r_1}^{r_2}f(r)r^3dr+\ldots+\int_{r_{m-1}}^{r_m}f(r)r^3dr\right)\Big/\int_0^{r_m}f(r)r^3dr\,. \quad (16)$$

Thus, the value S_K, which is calculated at a certain ultrasonic oscillations intensity in the ore suspension flow determines the density of solid phase particles or useful component concentration in ore suspension solid phase fractions of appropriate size.

Conclusions

Since all calculations are made on the basis of measurements relative to characteristics of the reference material, the obtained results are protected from various disturbing factors, which reduce the accuracy of measurement parameters of ore suspension solid phase.

Thus a method of ore suspension parameters automatic control allows to increase the stability and reliability of measurement results of ore suspension solid phase.

References

1. Patent 27086 Ukraine, МРК G 01 N 29/02. *Sposib avtomatychnoho kontrolyu parametriv tverdoyi fazy pulpy* [The automated control method of pulp solid phase parameters]. №200708421; Appl. 23.07.07; Publ.10.10.07, Bul.№16.
2. Golyamina I.P. Ultrazvuk: Malenkaya entsiklopediya [Ultrasound: Little encyclopedia]. Moscow: *Soviet Encyclopedia*, 1979.
3. Rosenberg L. D. (1967). *Fizika i tekhnika moshchnogo ultrazvuka. Istochniki moshchnogo ultrazvuka* [Physics and techniques of powerful ultrasound Powerful ultrasonic source]. Moscow: *SCIENCE*.
4. Grinman, I., Blyakh, G. (1967). *Kontrol i regulirovaniye granulometricheskogo sostava produktov izmelcheniya* [Control and regulation of ground product particle size distribution]. Alma Ata: Nauka.
5. Bergman L. (1957). *Ultrazvuk i yego primeneniye v nauke i tekhnike* [Ultrasound and its application in science and technology], Moscow, Foreign literature publishing.
6. Landau L.D., Lifshits Ye.M. (1954). *Teoreticheskaya fizika. Mekhanika sploshnykh sred* [Theoretical physics. Continuum Mechanics], Moscow:*GITTL*.
7. Kozin V.Z., Tikhonov O.N. (1990). *Oprobovaniye, kontrol i avtomatizatsiya obogatitelnykh protsessov* [Testing, monitoring and automation of enrichment processes], Moscow: Nedra.
8. Protsuto V.S. (1987). *Avtomatizirovannyye sistemy upravleniya tekhnologicheskimi protsessami obogatitelnykh fabrik* [Automated process control systems of concentrating plants]. Moscow: Nedra,.
9. Morkun V., Morkun N., Pikilnyak A. (2015). Adaptive control system of ore beneficiation process based on Kaczmarz projection algorithm, *Metallurgical and Mining Industry,* No2, pp.35-38.
10. Morkun V., Morkun N., Tron V. (2015). Formalization and frequency analysis of robust control of ore beneficiation technological processes under parametric uncertainty, *Metallurgical and Mining Industry,* No 5, p.p. 7-11.
11. Morkun V., Morkun N., Pikilnyak A. (2014). Simulation of the Lamb waves propagation on the plate which contacts with gas containing iron ore pulp in Waveform Revealer toolbox. *Metallurgical and Mining Industry,* No5, p.p. 16-19.

Floors lift technique in old building retrofitting

Yevgen Diachenko

PhD in Technical Sciences, Associate professor
Poltava Nation Yuri Kondtatyuk University, Poltava, Ukraine
E-mail: evgeny1210@gmail.com

Olena Voskobiinyk

Doctor of Technical Sciences, Senior Research Scientist
Poltava Nation Yuri Kondtatyuk University, Poltava, Ukraine
E-mail: lvosko@mail.ru

Inna Lomiga

PhD in Technical Sciences, Associate professor
Poltava Nation Yuri Kondtatyuk University, Poltava, Ukraine
E-mail: i-parhomenko@mail.ru

Abstract
The current article proposes the idea of using floor lift for retrofitting of living spaces and premises under conditions of dense urban building and analyzes the feasibility of the claimed issue. We report on the advantages of the method described in the article over the other constructional techniques, which require floors substitution or embedded structures erection.
Key words: RETROFITTING, LIVING SPACES, PREMISES, FLOORS SUBSTITUTION, EMBEDDED STRUCTURES, FLOOR LIFT TECHNIQUE, MONOLITHIC CONSTRUCTIONS

Retrofitting of the living spaces located in the old city, which in most cases are of historic value and create the architectural signature of the city centre, is definitely a significant problem of the present day. The urgency of this problem is explained by the necessity for us to meet the conditions when we need to maintain architectural integrity of the historical buildings and at the same time to adapt their constructions and designs for the modern conditions of operation. The main reason, why retrofitting is demanded, is that the existing old buildings with timber floors designs do not meet the contemporary conditions. Moreover, due to long years of operation, the timber floors are usually in dad conditions and require substitution as they cannot withstand under new increased operational loads. One of the methods to refurbish such buildings is to erect embedded systems while preserving their closure constructions (Figure 1). The retrofitting works have the specific feature: they are carried out under conditions of dense urban area and, in particular, within the historical centres, therefore the very limited area of the construction site is their characteristic.

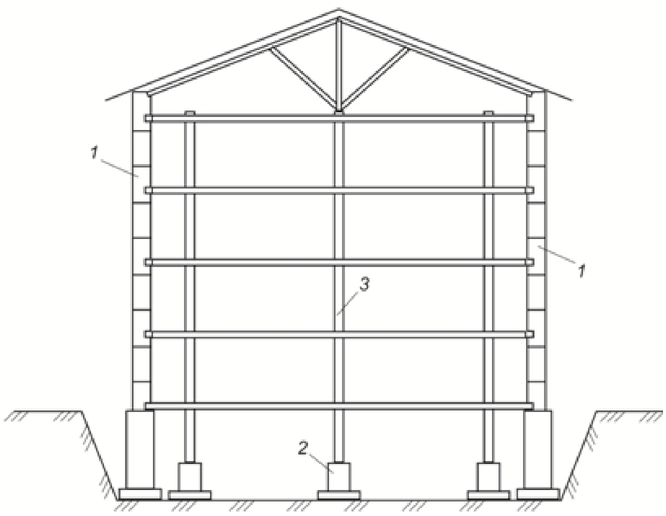


Figure 1. House retrofitting with embedded systems:

1 – existing closure constructions; 2 – embedded system foundation; 3 – embedded constructions

This crucially affects the opportunities to apply the building machines and cranes on the site. Moreover, the work of a crane under these conditions in some cases demands the relief of traffic or even traffic interruption within the neighboring areas for a long period of time and in other cases the use of cranes is absolutely technically impossible. This makes builders eliminate the use of assembled reinforced concrete structures but apply monolithic reinforced structures as embedded carcass work. However, the operations with monolithic reinforced structures are also performed with cranes because they lift reinforcing carcass and formworks. One of the techniques, which allows us to reject cranes completely for embedded constructions, is the method of floors lift [1].

Based on the fact that the problem of old buildings retrofitting for living spaces and premises is very topical, a big number of papers have recently been published on this theme in Russia and Ukraine [2 – 6] as well as in other countries [7 – 15]. The publications [2 – 6] discuss the specific features of old buildings retrofitting, problems of building machines operation within the tight building site and compare application of reinforced concrete structures assembly versus monolithic reinforced structures. The above authors conclude that old building retrofitting with the techniques of floors substitution and embedded constrictions enables us to sustain the architectural face of the city and meet the new requirements for building operation. The other papers are devoted to the case studies on retrofitting [7 – 9], reinforcing the constructions of the historical buildings [10 – 12] and general problems of older buildings retrofitting [13 – 15].

Despite a big number of publications devoted to the above stated problem, there is still no solution how to obviate completely the use of cranes while retrofitting old buildings though this permits us to ease building works organization on a small construction site and to exclude intervention into traffic on the nearby roads. This issue is still open for discussion.

The presented article aims at the contributing to the problem under discussion by reaching the targets as follows:1) to analyze the specific character of floor lift technique within the method of embedded constructions erection for both living spaces and premises retrofitting; 2) to outline the advantages of the mentioned technique over the other ones.

As it has been stated [1], floor lift technique in building carcass multi-storied houses with monolithic reinforced concrete framing or assembled and monolithic one is based on development of the floor on the ground surface or on panel floor, over the substructure of the whole panel floor arrangement. After placing the panel floors and obtaining the required hardness of the concrete, the panels are lifted against the previously settled columns by the hoist means in the position designed by the project. This technique consists of the following order of works to be performed: 1) construction of the substructure by the conventional methods, which demand the foundation construction for the columns, mounting of the underground parts of the columns, arrangement of underground parts of the closure structures, etc. (Figure 2); 2) installation of stiffening core to ensure the steadiness of the house both transversely and longitudinally; stair enclosures and lift shafts are, as the rule, located within the stiffening cores; 3) mounting or installation of the monolithic columns of the first tier; 4) arrangement of all the panel floors within the building lines to cover all the building area or the bay; 5) after the concrete pad with the panels is hard enough, the panels arrangement is lifted by into the intermediate position, these operations are carried out by means of the hoists fixed against the columns; 6) mounting or installation of the next column tier, shift of the hoisting means and lift of panel floors; 7) after all the floors are lifted and set into the positions required by the project, the hoists are removed, the builders construct the roof, mount the closure structures, and perform all the general and decoration works.

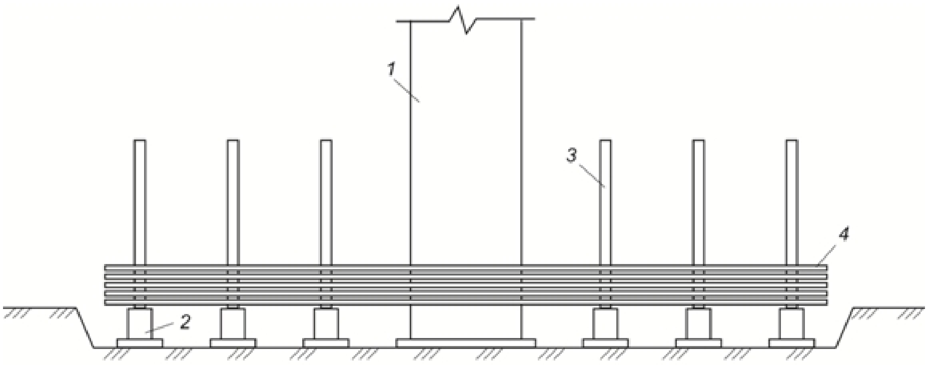


Figure. 2. Building by floor lift technique:

1 – stiffening core; 2 – foundation; 3 – columns; 4 – packages of panel floors

Among the advantages of the above-described technique, one can single out the shorter period of cranes operation (in some cases their elimination), greater reduction in the construction site area and freedom of engineering solution choices on designs and constructions owing to the absence of the load-bearing walls.

This technique was initially developed for building new houses and had not been considered as one for retrofitting of refurbishing.

However, the analysis on the technique advantages implies that its use for retrofitting and refurbishing with the approach of embedded systems erection would enable the works to be carried out within the area limited by the conditions of dense urban districts. The floor lift technique with its feasibility to eliminate the cranes permits the reduction in the site area nearly to the room of the house under construction. Thus, there is no need to impose the traffic relief or interruption, to ban the pedestrian movement or to interferer with operation of the nearby houses.

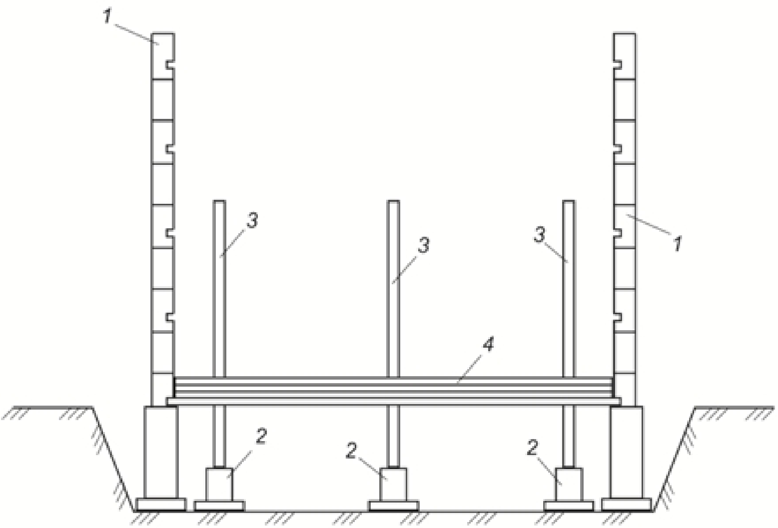


Figure. 3. Layout of the embedded carcass. Floor lift technique at the stage of concrete placing for the panels floor:

1 – existing walls; 2 – foundation for the embedded carcass; 3 – columns; 4 – panel floor arrangement

We find it reasonable to describe the work organization structure when we apply the floor lift technique for retrofitting:

1) dismounting of the house internal constructions:

performing this works, one should strictly observe the sequence requirements of the dismount maps; strengthening of closure constructions are to be carried out if necessary;

2) ground processing for the embedded construction foundation, and installation of monolithic foundations for the embedded constructions. The concrete mixture could be prepared on the site and supplied by a concrete pump, set within the house area. As the concrete is hard enough, waterproof sealing of foundation and back filling with compacting are performed. The operation of concrete pad placing into the underground part of the house is the operation on requirement or optional;

3) installation of the monolithic columns of the first tier. The formwork and the reinforcing carcass are lifted from the scaffold while the concrete mixture is supplied with the pump;

4) installation of monolithic floor plate over underground house part; concrete is supplied from the single point and introduced into the formwork with the pump, located at the external part of the house;

5) after the concrete plate becomes as hard as required, all the panels of the arrangement are places on it, in a way of one panel after the other one (Figure 3); the panels are separated with the distributing layer;

6) as the concrete hardens more to the required value, the scaffold, the formwork, the reinforcing carcass and a light pump are placed on the last panel with the objective to perform concrete works for the next column tier;

7) the hoists to lift the panel arrangement are mounted on the first tier column heads[1]; the panels are lifted into the intermediate positions and fixed (Figure 4);

8) concrete works of the second column tier;

9) the lifting is not continued until the column concrete is not hard as demanded; the last two steps of the described procedure are repeated again before we complete the concrete works for the last column tier; at the final stage, the joints between the columns and panels, the ones between the panels and enclosure constructions are filled and the concrete pump is removed by the crane. The surface cover, internal works and decoration works are carried out with the conventional techniques.

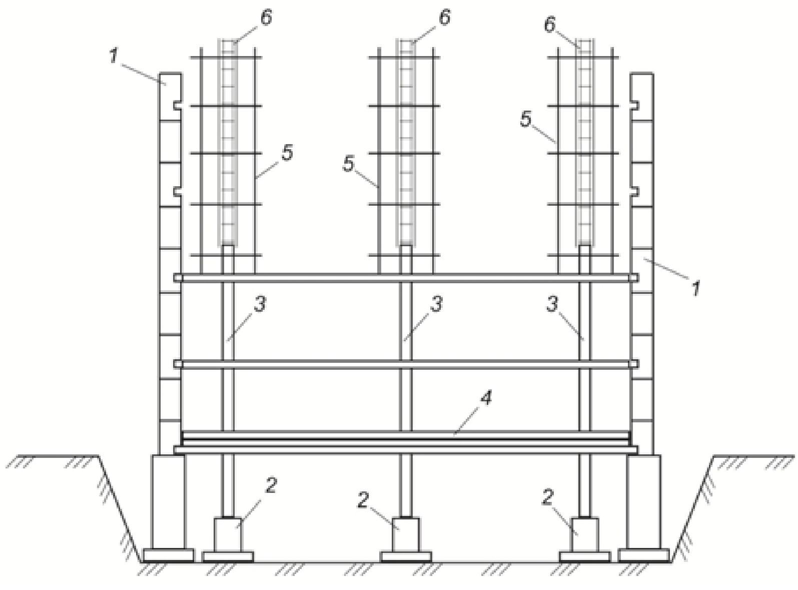


Figure 4. Embedded carcass installation with the floor lift technique (Concrete procedure for the second column tier):

1 – existing walls; 2 – foundation for the embedded carcass; 3 – columns; 4 – panel floor arrangement; 5 – scaffold; 6 – column formwork

The above described work procedure evidences that the technique proposed in the current articles enables us to minimize crane operation during the retrofitting of old buildings. This enhances building planning scheme ratio up to 60 – 80% while the conventional techniques possess the ratio of 10 – 40%. The method we propose excludes installation of the formwork for panel floor arrangement and the supports to bear it owing to the possibility to use the panels priory made with concrete as the formwork for the following ones. Thus, the drastic decrease in labour hours is achieved with the operations on panel floor.

However, the use of the lift technique under conditions of embedded systems erection foresees manual works for column formwork assemble, installation of reinforcing carcasses into the formwork as well as mounting and dismounting of the scaffold and the hoists.

Conclusions

The floor lift technique proposed in the current article foresees installation of carcass type embedded systems made from monolithic reinforced concrete and could be applied for retrofitting of the living spaces and premises. The rationality of this technique application becomes obvious after economic comparative analysis versus the other techniques used under the similar conditions.

The floor lift technique allows almost complete elimination of the cranes to be applied on the site and significant (50%) reduction in construction site area as compared against the techniques which use the cranes for embedded construction erection. Retrofitting work with the floor lift technique does not interfere into the traffic of the nearest areas and permits the construction operations under conditions of the dense urban districts.

One of the criteria to make the described technique feasible is the presence of the stiffening core in the house. The walls of stair enclosures, which are left untouched by reconstruction and does not undergo dismounting, could serve as the stiffening core.

References

1. Telichko V. I. (2004) *Tekhnologia vozvedenia zdanii i sooruzhenii* [Building technology for houses and modules]: Moscow: Vyssh. shk. 446 p.
2. Osipov A. F. (2002) Osobennosti ob»emno-planirovochnykh i konstruktivnikh kharakteristik rekonstruiruemykh zhilykh zdaniy [Specific features of spacial arrangements and constructional characteristics for living spaces]. *Stroitel'stvo i tekhnogennaya bezopasnost'* [Building and Safety]. No 6, p.p. 260–265.
3. Osipov A.F. (2005) Vozvedenie monolitnykh perekrytiy pri rekonstruktsii zhilykh zdaniy [Monolithic floors erection for living houses reconstruction]. *Novi tekhnolohiyi v budivnytstvi* [New building technologies]. No 1, p.p. 46–52.
4. Osipov O.F. (2006) Rekonstruktsii zhilykh zdaniy. Metody vozvedennya monolitnykh perekrytiy [Houses reconstruction. Monolithic floors technique]. *Novyny nauky Prydniprovia* [*News in science in Pridniprovia region*]. No 3, p.p. 9–15.
5. Osipov A. F. (2009) Razrabotka organizatsionno-tekhnologicheskikh modeley zameny perekrytiy v zdaniyakh istoricheskoy zastroyki [Organizational and technological model development for floors substitution in houses of historic value]. *Stroitel'stvo i tekhnogennaya bezopasnost'* [Building and Safety]. No 29, p.p. 101–108.
6. Voskobinyk O.P. (2012) Osoblyvosti tekhnolohii vykonannia robit pry rekonstruktsii budivel za dopomohoiu vbudovanykh system [Specific character of embedded systems operations for houses reconstruction]. *PNTU* [*University PoltNTU named after Yurii Kondtatiuk*]. No 33, p.p. 43 – 48.
7. Caldwell M. (2009) The Fort Stanwix Administrative History: A Superintendent's Perspective. *The Public Historian*. Vol. 31, No 2., p.p. 66-70
8. Korkmaz E. (2013) Retrofitting Deniz Palace Historic Building for Reusing. *International journal of electronics; mechanical and mechatronics engineering*.Vol. 2, No 3, p.p. 269 – 278.
9. Korkmaz E. (2008) Research on Techniques Using For The Retrofitting Of Historical Masonry Structures – Case Study Deniz Palas Building. *CHRESP: 8th EC Conference on Sustaining Europe's Cultural Heritage (10-12.11.2008).*
10. Guh T.J. (2006) Seismic Retrofit of Historic Building Structures. *8th U.S. National Conference on Earthquake Engineering (April 18-22).*
11. El Gawady M. A. (2004) Review of Conventional Seismic Retrofitting Techniques for URM.*13th International Brick and Block Masonry Conference (July 4-7).*
12. Smith A., Redman T. A. (2009) Critical Review of Retrofitting Methods for Unreinforced Masonry Strucutres. *EWB-UK Research Conference, The Royal Academy of Engineering.*
13. Drury P. McPherson A. (2008) Conservation Principles, Policies and Guidance for the Sustainable Management of the Historic Environment. *English Heritage.*
14. Holland A.G. (2011) The Retrofitting of Historical Buildings. Virginia: Commonwealth University, Richmond, Virginia. 120 p.
15. Green M. (2012) Building Codes for Existing and Historic Buildings. USA, Hoboken: Wiley. 247 p.

UDC 625.42.8-331.45

Psychological aspects of workplace safety in the infrastructure projects of underground

Voznenko A. D.

Ph.D., Professor
Director of Ukrainian State University of Railway Transport, Kyiv

Kulbovsky I. I.

Ph.D., associate professor of the Department of Building constructions and facilities
Ukrainian State University of Railway Transport, Kyiv

Sorochinskaya O. L.

Ph.D., associate professor of department of Ecology and life safety
Ukrainian State University of Railway Transport, Kyiv

Abstract
The relationship of work safety psychology and occupational injuries was studied and analyzed; the reasons for causing injuries in the workplaces in the structural divisions of underground were stated. The measures to improve the labor safety management systems in enterprises of underground were proposed.
Key words: WORK SAFETY PSYCHOLOGY, OCCUPATIONAL INJURIES, SOCIAL SECURITY, ISO STATE STANDARD, UNDERGROUND, PROJECT, INFRASTRUCTURE, PRODUCTION PROCESS, MEASUREMENT TOOLS

Work safety psychology is a branch of psychology that studies the psychological causes of accidents occurring in the course of work and other activities and develops psychological methods to improve safety. The objects of research are mental processes (perception, attention, memory, etc.), which are generated by human activities and affect the mental state of a person, personality characteristics and its safe behavior during the work.

The properties and characteristics of psyche and consciousness play an important role. The factors determining the nature of human work activity are physical activity, the amount of nervous and emotional stress, rhythm, pace of work, its monotony, the volume of perception and processing of information, etc. The mental condition namely the existence of conflicts, weariness, exhaustion, illness, dependence on drugs, alcohol, nicotine, particularly of the human psyche have a special influence on the person labor safety.

Analysis of occupational injuries shows that the main cause of injuries and death of people in the workplace is a bad mental state of workers while performing work duties.

The activities for the prevention of occupational injuries are important to ensure reliable and uninterrupted production process. Stop of production for various reasons is now frequently encountered and leads not only to a sharp decrease in labor productivity, production losses, but also to a sharp deterioration in the physical and psychological health of the staff, it gives rise to various kinds of errors in the work, stress state, increases the risk of accidents and injuries. Such production is accompanied by significant mental stress, disruption of the normal work rhythm, disputes of workers with their colleagues and the leadership of the enterprise [1].

On this basis, in conditions of instability of production, along with safety condition of equipment, working environment and measuring devices, considerable attention from the leadership of the enterprises structural divisions should be given to improve the reliability of the human factor in “man - machine - environment” system [2, 3]. It is necessary not only to improve the quality of staff training and briefing on the labor safety and first of all to carry out the proper psychological work in order to bring up the psychology of safe work in workers conscience, when they will be able to evaluate every step and every action from the point of view of its safe performance in compliance with state standards.

Before the accident, usually some kind of dangerous situation occurs when the person can understand the approach of such a case and can take necessary measures to prevent it. The inability of man to realize the dangerous situation in time and to take adequate measures leads to accidents and crashes. A person should envisage the development of the manufacturing process and his behavior, to realize in time the dangerous situation and prevent accidents. Sometimes these cases are considered as a consequence of inadequate behavior of the person in a dangerous situation.

The safety human behavior on the production depends on the following factors:

- state of unconditioned reflexes, which people unconsciously use respond to various dangers that threaten his organism (e.g., automatic hand moving away from a hot object);
- psycho-physiological qualities of man, which appear in its sensitivity to the signals of danger, its high-speed response capability to these signals, in the emotional reactions of danger when determining a dangerous situation and responding to it. The emotional, mental and physical condition effects on the human behavior. Thus, the state of anxiety sharpens the sense of danger and the state of weariness reduces the human ability to identify and counteract the danger;
- professional qualities and experience of the person, i.e. knowledge of the profession and safety rules, life experience;
- motivation to safe work, compliance of technological processes performance.

Sometimes the motives of some benefits (time savings, increased production) exceed the safety performance motives. The workers should be morally and materially encouraged to comply with the requirements of work safety and state standards to increase their motivation. The costs of such encouragement justify the prevention of accidents. This will make safe work financially profitable. A worker will earn more not only due to the productivity of labor, but also due to the fact that he works safe according to the instructions. And it is important that every violation of normative documents on labor safety should not be unnoticed, all employees should be aware that any violation of the instructions will be punished.

Motivation of the worker to safe labor increases when they notice that there is a strict control over the compliance with safety regulations in the company. The employees are financially and morally encouraged for the high safety conditions. The condition for bonus payments should be work without injuries and accidents. The executives of the enterprise units from the material incentive fund can be paid a reward only under the condition that at the sites and services, which they head, there are no injuries and violations of labor safety requirements and the means of individual and collective protection, equipped with medical kits, etc are available.

Management of the enterprises should abandon the principle of “production and safety separately”, and move on to the principle of “production in safety conditions”, when safety becomes a means of achieving efficiency. The labor safety policy should be directed to the collective search for ways to prevent accidents. Each in its place should make proposals in this direction. The mental attitude aimed at safety should be created in the stuff.

Psychological processes of human labor activity and work safety are characterized by a number of basic types of mental activity (sensation, perception, attention, etc.). The worker receives information from several sources of irritation simultaneously by different senses. This is a perception process. Time of perception by different senses reaches the second and more. It is important for the worker to know which objects he should watch over very carefully during the production process [4].

The concentration of attention can be caused by external factors (noise, light). This is unconscious concentration of attention. The conscious concentration, which is carried by the second signal system (speech, thinking, etc.), is of great importance. The unconscious concentration of attention may cause distraction from the main work and can lead to an emergency situation. At the same time, the person is able to divide the mental processes, for example, to do the work automatically and think about something else. However, work will be safe under condition that the worker at any time is able to connect a second signaling system for the adoption of urgent solutions. This is achieved by education and development of appropriate skills. Thus, the development of skills and the ability to consciously control mental activity is an important condition for work safety.

The human ability to keep the attention on one object determines the attention stability and the ability to transfer attention to other objects is the phenomenon of refocusing. Distraction factor can cause attention wander, which leads to errors. If a person simultaneously watches over the several objects, it causes the attention allocation. However, a person cannot simultaneously observe more than 4-5 objects. Studies show that the man can observe one object with the same degree of attention no more than 10-20 minutes. Weariness influence significantly the attention. It reduces the range of attention and decreases the time of its concentration. Therefore, it is necessary to provide a rest pause (15 min break after every 2 hours) for such work [4].

The labor collective is also an important moment in the formation of safety psychology. Each collective has formal and informal leaders, which determine the attitude of workers to performing the instructions on labor safety. Thus, it is necessary to form the right attitude of the collective to the safety by involving the leaders to the activities as authorized for the labor protection. Safety measures coincide with the objectives of the collective and production process. The leader must regularly remind to the workers about this. The authority of leader is created if the instructions are not carried out due to administrative subordination, but due to a result of awareness by the subordinates of their correctness.

Thus, the physiological hazards factors directly affect the person, the physical and physiological processes, performance, mood, productivity and life in general.

First of all, the fight against weariness is improving the sanitary and hygienic conditions of the production environment (elimination of air pollution, noise, vibration, microclimate normalization, rational lighting, etc.). The professional selection, organization of workplace, the correct working position, the rhythm of work, rationalization of the labor process, the use of emotional stimuli, the introduction of rational modes of work and rest play a special role in the prevention of weariness of workers.

In addition, the specific methods such as the means of recovering the functional state of visual and musculoskeletal system, hypodynamia reducing, brain blood circulation increasing, mental performance optimizing are applied for the prevention of weariness of workers.

From the medical point of view, the exercises including psychotherapy, physical, water and air procedures, physiotherapy, massage, adequate nutrition, vitamins and minerals, relaxing music and exercise, meditation, autogenous training are recommended to use for the prophylaxis, prevention and rehabilitation of the consequences of emotional stress.

In the prevention of weariness and overwork of worker, a significant role also belongs to the rational organization of work and rest. Physiologists have substantiated five conditions for improving working efficiency that promote effective prevention of weariness:

- you need to enter slowly to any work;
- measured pace and rhythm are the condition of successful working efficiency;
- familiarity, sequence and planning;
- negligence and haste in the work are not permitted;
- physiologically reasonable alternation of work and rest, as well as changes in the forms of activities (the most effective relaxation is associated with the active state of the muzzle);
- favorable attitude of society to work (labor motivation and social conditions).

The negligence of the worker himself is one of the common causes of occupational injuries in the underground facilities. The worker actions can be considered as of negligence if he is inattentive at work, does not use personal protective equipment, and applies carelessly to the requirements of labor protection instructions. Sometimes workers with great experience of more than 10-15 years ignore the implementation of safety rules and regulations on labor protection.

The human factor is the cause of most accidents (75%), so the main focus of the preventive work should be improving the workers' health and preservation of it during working hours. An important direction of this work is the early diagnosis of occupational pathology and the disease condition of the nervous system. The accident is the result of failure taking into account the potential danger. The physical condition of the worker (good sight, hearing, etc.) plays an important role [5].

Perfect vision is an important condition for work safety. A large part of accidents occur as a shortcomings result of poor lighting of tunnels races, mines, machinery spaces of escalators, transformer and traction step-down substations of workplaces, etc. Uneven lighting requires frequent readaptation of vision that takes up to 6 seconds while an accident can occur.

A high background noise and hearing losses lead to rapid weariness and delayed reactions to the sound signals. The more tired is the person, the longer it takes for the perception and reactions to a dangerous situation.

Reduction of incidence and preservation of health of workers are important social and economic problems. Radical measures in this direction are improving of working conditions, conducting therapeutic and preventive measures (health education, promotion of healthy lifestyles, industrial gymnastics, medical examination, etc.). This will reduce the level of injury and increase economic efficiency of production.

Workers should know and follow occupational safety instructions when working. However, the instructions cannot foresee everything. Vital activity is much more difficult than the detailed instruction. Therefore, it is very important to bring up at workers the ability to observe, to be cautious and careful.

The workers poll have shown that the majority of them consider the imperfect labor organization, bad mood, weariness, conflicts in collective with manager, inattention of managers to the subordinates, unsatisfactory psychological climate as the most common causes of injury.

The violation of work and rest rhythm has a significant impact on the working efficiency. Therefore, in determining the working time mode, the shifts schedules should be set so that the duration of rest between workers shifts when taking into account intra-shifts breaks is not less than double length of working time of its previous shift. Working time established by legislation cannot be changed by the administration even with the employee's consent.

The requirements to his performance should be sufficiently high considering that the worker error during operation may endanger the health and life of both worker and other people. Most employees feel weariness at the end of shift, which increases probability of traumatic situation occurrence, therefore strict adherence to the established legislation and work and rest rules is very important.

The biorhythms have a huge impact on health, working efficiency and reliability of human. It is known that the human body has more than 100 different rhythmic processes. There are many publications on the effectiveness in regulating the workers operation regimes of work and rest taking into account the three sinusoids with periods of 23, 28 and 33 days characterizing the physical (working efficiency, energy), emotional (mood, reaction) and intellectual (intelligence, memory) state [6].

In order to prevent accidents and diseases, the safe working methods should be promoted. The following methods of mass agitation work are applied: briefings, lectures, films, radio programs on issues of work safety. The posters and memos are widely used. Posters promote to keep right and safe work practices in the minds of worker. Effective labor protection propaganda is a form of public reviews, which are conducted by the administration together with trade union activists. It is important to use such forms of propaganda, as exhibitions, stands, corners of safety information, etc.

However, formation of motives forcing worker to observe safety regulations is more effective than methods listed, not because the employer requires so, but because this is his personal desire to psychological setting on safe work. This setting is achieved by improving the psychological climate, attracting workers to the control of occupational safety, educational work, managers' personal example.

Thus, the social and psychological safety management methods are based on the use of a set of interrelated factors, such as knowledge of safety requirements, skills of safe work, motivation, professional performance, moral stimulation for compliance with safety regulations, the humanization of labor, respect for science-based work and rest, promotion of occupational safety, therapeutic and preventive measures.

For this reason, the professional selection and professional orientation of employees for certain responsible professions are the important factors among the social-psychological methods of occupational safety management. Not only physiological, but also psychological data, i. e. a sense of responsibility, degree of confidence in their capabilities, volitional qualities (self-control, perseverance, determination) should be taken into account. The probability of accidents increases with the inclination of the worker to risk, adventurism, indiscipline, frivolity, social instability, aggressiveness and impulsivity.

Existing methods of economic motivation of labor protection at the enterprises in modern conditions of managing are complicated by the lack of funds to carry out appropriate administrative and technical measures and incentives for staff. Therefore, the solution of work problems on labor protection at the enterprises can be achieved by improving the efficiency of economic activity. The existing procedure for the centralized management of economic activity at the enterprise, when all of control levers are located at the first head, is out of date. This procedure suppresses initiative and productivity in the labor collectives. It is necessary to radically change the order of performance management.

Economic mechanism of occupational safety management should provide an incentives system for the employees who conscientiously comply with the requirements of occupational safety; do not allow violations and breaches of personal and collective safety; take the active and creative part at implementation of measures to improve the level of occupational safety at the enterprise. The collective agreement should fix the various kinds of moral and material incentives of the employees such as salaries, bonuses (including special incentive bonuses for the achievement of a high level of occupational safety), reward for inventions and rationalization proposals on labor safety issues. The bonuses to workers teams, sites, shops for a long work without violations of safety rules, without injuries and accidents bring the positive results. In case of dangerous and harmful production factors, which are constantly threaten the employee's health, it is recommended to pay a premium for extra caution. In addition to material incentives, the moral stimulation is also important, which one time has been used in our country and successfully applies in foreign firms. Forms of moral incentives can be very diverse: from the announcement of gratitude to the amusement evenings, picnics, cruises for collectives that have achieved the best results on a labor safety.

The unsatisfactory state of occupational safety at the enterprise leads to inhibition of the economic and social progress of the country in general. According to the experts of the International Labour Organization losses due to the accidents at work and occupational diseases accounted for 4% of global gross domestic product (GDP). Thus, the improvement of occupational safety system is one of the most urgent issues at the level of both the State and the individual enterprise.

The occupational safety and health management at the enterprise is a set actions of officials carried out on the basis of ongoing analysis of information on the state of occupational safety in all workplaces to improve and maintain it at a certain level in accordance with the laws and regulations. [7]

The attitude of workers to the labor duties depends not only on wages but also in many ways on their confidence in the permanent employment, respect, recognition, interest in the work. The manager task is to combine the strong leadership with the giving to the subordinates the opportunity to show their creativity, initiative and individuality. The head should inform his subordinates about the state of business. This increases the interest of people to work. Every employee must realize that his work is very important that the enterprise may stop without his participation. The favorable and safe working conditions in the workplaces are important factors in increasing labor productivity. Additional costs for the improvement of occupational safety are repaid many times. This is evidenced by the experience of developed countries.

Efficiency measures for labor protection activities in the structural divisions of underground:

1. The key to decrease in the level of workplace injuries and improve of occupational safety is the rise of the economy, which in the current economic conditions can only be achieved by production decentralizing.

2. Improving the state of labor protection in structural divisions of underground can be achieved by transition from carrying out the certain disconnected activities to the system of planned purposeful management of the activities with a clear definition for each of the structural division of the enterprise, the list and contents of the tasks and functions of management. Occupational safety work tasks are derived from the entire production of the enterprise departments and aimed at the implementation of Occupational safety requirements of public policy.

3. In order to meet plan and other tasks of labor protection work at the enterprises, the funds of occu-

pational safety should be created paying 0.5% of the volume of sales of products (services).

4. In the structural subdivisions of underground the systematical engineering support of OSH management system should be carried out by bringing manufacturing equipment, processes, buildings and structures, timely verification of measuring instruments, sanitary and hygienic state, sanitary and domestic security, etc. in compliance with the requirements of normative acts on occupational safety with the use of modern methods of engineering and reengineering in order to eliminate unacceptable risks and adherence with state standards.

5. For briefing and training of employees in occupational safety the modern methods of active studying, the training of workers in psychology and culture of safety should be used when someone's threatening action would have been impossible. Before each potential danger, operation its implementation plan is made, the work permit is written out and a detailed briefing is conducted. At the first violation of safety rules the violator is given a warning, at repeated one he acts under the Labor Code. The occupational safety management system is a daily serving functional management subsystem of enterprise, institutions and organizations [8].

According to the legislation current in Ukraine the certification of enterprises in compliance with state standards DSTU ISO 9001-2001 "Quality Management Systems. Requirements" and GOST ISO 14001-97 "Environmental Management System" is carried out. The occupational safety management system is also subjected to certification. According to international standards, the following points are checked: the presence of a safety certificate, the integration of this system with the systems of quality management and availability of environmental protection document "Work Safety Policy at the Enterprise" signed by the first head and the implementation of this policy. The availability of normative legal acts of occupational safety, carrying out the certification of workplaces and evaluation of occupational risk on them, the availability of personal protective equipment, staff training, safety during high-risk works, certification of sanitary condition and the availability of means of occupational safety in the workshops, conducting audits of occupational safety state in the shops and at the enterprise in general are checked. [9]

References

1. Handzyuk M. P., Zhelibo E. P., Halimovskiy M. O. (2003) *Osnovi ohoroni pratsi: Pidruchnik dlya stud. vischih navch. zakladiv, 3-te vid* [Basics of occupational safety: Textbook for students of higher education institutions, 3rd ed]. Kyiv: Karavela, 392 p.
2. Fomin O. V. (2015) Increase of the freight wagons ideality degree and prognostication of their evolution stages. *Scientific Bulletin of National Mining University*. No 2. p. p.68-76.
3. Fomin O. V. (2015) Improvement of upper bundling of side wall of gondola cars of 12-9745 model. *Scientific and technical journal «Metallurgical and Mining Industry»*. No. 1. p.p. 45-48.
4. Hohitashvili H. H., Lapin V. N. (2005) *Osnovi ohoroni pratsi: Navch. Posib.* [Fundamentals of labor safety: Scientific manual]. Kyiv: Znannia, 408 p.
5. Ageev E. Ya. (2009) *Osnovy ohorony pratsi: Navchalno-metodichniy posibnyk dlia samostiynoi roboty po vivchennyu distsipliny* [Fundamentals of labor safety: Textbook for individual work on the study of discipline]. Lviv: Novyi Svit – 2000. 404 p.
6. Handzyuk M. P., Zhelibo E. P., Halimovskyi M. O. (2005) *Osnovi ohoroni pratsi: Pidruchnik dlya stud. vischih navch. zakladiv* [Basics of occupational safety: Textbook for students of higher education institutions]. Kyiv: Karavela. 408 p.
7. Moskaleva V. M. (2005) *Osnovi ohoroni pratsi: Pidruchnik* [Fundamentals of labor safety: Textbook]. Kyiv: Profesional, 672 p.
8. Tkachuk K. N. (2011) *Osnovi ohoroni pratsi: Pidruchnik, 3-te vid* [Fundamentals of labor safety: Textbook, 3rd edition]. Kyiv: Osnova. 480 p.
9. GOST ISO 9001-2001 *Sistemy upravlinnia yakistu. Vymogy* [Quality management systems. Requirements]

UDC 622.24.0010

Studying the structure of railway rolling stock resistance

Tkachenko V.P.

D. Sc. in Engeneering, Professor
v.p.tkachenko.detut@gmail.com

Sapronova S.Y.

D. Sc. in Engeneering, Professor

Maliuk S.V.

post-graduate student

Kulbovskyi I. I.

PhD. Sc., Associate professor
State Higher Educational Institution
"State Economy and Technology University of Transport"
Kyiv, Ukraine

Abstract
The purpose of the work is to improve the structure of the resistance to movement, based on the formalization of its components related to the frictional interaction of the wheels and the rails and the vehicles directing by rail track. The formalized structure of the general resistance to movement of railway vehicles on the basis of clarifying the origin of its components associated with the direction of the vehicle by the rail track is presented in the article. The mechanism of the influence of dynamic

processes frictional interaction of wheel sets and the rail track on the resistance to movement was developed. A new terminology for the resistance to movement associated with the vehicle directing by rail track was proposed.

Key words: RAILWAY VEHICLE, RESISTANCE TO MOVEMENT, FRICTIONAL INTERACTION OF VEHICLE AND RAIL TRACK, WHEEL SET, RAIL

Problem statement

Railway Transport of Ukraine, as earlier, plays a crucial role in freight and passenger transportation of the country. For its operation up to 18% of the total consumption of diesel fuel and 4.5% of electricity are consumed. Up to 75% of energy is consumed to overcome the resistance of trains. Thus, the resistance to movement is one of the main factors influencing the energy indicators of the railway transport.

The idea of reducing the resistance to movement is very attractive due to economic factors, such as the resistance reduction just by 1% would allow annual savings of one railroad engine to 150 MW·h of electricity, or about 12 tons of diesel fuel.

Determination of unsolved problems

When designing new types of rolling stock the characteristics of resistance to movement are not analyzed due to the lack of appropriate methods [1-4]. This often leads to an unjustified increase in operating of the friction loads on the contacts of wheels and rails, which acting as friction dampers with high power dissipation level and create additional resistance to movement. The operational data on intensive flanges worn sharp and side wear of the rail heads can be the indirect proof of that [6].

The authors believe that the component of the resistance to movement connected with the vehicles directing by rail track is the most attractive to reduce it.

Analysis of recent researches and publications

The work of H. Hayman [5] can be considered as the first and the most detailed study of the vehicles directing by rail track as frictional interaction of wheels and rails. The paper laid down the basic ideas of the vehicle directing by rail track. Although the main focus was on the direction forces, the work became the basis for further research of the resistance to movement connected with directing of the wheel sets by rail track.

Relative kinematics of the wheel sets and rail track and the wear of surveying rods and wheels in the curved sections of the rail track was studied in [7]. Model of rails vehicles and rail track is considered as the system of a multi-point contact of wheels and rails. The kinematic slippages in contacts when the radial and optimum setting of wheel sets on the rail track are analyzed. It is concluded that there is significant impact of the parasitic slippages on the wheels and rails wear.

The work [8] was dedicated to evaluation of directing forces during the passage of small radius curves by the vehicle. The evaluation has been made in accordance with European standard EN 14363 or UIC 518, which is used in the development of new, reconstructed or upgraded railway vehicles. The stated method of determining the quasi-static directing force indirectly confirms the significant level of resistance to movements associated with the vehicle directing by small radius rail track.

The losses related to the impact on railway infrastructure, track condition and rolling surfaces wear of the wheels of the vehicles are one of the most urgent issues in the railway field. The work [9] was dedicated to the research of influence of rolling stock operating conditions on the evolution of the railway wheels wear and, as a result, on the change of their profiles and interaction force of the vehicle and the track. The dynamics of the train movement in the curved sections of the track was studied in [10] on the basis of dynamic multimass mathematical models. The objective of research was to determine the influence of operating conditions of the train movement on the process of degradation of wheels and rails. For this purpose the concept “working operating conditions” was introduced, as the base for comparison of studies results. Various options for the geometry of the wheels and rails were considered. According to the study results, a great influence on the degradation of the wheels and rails was noted, especially on the geometry of the wheel profile and the curve radius. It was concluded that dependence of the degradation type of wheels and rails rolling surfaces from the operating conditions, namely the fatigue failure of the rolling surfaces dominated in the large radius curves with a high level of lateral unevenness.

In the paper [11], this problem can be solved using the mathematical model of high-speed train, where wheels are considered as flexible bodies and the way has no unevenness. The wearing depth of the wheel profile has been calculated according to known Archard law. Using this model, the impact of the wheel profile, the original hardness of suspension, the way width on the wheel profile wear has been studied. Simulation results allowed us to compare the wheels profiles according to the wear resistance of rolling surfaces and to define the parameters of the “optimal” profile. XP55 type profile showed the smallest total wearing depth and the LM profile had the greatest wearing depth. It was concluded that in order to reduce the profile wear the slope of the rolling surface must be within1:35 - 1:40.

The paper [12] is devoted to analysis of factors influencing the friction processes of wheels contacting with the rails. The harmonious model of wheel wear in underridged and ridged part of the rolling surface profile was considered in details. Based on the theoretical positions of Klingel theory, the authors believe that the kinematic transverse oscillations called “wabbling” are the main cause of dynamic normal and tangential stresses during contact of the wheels with the rails. These loads should include forces of resistance to movement as related to the vehicle directing by rail track. The authors have suggested the characteristics of dependency of these forces on the geometry and material properties of the contact surfaces of wheels and rails.

Purpose of the work is improving the structure of the resistance to movement, based on the formalization of its components associated with the friction interaction of wheels and rails and the vehicle directing by the rail track.

Presentation of the main research material

According to existing classification the resistance to movement it is divided into primary and secondary (Figure 1).

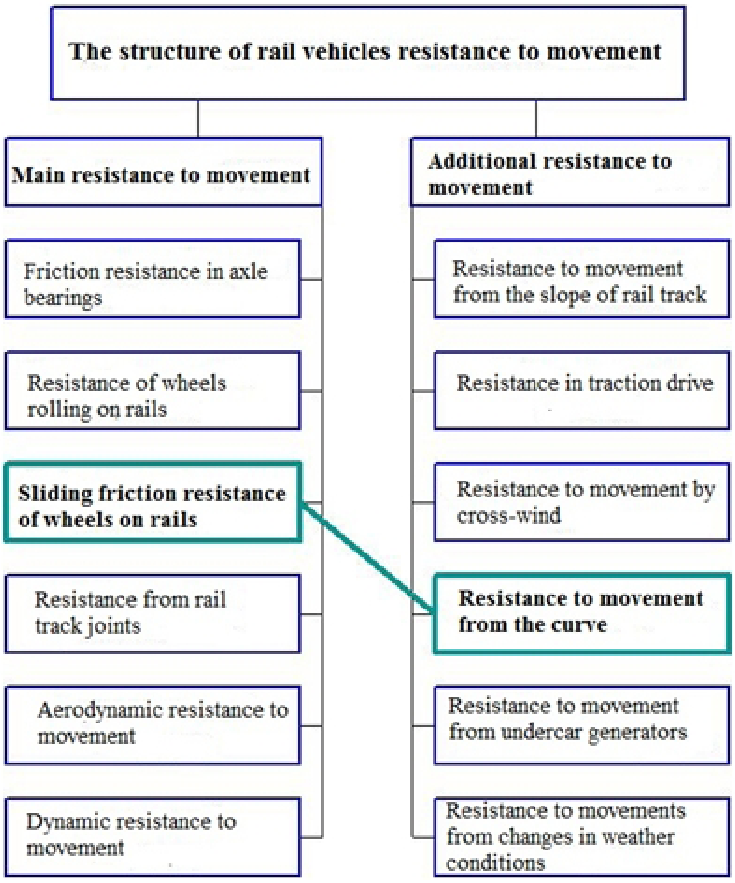


Figure 1. The structure of rail vehicles resistance to movement

The main resistance to movement includes the components always acting while moving along a straight horizontal rail track and the additional includes the components that do not always act or appear under specific conditions of movement. The system of railway vehicles directing by rail track is a grouped multiwheeled and multicontacted friction engine. Compared to the other wheel equipment the railway vehicles have three main differences. First is that railroad engine and cars have twin wheels on almost rigid axes - wheel sets. Second is that the wheel sets are formed by two or three carts with parallel axes. Third is that the vehicles directing by rail track occurs mainly due to the presence of ridges on wheel sets, which act as limiters of lateral movement within the rail track. These differences are the reason of the kinematic resistance to movement to the study, to which this article is devoted.

According to typology, the classification is built on essential characteristics and it is based on the concept of the type as the distribution unit of the classification object. The correctness of the distribution is based on two principles: the fullness and purity of distribution. According to the first principle, all terms of the division should be listed. According to the second one, the terms of the division should not be simple concepts [15].

It is considered by authors that **kinematic resistance to movement** is the resistance associated with the frictional contact interaction of vehicle and rail track occurring from the kinematic sliding in the contact of the wheels and the rails.

Theory of wheel sliding relative to the rail was proposed by Reynolds. It formed the basis of many scientific papers making this direction in the study of rolling resistance the most advanced. Forms of wheel and rail profiles determine the different rolling radii of circles as the individual wheels of the wheel set as well the various contact points of the wheel at a two-point contacting. The spatial velocities distribution leads to a differential sliding between the main and the ridge contacts within one wheel. Differential sliding is the cause of idle forces in the closed power circuits with the nodal point in the centers of frictional contact and, as a consequence, the occurrence of additional resistance to movement. The authors propose to call the resistance to the movement associated with the differential sliding in two-point contact – differential resistance to movement as a component of the kinematic resistance to movement [15].

Differential resistance to movement

Fig. 2 shows a schematic diagram of two-point contact of the wheel and the rail, which explains the nature of the differential resistance to movement occurrence. Between the main (K_1) and the ridge (K_2) contacts the four-square torque loop is created, which is the cause of parasitic sliding and occurrence of the resistance to movement force (F_r).

The system of equations of forces and moments equilibrium acting on the wheel is of the following form

$$\begin{cases} F_r = F_{bp1} - F_{bp2}; \\ F_{bp2} \cdot R_2 - F_{bp1} \cdot R_1 = 0, \end{cases} \quad (1)$$

where F_r – resistance to movement;

F_{bp}, F_{bp2}– binding powers in the main and ridge contacts respectively;

R_2, R_1 – tread circle radii for the main and ridge contacts respectively.

From the system of equations (1) an expression for the differential resistance to movement can be obtained

$$F_r = F_{bp1} \cdot \left(1 - \frac{R_1}{R_2}\right). \quad (2)$$

The binding powers are determined by the following formulas

$$F_{bpi} = N_i \cdot \Psi \cdot k_i, \quad (3)$$

where N_i – normal load in the contact;

ψ – physical friction coefficient in contacts of wheels and rails;

k_i – coefficient of binding use.

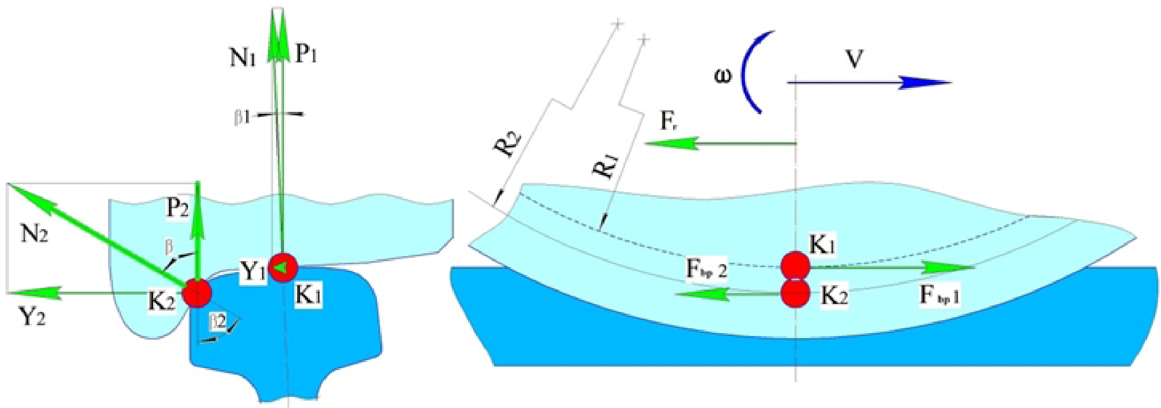


Figure 2. The scheme of the differential resistance to movement formation during the two-point contact of the wheels and the rails

The values given in equation (2) are determined by the following formulas

$$N_i = P_i \cdot \sqrt{1 + tg^2(\gamma_i)}, \quad (4)$$

where P_i– vertical loads in the contacts;

γ_i – slope angles of the rolling surface profile at the contact points.

Vertical load in the contacts is formed by the external forces acting on the wheel from the side of the rails and the bogie frame. Redistribution of the vertical load between the contacts is characterized by the re-laying coefficient of contact χ

$$\begin{cases} P_1 = (\chi - 1) \cdot P_0; \\ P_2 = \chi \cdot P_0. \end{cases} \quad (5)$$

The coefficient of binding use

$$k_i = \frac{\varepsilon_i}{a \cdot \varepsilon_i^2 + b \cdot |\varepsilon_i| + c}, \quad (6)$$

where ε_i – the relative sliding in the contacts;

a, b, c – correlation coefficients of binding characteristic *k (ε)*.

The relative sliding in the contacts

$$\varepsilon_i = \frac{\omega \cdot R_i - V}{V} = \frac{R_i - R_0}{R_0}. \quad (7)$$

Where V– velocity of the wheel center motion;

ω – angular velocity of wheel set rotation;

R_0 – average radius of the wheels tread circle.

To evaluate the level of the differential resistance to movement it should be noted that in real conditions when two-point contact the difference of radii contacts $\Delta R = R_1 - R_2$ can reach 10…14 mm. At the same time sliding value can respectively reach 0.9 ... 1.3%, which is close to critical when $k_i=1$.

With taking into account (2) - (7) the differential resistance to movement can reach levels that are determined by the following formula

$$F_r = N_1 \cdot \Psi \cdot k_1 \cdot \left(1 - \frac{R_1}{R_2}\right), \quad (8)$$

Where for $k_1=1$ and ψ = 0.33, the specific level of the differential resistance to movement is obtained

$$w_d = \chi \cdot 6 \cdot 10^{-4} \cdot \sqrt{1 + tan^2\gamma} = 0{,}6 \cdot \chi \ {}^{H}/_{kH} \quad (9)$$

Differential resistance to movement occurs whenever the conditions for the ridge contact of wheels and rails are provided, i.e. in the following cases:

- when driving the vehicle in curved sections of the way where one or more wheels have ridge contact with the rail;
- when moving in straight sections of the rail track in the mode of impact wheel climbing on the rails. This mode is typical at medium and high speeds of rolling stock movements;
- when the faults in geometry of the wheel sets settings in the bogie frame: oblique setting, transverse deviations from the normal position.

In [13], during the tests on the experimental bench installation, a significant increase in resistance to movement of the wheel set from the difference between the wheels radii, which occurs when the transverse shift or angular rotation of the wheel set relative to the rail track axis has been confirmed.

Circulation resistance to movement

A significant part of the resistance to movement in the curved sections of the rail track is the resistance due to the circulation of the idle power in closed power circuits of the group wheeled engine, as the system of the vehicle directing by rail track. Wheels and wheel sets while driving as part of one vehicle have a mutual influence on each other through the ever-changing kinematic parameters of each individual wheel and rail contact.

The principle of vehicle direction by the rails due to the interaction forces of the vehicle and the rail track in the contact points requires the control influences from the rails, which will inevitably lead to the resistance to movement. Additional resistance to the movement, which is the result of group interaction of wheels with rails and circulation of idle power in closed power circuits of wheel sets and bogies authors propose to call the circulation resistance to movement.

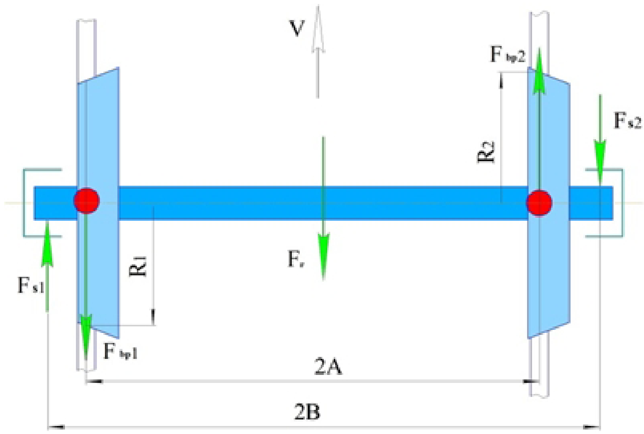


Figure 3. Scheme of circulation resistance to movement of the wheel set

Circulation resistance to movement F_r can be determined from the system of equations

$$\begin{cases} F_r + F_{bp1} - F_{bp2} = 0; \\ (F_{b1} + F_{b2}) \cdot B - (F_{bp1} + F_{bp2}) \cdot A = 0. \end{cases}$$

When driving the wheel set in rail track, its each transverse position relative to the axis of the rail track that defines the wheel rolling radii cones corresponds to the instantaneous turning radius, at which it can roll over without slipping in contact with the rails when moving in so-called equilibrium trajectory. However, as a result of interaction between the wheel sets through the bogie frame, the actual rolling trajectory of each wheel set differs from the equilibrium. Enough tight angular coupling between the wheels leads to the circulation of power in “rail track-wheel set” circuit. It also results in power flow redistribution between the wheels and, as a consequence, in the resistance to movement increase, while the railroad engine has deterioration of coupling properties [15].

In the case of group drive of wheel sets, the power circuit has multiple branched circuits. Power circuit circulation energy is absorbed mainly in the contact of the wheels with the rails, and partly in dissipative connections of bogie. The uneven redistribution of power flow between the wheels depends on several factors:

- stiffness of friction characteristics
- torsional stiffness of the axis, that is connection parameters of the wheels;
- the geometric characteristics of the wheel set including conicity and diameter of the wheels rolling surfaces, the width of the rail track and the bogie base;
- parameters of the longitudinal and transverse axle connections of the wheel set with bogie frame;
- radii of curved sections of the rail track.

Differential and circulation resistances to movement are components of kinematic resistance to movement. The kinematic resistance to movement has features of main and additional resistance, therefore, conventionally, when moving in the straight sections of the way it should be considered as part of the main, and when driving in curves, as part of the additional. Differential and circulation resistance to movement usually occurs in case of presence of closed power circuits typical not only for the case of interaction between railway vehicle and rail track, but also for many other dynamic systems with multi-threaded transfer of forces and moments. In the domestic and foreign literature information on quantitative characteristics of the kinematic resistance to movement is extremely few. Virtually as the only and far from complete, its study can be considered as theoretical and experimental works made for freight cars at the US Railroad Research Center in Pueblo in 1984-85. In the paper [14] devoted to these studies, a significant increase in the resistance to movement in the curved sections of the way even with a slight divergence in the diameter of the wheels on one wheel set is noted.

Conclusions

The existing classification of the resistance to movement is based on the principle of convenience for the experimental study and use in traction calculations, but it constrains the search for ways to reduce it. It is proposed to allocate a separate component of the resistance to movement associated with the vehicle directing by the rail track and call it a kinematic resistance to movement with the differential and the circulating components.

The above improvement of the resistance to movement structure offers prospects for reducing the resistance to movement on the basis of new technical solutions of running parts constructive performance allowing us to manage the kinematics and dynamics of frictional interaction of rolling stock wheels with the rails. It primarily relates to the study of the horizontal forces in the contacts of the wheels with the rails resulting at vehicle directing by rail track. These conclusions are fundamental for solving the problem of reduction of the rolling stock resistance to movement.

References

1. Fomin O.V. (2015) Increase of the freight wagons ideality degree and prognostication of their evolution stages. *Scientific Bulletin of National Mining University*. No 2. p. p.68-76.
2. Kelrykh M. (2014) Perspective directions of planning carrying systems of gondolas. *Metallurgical and Mining Industry*. No. 6, p.p. 64-67.
3. Fomin O. V. (2014) Modern requirements to carrying systems of railway general-purpose gondola cars. *«Metallurgical and Mining Industry»*. No 5, p.p. 31-43.
4. Fomin O. V. (2015) Improvement of upper bundling of side wall of gondola cars of 12-9745 model. *Metallurgical and Mining Industry*. No. 1, p. p. 45-48.
5. Heyman H. (1957) *Napravlenie ekipazhey relsovoy koleey* [Vehicles direction by the rail track]. Moscow: Transzheldorizdat. 416 p.
6. Babaev A. M. (2006) Issledovanie soprotivleniya dvizheniyu avtonomnogo relsovogo ekipazha [The study of resistance to movement of autonomous rail vehicles]. *Bulletin of DNUZT after V. Lazaryan*. No 12, p.p. 107-109.
7. M. Rosenberger, P. Dietmaier, J. Payer and K. Six. (2008) The Influence of the Wheelset Relative Kinematics of Railway Vehicles on Wheel. *Rail Wear in Curved Track. Vehicle System Dynamics*. Vol. 46. No. 1. p. p. 403-414.
8. Zelenka J., Michalek T. (2010) A New Method of the Assessment of Rail Vehicles Guiding Behaviour in Small-radius Curves. *International Journal of Applied Mechanics and Engineering*. No 15 (2), p.p. 511–519.
9. Pombo J., Ambrosio J., Pereira M., Verardi R.,

Ariaudo C., Kuka N. (2011) Influence of Track Conditions and Wheel Wear State on the Loads Imposed on the Infrastructure by Railway Vehicles. *Computers and Structures*. Vol. 89. No. 21-22. p. p. 1882-1894.

10. Karttunen K. (2015) Influence of rail, wheel and track geometries on wheel and rail degradation. *Doctor Thesis. Göteborg*.
11. Wu N., Zeng J. (2014) Parametric analysis of wheel wear in high-speed vehicles. *Journal of Modern Transportation*. Vol. 22, Issue 2. p. p. 76-83.
12. Crabb G., Brown S., Sanders P., Wright D., McRobbie S., Viner H. (2013) Investigation of novel systems for monitoring rail adhesion. *Published Project Report - PPR 678. Transport Research Laboratory*. 45 p.
13. Miyamoto Masayuki (1985) *Eksperimentalnoe issledovanie protsessov uprugogo skolzheniya v zone kontakta kolesa i relsa* [Experimental study of the elastic slip processes in the wheel and rail contact zone]. *Railway Eng.Assoc.*V.28. No 7. p.p. 16178-16181.
14. Elkins J.A., Wilson N.G. (1985) Train Resistance Measurement Using a Roller Rig. *Vehicle Sist. Dyn*. V.14. No1-3. p.p. 46-51.
15. Tkachenko V. P. (1996) *Kinematicheskoe soprotivlenie dvizheniyu relsovyih ekipazhey: monografiya* [Kinematic resistance to movement of railway vehicles: monograph]. Lugansk: VUGU. 200 p.

Dynamic synthesis of non-harmonic vibration exciter of pulse action directed on the foundation

Elemesov K.K.

PhD in Technical Sciences, Associate Professor,
Kazakh National Research Technical University after K.I.Satpayev
Almaty, Kazakstan

Tusupova A.E.

PhD in Technical Sciences, Associate Professor,
Kazakh National Research Technical University after K.I.Satpayev
Almaty, Kazakstan

Daurova R.V.

Assistant Professor,
Kazakh National Research Technical University after K.I.Satpayev
Almaty, Kazakstan

Aytoreeva G.

Assistant Professor,
Kazakh National Research Technical University after K.I.Satpayev
Almaty, Kazakstan

Moldagozhina M.

Assistant Professor,
Kazakh National Research Technical University after K.I.Satpayev
Almaty, Kazakstan

Abstract
The problem of dynamic synthesis for non-harmonic vibration exciter of hinge-lever type is discussed in the current article. The article also reports on the developed mechanism for vibration exciter and its pulse action with regard to the foundation. The numerical results of the stated problem are described.
Key words: VIBRATION, FOSSILS, ECCENTRIC MASS, LEVER MECHANISM, PULSE, DYNAMIC SYNTHESIS, APPROXIMATION, MASS AND INERTIA PARAMETER, INERTIA

Introduction

The vibrating mechanisms are widely applied in various industrial fields and agriculture. They are of significant importance for operations in metallurgy. With vibration, people can crush materials, separate mixtures, compact concrete, sink piles, screen various substances in industry; the vibration phenomenon is also applied in the household. A number of manufacturing processes cannot produce without vibrating technology: extracting and processing of fossils and minerals, handling substances in chemical production, participation in the metallurgical route, building materials handling and erection of various engineering constructions [5, 6, 7]. All the machines involved in the above described processes contain various types of vibration exciters [7, 8].

The analysis on the research papers, devoted to the problem of vibration exciters and their development, reveals the issues to be improved. The point is that the most widely applied equipment here is inertial vibration exciter, in which the exciting force is generated by rotation of several unbalanced masses. The directional effect of the force exciting in it is provided by the vibration exciter of self-balancing type. This exciter consists of twin exciting units with eccentric masses, which synchronically rotate in opposite directions but with the same rotational speed. In order to synchronize the rotation of the eccentric masses, the kinetic pair is used. Such an arrangement of the mechanism imposes teeth wearing, but the engineering solution to apply separate drives is to raise the problem of the synchronic operation. Moreover, considering the operational conditions of self-balancing vibration exciter from the standpoint of the effect produced on the foundation, we observe that it influences the foundation harmonically and this type of equipment (for instance, pulse class) is not feasible to have non-harmonic impact on it. In order to generate mechanical vibrations of directional non-harmonic effect, the exciter with non-rounding are applied [4, 11]. However, the main rebukes on this mechanism are the teeth wear under impact and complicated shapes of teeth manufacture for this type of equipment.

The most common vibration exciters have non-harmonic impact on the foundation and are equipped with planetary gear [12, 13]. Among the principle drawbacks in their designs, we may single out the ones related to the kinetic pairs of higher degree in their constructions: the kinetic pair provokes elements wearing, generates the adverse vibrations transversely (there are certain difficulties with developing the directed impact on the foundation) and enables the drive trailing wheel slipping. Furthermore, due to the mentioned problems, this type of equipment requires special constructions.

The lever mechanism with its wide functionality is not applied in most cases here [4, 11]. However, the elimination of kinetic pair of higher degree in the above described mechanisms is able to ensure high speed modes of operation and to increase the parts service life. By choosing mass and inertia parameters or implementing rational arrangement of mass link centres and optimizing mass and inertia moment values, one can obtain actually any desired type of impact on the foundation and directed non-harmo- nic one, in particular, on condition of the appropriate regularity. However, nowadays there is no optimization mathematical technique of dynamic synthesis for the described machines and this makes a considerable obstacle for the developments in this direction. In addition to the above, the automating perspectives in design process are becoming important requirements to the modern techniques applied for machines and mechanisms construction.

The present article aims at development of the optimal method for dynamic synthesis of hinge-lever mechanisms based on the vibration exciter of the directed pulse effect on the foundation.

1. Analytical solution for dynamic synthesis

1.2 Synthesis equations

Let us assume that *OXY* is a system of absolute coordinates. Let us also regard that *OX* axis is directed along the line joining the centres of two hinges, this is done as a matter of convenience.

Consider the normalized conditions under which the mechanism produces impacts on the foundation with f_τ^0, f_n^0 and acts in two orthogonal direction τ and n ($\tau^T n = 0$), at this the axis is rotated with angle ψ_1 with respect to *OX* axis [5]. Thus, making a solution on the synthesis of non-harmonic vibration exciter, which produces τ direction pulse impact on the foundation, the action is equal to zero:

$$f_\tau^0 \equiv 0, \quad f_n^0(\phi) = \begin{cases} A_1 \; at & 0 \le \phi < \phi_1 \\ A_2 \; at & \phi_1 \le \phi < 2\pi \end{cases}$$

Relation $\lambda = \dfrac{A_1}{A_2}$ is to be set within 3 ÷ 8. $Ml_1\omega^2$, where

$$M = \sum_{i=2}^{n} m_i,$$

l_1 is the distance between the supports, and we write as:

$$\mathrm{f} = \frac{\mathrm{F}}{Ml_1\omega^2} \tag{1}$$

where $\mathrm{f} = [\mathrm{f}_x, \mathrm{f}_y]^T$ and $\mathrm{F} = [\mathrm{F}_x, \mathrm{F}_y]^T$. Moreover, for the synthesis solution we accept that ω = const, ε = 0, then for any six link mechanism $(n = 6)$ with the constituents of the principle vector of the inertia forces in normalized form, one can express as follows:

$$f_x = \sum_{i=2,4,6} \left[A_i \left(\varphi_i'^2 \cos\varphi_i + \varphi_i'' \sin\varphi_i \right) + B_i \left(\varphi_i'' \cos\varphi_i - \varphi_i'^2 \sin\varphi_i \right) \right] \tag{2}$$

$$f_y = \sum_{i=2,4,6} \left[B_i \left(\varphi_i'^2 \cos\varphi_i + \varphi_i'' \sin\varphi_i \right) - A_i \left(\varphi_i'' \cos\varphi_i - \varphi_i'^2 \sin\varphi_i \right) \right] \tag{3}$$

Furthermore, in the previously developed expressions for A_i, B_i, i = 2, 4, 6 all the linear dimensions are treated as relative (with respect to l_1 length or *AD* is taken as 1 unit), all the masses are non-dimensional and ω = 1. As vectors, these expressions are written in the form as:

$$\mathbf{f} = \sum_{i=2,4,6} C(\phi_i', \phi_i'') D(\phi_i) \mathbf{u}_i \tag{4}$$

where

$$\mathbf{u}_i = [A_i, B_i]^T, \quad \mathbf{B}(\varphi', \varphi'') = \begin{bmatrix} \varphi'^2 & \varphi'' \\ -\varphi'' & \varphi'^2 \end{bmatrix}$$

As the preset directions (τ As the preset directions (**τ, n**) of foundation impact are rotated with angle ψ_1 with respect to *OXY* coordinate system, which is rigidly jointed with the stand, then we can develop the synthesis equation by rotation of the fixed coordinate system with the turn for the stand with angle $\psi = -\psi_1$ (this corresponds to the turn of the whole mechanism with the stand). Thus, the synthesis equation is as follows:

$$\mathrm{AU} = \mathrm{f}^0 \tag{5}$$

where $\mathrm{A} = \mathrm{D}(\psi)[\mathrm{C}_2\mathrm{D}_2 | \mathrm{C}_4\mathrm{D}_4 | \mathrm{C}_6\mathrm{D}_6]$, $\mathbf{U} = [\mathbf{u}_2^T, \mathbf{u}_4^T, \mathbf{u}_6^T]^T$, $\mathbf{f}^0 = [f_\tau^0, f_n^0]^T$.

The dimensions of A matrix and U vector are dim A = 2x6 and dim U = 6 respectively.

It is important to emphasize that A matrix depends only on the geometrical dimension and linkage parameters (on the position, analogs of velocities and link accelerations). On the other hand, U vector includes all the mass and inertia parameters, in case of six link linkage, the total number of them is only 15 (the dimension of U vector is equal to 6); the components of U vector are generalized eccentric masses.

1.3 Explicit solution for dynamic synthesis problem

For the analytical synthesis of the vibration exciter, we accept that the mechanism kinematic analysis is carried out at the preset links dimensions and at the crank angular velocity ω = 1, (ε = 0). This results in determining the angular positions, angular velocities and acceleration of all the links in the preset N positions of crank 2. However, we do not need to know more than the values for the even numbered links. An additional point is that values $\mathrm{f}_k^0 = [f_{\tau k}^0, f_{nk}^0]^{\mathrm{T}}$, k=1,…,N are set for the problem of the dynamic synthesis. This corresponds to the preset N positions of the mechanism.

The equations for synthesis can be written as follows:

$$\boldsymbol{\delta}_k \equiv \mathbf{A}_k \mathbf{U} - \mathbf{f}_k^0 = 0, \, k=1,\ldots,N \quad (6)$$

Hence, we obtain 2*N* equations of synthesis, while the number of variables is 6. Therefore, the problem under discussion has the explicit solution provided that *N* = 3, in other words, we set numerical values for the component of total inertia force with three set position of the mechanism. In this case, in order to determine unknown parameters of **U**, we are to receive six linear equations with six variables.

$$\begin{bmatrix} [\mathrm{A}_1] \\ [\mathrm{A}_2] \\ [\mathrm{A}_3] \end{bmatrix} \mathbf{U} = \begin{bmatrix} \mathrm{f}_1^0 \\ \mathrm{f}_2^0 \\ \mathrm{f}_3^0 \end{bmatrix} \quad (7)$$

Eventually, the obtained equations have the only solution, on condition that the determinant *det* is not equal to 0:

$$\begin{bmatrix} [\mathrm{A}_1] \\ [\mathrm{A}_2] \\ [\mathrm{A}_3] \end{bmatrix} \neq 0$$

2.1 Quadratic approximation solution

For the general case, if *N*>3, then the number of variables is bigger in equations (6) than the possible number of variables. Owing to this, the explicit solution is absent. We need to apply here approximate solution, where equations (6) are performed approximately [7].

$$S_2 = \|\Delta\|_2^2 = \frac{1}{2}\Delta^{\mathbf{T}}\mathrm{W}^{\mathbf{T}}\mathrm{W}\Delta \quad \Rightarrow \quad \min_{\mathrm{U}} \quad (8)$$

where

$$\boldsymbol{\Delta} = \left[\boldsymbol{\delta}_1^{\mathrm{T}}, \boldsymbol{\delta}_2^{\mathrm{T}}, \ldots, \boldsymbol{\delta}_N^{\mathrm{T}}\right]^{\mathrm{T}}, \quad \boldsymbol{\delta}_k = \left[\delta_k^n, \delta_k^\tau\right]^{\mathbf{T}},$$

$$\mathbf{W} = diag\{w_1, w_2, \ldots, w_{2N}\}$$

that is the matrix of the weight numbers.

The solution problem (126) is written as follows:

$$\mathrm{U}^0 = \mathrm{C}_{\mathrm{p}}^{-1}\mathrm{d} \quad (9)$$

where

$$\mathrm{C}_p^{-1} = \left[\mathrm{C}^{\mathbf{T}}\mathrm{W}^{\mathbf{T}}\mathrm{W}\mathrm{C}\right]^{-1}\mathrm{C}^{\mathbf{T}}\mathrm{W}^{\mathbf{T}}\mathrm{W}$$

is the left pseudoinverse of matrix

$$\mathrm{C}, \; \mathbf{C} = \left[\mathbf{A}_1^{\mathrm{T}}, \mathbf{A}_2^{\mathrm{T}}, \ldots, \mathbf{A}_N^{\mathrm{T}}\right]^{\mathrm{T}},$$

$$\mathrm{d} = \left[\mathrm{f}_{\mathbf{1}}^{\mathbf{0T}}, \mathrm{f}_{\mathbf{2}}^{\mathbf{0T}}, \ldots, \mathrm{f}_N^{\mathbf{0T}}\right]^{\mathbf{T}}.$$

This solution can be found from the necessary conditions for the minimum of function S_2:

$$\frac{dS_2}{d\mathrm{U}} = 0 \cdot$$

Furthermore, the matrix of second derivatives

$$\frac{dS_2}{d\mathrm{U}} = \mathrm{C}^{\mathbf{T}}\mathrm{W}^{\mathbf{T}}\mathrm{W}\mathrm{C}$$

is nonnegative definite along with leading subdeterminants. Therefore, when *det* $\mathrm{C}^{\mathbf{T}}\mathrm{W}^{\mathbf{T}}\mathrm{W}\mathrm{C} \neq 0$, the necessary conditions for the minimum are the sufficient ones.

2.2 Analytics and optimization method

In the dynamic synthesis developed for the mechanism, its mass and inertia parameters are determined as total eccentric masses, and the mechanism dimensions are suggested to be preset. However, at preset geometric parameters, it is very difficult to obtain the desired approximation accuracy. This makes us to perform the mechanism synthesis by all **X** parameters at once, that is to search not only mass and inertia parameters for **U**, but also the mechanism metric parameters $\mathbf{X}_1$ = **X**/**U** (links dimensions). These parameters are included into the effectiveness function (6) nonlinearly: kinematic parameters $\varphi_i, \varphi_i', \varphi_i''$, which participate in the approximation error expression, depend on them. Thus, in order to determine the rest of nonlinear parameters of the mechanism geometrical dimensions $\mathbf{X}_1$ = **X**/**U**, we introduced modified effectiveness function taking into account an analytical solution as follows:

$$S^m \equiv \min_{\mathbf{U}} S_2(\mathrm{X}_1, \mathrm{U}) = S_2\left(\mathrm{X}_1, \mathrm{C}_p^{-1}(\mathrm{X}_1)\mathrm{d}(\mathrm{X}_1)\right) \quad \Rightarrow \quad \min_{\mathrm{X}_1} \quad (10)$$

Therefore, the introduction of generalized eccentric masses and analytical solution for the mass and inertia variables allows a sufficient reduce in the dimensionality of the original optimization solution.

Based on the suggested method, the dynamic synthesis program for mechanisms with vibration exciters of hinge-lever type is developed. Mass and inertia parameters of the mechanism are determined on each step of the descent algorithm by minimization of the Euclidean or Chebyshev norms of approximation error. Numerical implementation of minimization procedure is carried out on the basis of Nelder Mead algorithm.

2.3 Numerical results

Summarizing the results of the researches made, we would like to report that there is a program developed, which provides a possibility for the user to denote optimization parameters and those ones which freely varied or scanned. The initial optimization parameters values and the scanned parameters values are defined with the use of the generator of LPt sequences, uniformly distributed in the searching range [9]. We have to note that the further nonlinear optimization is not applicable with the scanned parameters.

Moreover, the synthesis with Nelder Mead optimization method or the method of deformed polyhedron is carried out under the conditions described below.

The coordinates of stands have fixed values: $X_A = Y_A = 0.0$, $X_D = 1.0$, $Y_D = 0.0$, $X_G = Y_G = 0.0$.

The bounds of optimized variables are being changed under the following limits:

- $0.5 \leq l_3(BC) \leq 1.4$
- $0.35 \leq l_4(CD) \leq 1.2$
- $0° \leq \theta_3$ (angle CBE) $\leq 360°$
- $0.5 \leq a_3(BE) \leq 1.2$
- $0.4 \leq l_5(EF) \leq 1.1$
- $0.45 \leq l_6(FG) \leq 1.1$
- $0° \leq \psi \leq 360°$
- $0° \leq \varphi_{0cr} \leq 360°$ (here φ_{0cr} is the initial angle of crank turn)

Thus, optimization is carried out with 8 parameters. The generalized eccentric masses are determined on each step of the optimization, which makes numerical optimization significantly easier.

Parameter l_2 is the length of *AB* crank and is not employed by optimization parameters: its values vary freely within $0.1 \leq l_2 \leq 0.4$ along with initial values of optimization parameters.

Furthermore, we chose the dyad groups of *BCD* and *EFG*: $i_{BCD} = -1$, $i_{EFG} = -1$.

Table 1 shows the desirable values for component $\mathbf{f}^0$, in other words f_n^0 and f_τ^0 in $N_S = 18$ positions of crank (the angles of φ_{cr} f_i and f_τ^0). The last column of the table contains the values of weight numbers w_k, $k = 1,\ldots, N_S$. The proper choice made on these weight numbers determines the numerical results of optimization. At the first stage of the procedure, these values are assumed as equal to 1 unit element ($w_k = 1$).

Table 1. The desirable values for component $\mathbf{f}^0$

k	φ_{cr}	f_n^0	f_τ^0	w
1	0.00000	0.30000	0.00000	0.10000
2	15.00000	0.90000	0.00000	0.10000
3	30.00000	1.30000	0.00000	1.00000
4	45.00000	0.90000	0.00000	0.00000
5	60.00000	0.30000	0.00000	0.00000
6	80.00000	-0.20000	0.00000	1.00000
7	100.00000	-0.20000	0.00000	3.00000
8	120.00000	-0.20000	0.00000	2.00000
9	160.00000	-0.20000	0.00000	1.00000
10	180.00000	-0.20000	0.00000	1.00000
11	200.00000	-0.20000	0.00000	1.00000
12	220.00000	-0.20000	0.00000	1.50000
13	240.00000	-0.20000	0.00000	1.50000
14	260.00000	-0.20000	0.00000	1.50000
15	280.00000	-0.20000	0.00000	1.50000

16	300.00000	-0.20000	0.00000	1.00000
17	320.00000	-0.20000	0.00000	3.00000
18	340.00000	-0.20000	0.00000	1.00000

After several experimental runs of the program, we corrected these values and the final results are presented in Table 1.

The mechanism developed as a result of synthesis is demonstrated in Figure 1, its dimensions are given along with kinematic configuration. The crank length is $l_2 = AB = 0.372$.

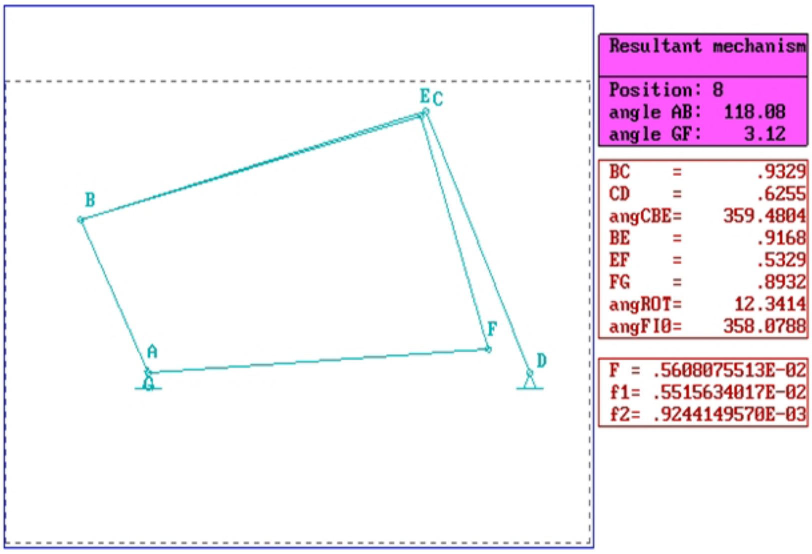


Figure 1. Kinematic configuration of nonharmonic vibration exciter

Below we report on the values of generalized eccentric masses, at which the regularity of the influence on the stand is achieved:

$A_2 = 9.604306E{-}02$ $B_2 = 5.042776E{-}02$

$A_4 = -1.252109E{-}01$ $B_4 = -8.328925E{-}02$

$A_6 = -1.886204{+}00$ $B_6 = -5.349329E{+}00$

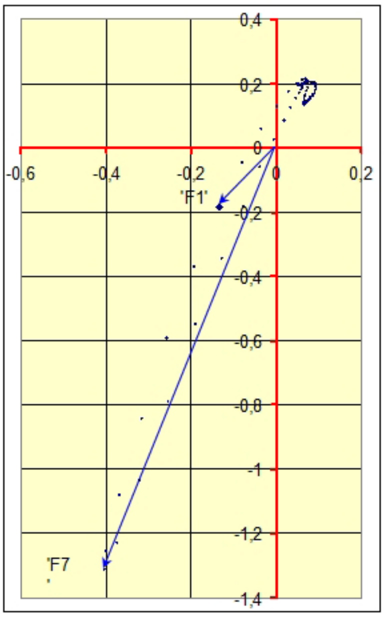


Figure 2. Hodograph of total inertia force for lever mechanism

The results of kinematic and kinetostatic analysis enable us to develop the graph of the force and the inertia acting on the foundation. In Figure 2, a hodograph describes the changes in the total impact action of inertia forces on foundation of the mechanism; in Table 1, the numerical values of components F_x of F_y are given.

Research results

Developed as the result of dynamic synthesis, the new mechanism of vibration exciter of directed pulse impact on foundation has advantages over the existing ones: the use of turning kinematic pairs allows elimination of the teeth wearing to the degree typical to its prototype; the regularity of inertia forces impact on the foundation is non-harmonic; the inertia forces acting in the orthogonal direction are actually absent.

On the base of hinge-lever type mechanisms, the program of dynamic synthesis of vibration exciter is developed. This permits faster completion of the designing cycle, gives opportunities to replace the expensive natural experiment with the computational one and enables multiple searches for solutions.

The analytic and optimization method is developed to determine optimal dimensions of the mechanism by employing the modified effectiveness function. As geometrical dimensions of the mechanism are included into

into effectiveness function nonlinearly (implicitly through angles of links turns, analogs of velocities and analogs of accelerations), the numerical optimization methods can be used to determine them. At this, it should be noted that the mass and inertia parameters of the mechanism are identified analytically on each step of descent to the minimum.

References

1. Doronin V.I., Dan'shin Yu.V. (1993) *Dinamicheskiy sintez ploskikh uravnoveshennykh rychazhnykh mekhanizmov* [Dynamic synthesis of planar balanced mechanisms of lever type]. Khabarovsk: DVG APS. 100 p.
2. Ualiev G.U. (2000) *Dinamika mekhanizmov i mashin* [Dynamics of mechanisms and machines]. Almaty: AGU-Tauar. 282 p.
3. Shchepetil'nikov V.A. (1982) *Uravnoveshivanie mekhanizmov* [Mechanisms balancing]. Moscow: Mashinostroenie. 256 p.
4. Dzhamalov N.K., Telibaeva A.E., Nurmaganbetova A.T. (2003) Modelirovanie zadach analiza i sinteza ploskikh rychazhnykh mekhanizmov [Simulation on analysis and synthesis of planar mechanisms of lever type]. *Materialy Vserossiyskoy nauchno-tekhnicheskoy konferentsii «Teoreticheskie i prikladnye voprosy sovremennykh informatsionnykh tekhnologiy»* [Proceedings of all-Russian scientific and research conference Theoretical and Applied Issues of Modern Informational Technologies]. Vol. 1, p.p. 87-91.
5. Moldabekov M.M., Tuleshov A.K., Malikov M.T. (2001) *Metody i algoritmy avtomatizirovannogo dinamicheskogo analiza rychazhnykh mekhanizmov* [Methods and algorithms of automatic dynamic analysis on calculated units]. Almaty: Ғylym. 189 p.
6. Dzholdasbekov U.A. (2001) *Teoriya mekhanizmov vysokikh klassov* [Theory of high class mechanisms]. Almaty: Ғylym. - 428 p.
7. Artobolevskiy I.I. (1935) Uravnoveshivanie sil inertsii ploskikh mekhanizmov [Balancing of inertia forces of planar mechanisms]. *Izv. NIIMASh* [Publication of scientific and research machine-building institute]. No. 10. – p.p. 5-26.
8. Shchepetil'nikov V.A. (1975) *Osnovy balansirovochnoy tekhniki. Uravnoveshivanie zhestkikh rotorov i mekhanizmov* [Fundamentals on balancing technique. Balancing of rigid rotors and mechanisms]. Vol.1. Moscow: Mashinostroenie. 527 p.
9. Dan'shin Yu.V. (1998) *Analiticheskiy metod resheniy zadach dinamicheskogo uravnoveshivaniya ploskikh rychazhnykh mekhanizmov* [Analytic method for engineering solutions on dynamic balancing for planar mechanisms of lever type]. Omsk: OmGTU. 35 p.
10. Ualiev G.U., Abdullina N. (2006) *Matematicheskoe modelirovanie dinamiki mekhanicheskikh sistem s peremennymi kharakteristikami* [Mathematical simulation of dynamic mecha- nical systems with alternating characteristics]. Almaty: Izd-vo KazNPU. 275 p.
11. Ualiev G.U., Dzhomartov A.A. (2003) *Dinamika mekhanizma tkatskikh stankov-avtomatov STB* [Dynamics of automatic weaver's loom mechanisms of STB series]. Almaty: Tauar. 377 p.
12. Ibraev p.M., Izmambetov M.B., Telibaeva A.E. (2005) Izotropnye konfiguratsii ploskikh manipulyatorov pozitsioniruyushchego i orentiruyushchego tipa [Isotropic configuration of planar manipulative devices of positioning and orienting types]. Vestnik KazNTU im. K.I. Satpaeva [*Journal of Kazakh National Research Technical University after K.I.Satpayev*]. Almaty: KazNTU. No. 2 (46). p.p. 79-83.
13. Tusupova A.E. (2005) Dinamicheskoe uravnoveshivanie sharnirnogo chetyrekhzvennika na osnove kvadraticheskogo priblizheniya [Dynamic balancing for hinge link device on the base of quadratic approximation]. *Materialy Mezhdunarodnoy nauchnoy konferentsii «Aktual'nye problemy mekhaniki i mashinostroeniya»* [Proceedings of International scientific conference Topical Problems of Mechanics and Machine-Building]. Vol. 2. p.p. 310-314.

Microstructure of low-carbon steel wire and its welding and fabrication properties

Oleksandr Grushko

Doctor of Technical Sciences, Professor,
Faculty for Machine Building and Transport
Vinnitsa National Technical University,
Vinnitsa, Ukraine
e-mail: grushko@svitonline.com

Yuliya Slobodyanyuk

Production engineer
PJSC PlasmaTec, Vinnitsa, Ukraine
e-mail: juliya_slobodyanyuk@mail.ru

Abstract
In this paper, we researched the impact of wire rod structure homogeneity on arc stability of welding wire. The microstructural analysis was carried out for low-carbon welding wire in its sections with steady and unsteady arc burning and it showed that equal distribution of carbide phase in ferrite matrix complied with the best arc burning. The presence of coagulated carbides in microstructure was typical for sections with unsteady arc burning. The results of Vickers hardness measurement evidenced that the best arc burning was appropriate for wire samples, characterized by increased and steady hardness.
The increased welding wire porosity could be caused by presence of gases in it (the increased concentration of nitrogen was found there) and it stipulated wire hardness decrease and unsteady arc burning as a result.
Key words: MICROSTRUCTURE, WELDING WIRE, WELDING AND FABRICATION PROPERTIES, ARC BURNING STABILITY, CARBIDES, HARDNESS, PORES, WIRE ROD, YIELD CURVES, COEFFICIENT OF HARDENING

Stability of welding wire arc burning is one of the most important characteristics of its welding and fabrication properties. For the consumers, this is the top priority index of product quality. The unsteady arc burning has the effect on the geometrical parameters of welding seam, chemical composition of welded metal and as a result, on mechanical properties of welding structures [1].

The reasons for unsteady arc burning can be related to the quality of electrode wire: insufficient copper coat adhesion and its inhomogeneity, deviations from the diameter and its very low hardness [2, 3].

During the course of production, PJSC PlasmaTec faced a problem when certain copper wire coil had alternating sections with staggered unsteady and steady arc burnings. Moreover, the parameters of production process were regular, and the wire completely met the standard requirements. The possible reason of this phenomenon could be the differences in microstructure of the mentioned sections. Indeed, there exist explanations on the reasons why wire rod breakage takes place during the process of drawing and they are conditioned upon structure factors mentioned in papers [4, 5]. However, the mentioned sources do not describe the influence of wire microstructure and mechanical properties on its welding and fabrication properties.

Owing to this problem, the present article concentrates on the purpose to analyze results of the microstructural and X-ray analyses of the welding wire samples characterized by steady and unsteady arc burning.

The metallographic researches were conducted for five samples of G3Si1 welding wire (analog of Sv-08GS grade) with the diameter of 0.8 mm. More detailed information on them is in Table 1. Sample No. 5 served for comparison and was taken from Chinese producer wire, which has been enjoying the demand on welding materials market and possesses good welding and fabrication properties.

Table 1. Research samples

Sample No	Heat No	Wire rod producer	Welding and fabrication properties and arc burning
1	21181	LLC "NLMK-Metyz", Russia	steady
2	21181	LLC "NLMK-Metyz", Russia	unsteady
3	260399	Arcelor Mital, Kryvyj Righ, Ukraine	steady
4	260399	Arcelor Mital, Kryvyj Righ, Ukraine	unsteady
5	-	Chinese producer wire	steady

The samples inspection and photographing of microstructures were carried out on NEOPHOT-22 light microscope with the use of OLYMPUS digital camera at different magnifications. Vickers hardness measurement was conducted at M-400 microhardness tester by LECO company at loads of 100 g and 1 kg. The hardness measurement results are given in Table 3. The carbide particles size measurement was performed with VERSAMET microscope at magnification × 1500. It should be noted that the contamination with nonmetallic inclusions of samples No1–No5 was almost similar and it corresponded to rate No.1 according to the scale GOST 1778-70 "Oksydy tochkovi" (Spot Oxides).

In order to reveal the microstructure of the samples, the microslices of the material were etched chemically in 4% alcohol solvent of nitrogen acid.

The results of microstructural analysis of welding wire samples are shown in table 2.

Table 2. Welding wire microstructural analysis

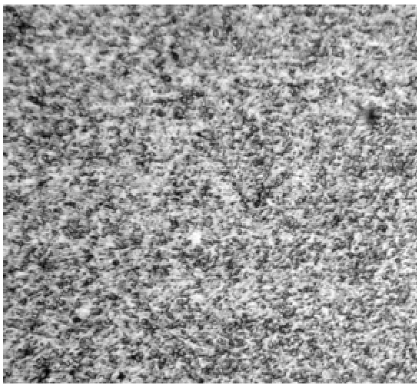
Sample No	Microstructure features		
	Microstructure type	Carbide maximal size, μm	Average carbide size, μm
1	Disperse ferritic-carbide mixture. Carbides are uniformly distributed on all the area of the polished section	1.2 ... 1.5	approximately 1
2	Ferritic-carbide mixture. In structure, there are coagulated carbides in the form of dark regions in microstructure	0.8 ... 1.0	approximately 0.5 ... 0.8
3	Uniformed distribution of carbide constituents with small regions of coagulated carbides and chains of carbides	approximately 1 μm (discretely with the size of up to 2 μm)	less than 1
4	Ferritic-carbide mixture with small amount of coagulated carbides	2.5 ... 3	1.2 ... 1.5
5	Uniformed ferritic-carbide mixture	approximately 2.2	1.8 ... 2.0

Table 3. Results of Vickers hardness measurement

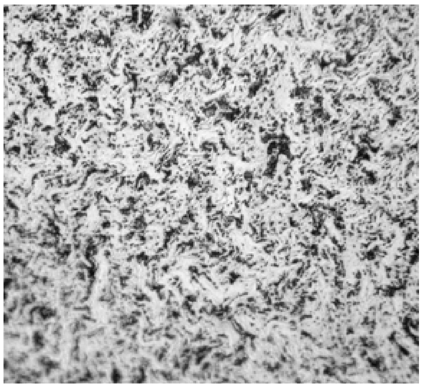
Sample No	Vickers hardness, 100 g, kgf/mm²	Integral Vickers hardness, 1 kg, kgf/mm²
1	282; 283; 283; 283; 283	318; 318; 318
2	258; 258; 258; 258; 254; 274; 285; 274; 285; 285; 285; 236; 285	321; 317; 317
3	309; 322; 322; 322; 297; 297; 322	320; 328; 327
4	297; 297; 274; 274; 274	320; 325; 318
5	357; 357; 357; 357; 357	370; 370; 370

Figure 1 illustrates the microstructure of welding wire samples taken from wire rod of heat 21181. They showed steady (sample No1) and unsteady (sample No2) arc burning. The results of microstructural analysis evidenced that the samples with uniformed ferritic-carbide structure had the best arc burning while welding wire samples with unsteady arc burning had coagulated carbides in their structure, which were observed as dark regions of the microstructure.

The results of Vickers hardness measurements (Table 3) witnessed that enhanced and steady hardness of welding wire were the characteristics of the samples with the best arc burning.



a)



b)

Figure 1. Microstructure of welding wire x1000

a) sample No1; b) sample No2

In order to find the causes of differences in samples microstructures and hardness values, methods of electronic microscopy and X-ray analysis were used. The microstructure study and the analysis of quantity element composition were carried out using scanning electron microscope study and X-ray microanalysis on the base of analytical complex, composed by scanning JSM-35CF electron microscope by JEOL (Japan) and X-ray diffraction instrument with dispersion on X-ray photon energy (model INCA Energy-350 by Oxford Instruments, the UK). The specific feature of X-ray microanalysis is in its local approach - the maximal excitement is 1 micron. The images were obtained in modes of secondary electron imaging (SEI) and backscattered electron imaging (BEI) at U = 20 kV.

The research of microstructure was performed at magnifications x600, x2000, x6000, x20000 with the samples, on which hardness measurements were made: there are rhomboidal imprints from diamond spheroconical penetrator of hardness measuring instrument seen in the photos. The images were taken in secondary electrons, which allowed us to analyze surface texture. The quantity element composition was analyzed on both microregions (at magnification x600) and locally separated structural constituents (at magnification x20000). All the results are submitted in % (mass).

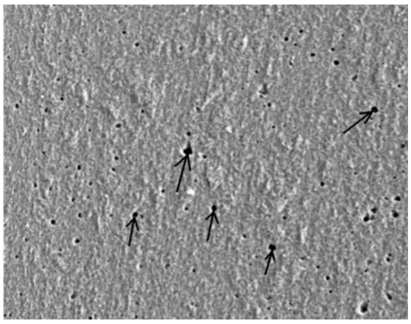
The results of element composition macroanalysis are presented in Table 4. They bring the conclusions that all the five samples had similar quantities of the main alloying elements (Si, Mn). Although it is necessary to note that this analysis cannot help us to determine the exact amount of carbon in the metal because of surface effect, that is why it was excluded from the analysis.

Table 4. Chemical composition of samples

Sample	Si	Mn	Fe
No1	0.79	1.57	97.64
No2	0.68	1.60	97.72
No3	0.59	1.61	97.81
No4	0.82	2.10	97.07
No5	0.91	1.70	97.39

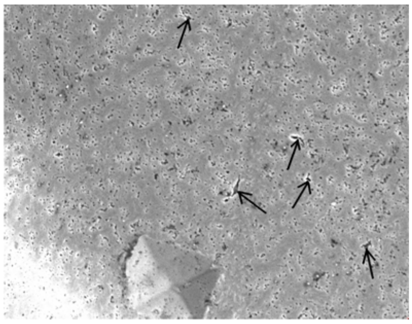
The results of microscopic study for the five samples at the same magnification (x2000) are shown in Figure 2. Based on these data, we can conclude that samples No 1-No 4 had pores. In the respective figures they are in form of black spots, the biggest onesare pointed by black arrows. Sample No5 had no porosity.

Moreover, samples No1 and No3 were similar with their low density, pores round shapes and small sizes. Sample No 2 had the highest level of pores concentration, and although their sizes were not very big, but many of them were elongated and crack-shaped with sharp edges. The pores concentration in sample No 4 was not very high, but their sizes were the biggest, they were elongated in the shape of wormhole, probably the result of pore chains fusion.



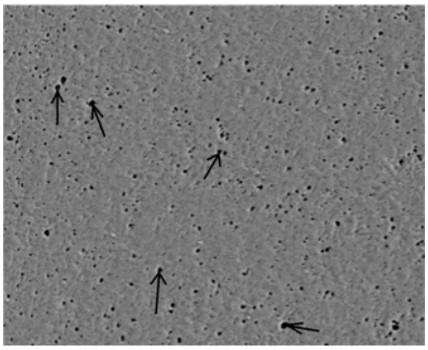
20 micron x2000

No 1



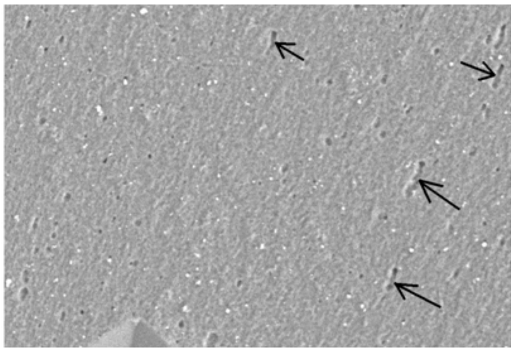
20 micron x2000

No 2



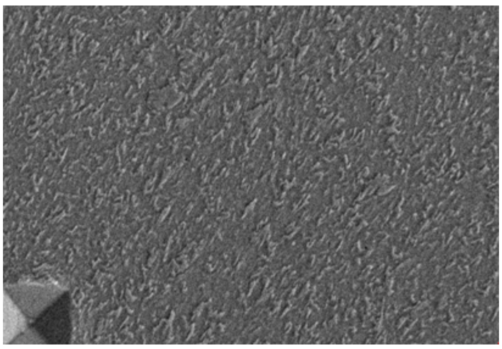
20 micron x2000

No 3



30 micron x2000

No 4



30 micron x2000

No 5

Figure 2. Sample surfaces in the mode of secondary electrons at the similar magnification x2000

In order to reveal the specific reasons of pores occurrence, we carried out the local analysis of element composition. The analysis was made inside the pores and on the meatal matrix outside the pores. It was found out that the content of Si, Mn, Fe in the middle of pores was similar to metal matrix composition (the deviation was not more than 10...15%), and it drew the speculation that the pore occurrence was probably conditioned upon gases. That is why the extra studies on samples No 2 and No 5 were made with the objective to analyze gases (oxygen, hydrogen, nitrogen). The contents of oxygen and hydrogen in the test samples were similar, but that of nitrogen was significantly different (sample No2 – 0.0107%, sample No5 – 0.0050%). The high nitrogen in sample No 2 prompted that the found porosity was conditioned upon this gas.

Furthermore, the significant point in good quality wire production is the preliminary inspection of mechanical properties of the product - wire rod at feed unit. The possibility to reveal the welding and fabrication properties on the stage when the production process is being developed is of particular interest. As the quality inspection of the mechanical characteristics is not a complicated process, the opportunity to apply it for the purpose to predict the product's welding and fabrication properties is attractive. One of the most important characteristics of the material plasticity is its yield curve or hardening one, according to which we can calculate the performance characteristics, carry out the simulation of FEM and study the mechanics of the drawing process. The nature of yield curves is not dependent on deformation type, with which they are made, their construction can be conducted on the base of the simplest tests, and results can be used for the analysis of the most complicated processes.

In order to define the mechanical properties of the wire rod of heats No. 21181 and No. 260399, tensile tests were carried out at IP100 tensile testing plant, in accordance with ISO 6892-1 Metallic Materials - Tensile Testing - Part 1: Method of Test at Room Temperature. IP100 tensile testing plant had gained metrological check certificate. We tested the samples of the wire rod prepared to the delivery. The gauge section was 200 mm and the diameter was 5.5mm. Visually, these yield curves of G3Si1 wire rod (heats No 21181 and No 260399) are shown in Figure 3. The curves were developed in accordance with the method described in paper [6]. In Table 5, we report on the values of calculated approximation coefficients and give the material standard mechanical characteristics, provided by tensile testing.

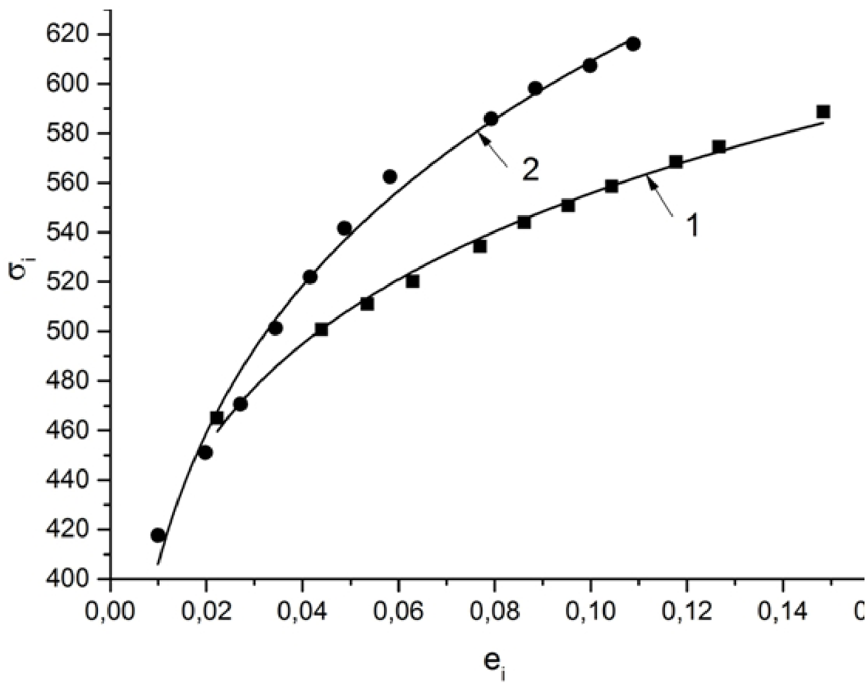


Figure 3. Continuous lines of yield curves (curve 1 – heat No. 21181; curve 2 – heat No. 260399 and σ_i, MPa) approximated by $\sigma_i = Ae_i^n$

Table 5. Values of approximation coefficients and standard mechanical properties

Curve No	Values of approximation coefficients			Mechanical properties		
	A, MPa	*n*	R^2_{adj}	σ_{rt}, MPa	σ_h, MPa	Δl, %
1	744±7	0.126±0.004	0.992	507	450	30.25
2	913±18	0.176±0.006	0.988	552	425	25

The specific feature of the materials under analysis was a relatively low hardening coefficient *n* (0.12...0.18), which was much lower than that for the materials, studied by us earlier, in paper [6] and for which there was no obvious impairment of the wire welding and fabrication properties. This fact can speak for the following: low hardening (coefficient *n* is less than 0.18) of the wire rod material in the feed unit indicated the possible decrease of the finished wire quality due to the unsteady arc burning.

The obtained yield curves show that in the initial state, the wire rods physical and mechanical properties were significantly different, this was conditioned upon certain difference in the chemical compositions and processing of semi-finished products. Thus, it allows us to conclude that although the initial physical and mechanical properties of the wire rod were formed through chemical compositions within the standard requirements, they could hardly influence welding and fabricated characteristics provided that such finished products met the quality requirements. The production route and the tradition of wire rod manufacturing plays a significant role in its further processing into good quality wire. This particularly concerns the presence of included gases or pores, coagulated carbides, et cetera. Moreover, the presence of pores in the wire rod directly decreases hardening property of metal at its. In its turn, pores in material of wire rod in the feed unit condition their presence in the structure of the wire. This peculiarity can be put into the basis of express diagnostics of the material of the wire rod. The case when hardening coefficient *n* of the material in the feed unit is less than 0.18 (at yield curve approximation according to two-parameter Ludwig function) could mean possible decrease in the finished wire quality in terms of arc burning instability. Such cases require additional control of finished products, for instance, by way of hardness measurement carried out on different sections of the wire or its microstructural analysis.

Conclusions

The stability of welding wire arc burning is provided not only with the appropriate finished product parameters, which usually correspond to the existing standards, but also with homogeneity of the wire rod structure, which is used by the wire producer during the process of the wire manufacture. Microstructural analysis of low carbon welding wire, carried out on its sections with steady and unsteady arc burning, showed that equal distribution of carbide phase in ferrite matrix corresponds with the best arc burning.

The high porosity of welding wire can be generated by the presence of gases in it (the high concentration of nitrogen was found in the samples) and it causes the decrease in wire hardness and unsteady arc burning.

The results of Vickers hardness measurement showed that the best arc burning is peculiar to wire samples characterized by enhanced and regular hardness.

Provided that hardening coefficient *n* of the wire rod material in the feed unit is less than 0.18, we can predict possible decrease in the finished product performance that is instability of arc burning.

Based on the results of microstructural analysis of welding wire, it is worth to note that the presence of coagulated carbides in its microstructure is typical for the sections with unsteady arc burning.

References

1. Medyushko V.A, Razorenov O.N., Krivorotov V.I., Medyushko (2007) Analiz pokazateley kachestva svarochnoy provoloki metodom statisticheskoy otsenki stabil'nosti ee khimicheskogo sostava [Analysis on welding wire parameters through its chemical analysis by the method of static evaluation]. *Industriya* [Industry]. No 2(49), p.p.76–77.
2. Rimskiy S.T. (2015) Metodika opredeleniya kolichestvennykh pokazateley, kharakteriziruyushchikh svarochno-tekhnologicheskie svoystva provoloki pri mekhanizirovannoy svarke v zashchitnykh gazakh [Methodology to determine the quantity index to describe the wire welding properties for welding in gaseous

medium]. *Svarshchik* [Welder]. No1, p.p.16 – 22.

3. Voropay N.M. (2002) Tekhnologicheskie svoystva omednennoy svarochnoy provoloki [production characteristics of welding copper wire]. *Svarshchik* [Welder]. No4, p.p. 16-20.
4. Lutsenko V.A., Murikov M.A., Polyakov V.A., Kondrashkin V.A., Gritsaenko V.I. (2012) Osobennosti i perspektivy proizvodstva katanki svarochnogo naznacheniya s vysokoy tekhnologicheskoy plastichnost'yu [Specific character and perspectives of wire rod production with high production plasticity for welding]. *Lit'e i metallurgiya* [Casting and Metallurgy]. No3 (66), p.p. 56-58.
5. Nesterenko A.M. (2006) Issledovanie prichin razrusheniya pri volochenii katanki-provoloki iz stali Sv-08G2S [Research on destructions of Sv-08G2S rod wire in drawing]. *Metallurgicheskaya i gornorudnaya promyshlennost'* [Metallurgical and mining industry]. No6, p.p.60-63.
6. Grushko O.V. (2016) Krivi techiï katanki marok G3Si1 ta Sv-08G2S [Yield curves of G3Si1and Sv-08G2S wire rods]. Obrabotka materialov davleniem : sb. nauch. tr. [Metal forming: publication of scientific papers]. No1(42), p.p. 207-213.

UDC 621.914.1

Experimental study of turn-milling process using special friction mill made of steel Hardox

Karibek Sherov

Doctor of Technical Sciences
Professor of the Department of “Technology equipment, mechanical engineering and standardization”
Karaganda State Technical University

Muratbay Sikhimbayev

Doctor of Economic Sciences
Professor of the Department of “Technology equipment, mechanical engineering and standardization”
Karaganda State Technical University

Medgat Musayev

Doctoral student of the Department of “Technology equipment, mechanical engineering and standardization”
Karaganda State Technical University

Aset Rakishev

Doctoral student of the Department “Technology equipment, mechanical engineering and standardization”
Karaganda State Technical University

Bakhytzhan Donenbaev

Doctoral student of the Department "Technology equipment, mechanical engineering and standardization"
Karaganda State Technical University

Abstract
The modern national economy of Kazakhstan Republic is characterized by the rapid progress of aviation, rocket, electronic, atomic and mining equipment, power, chemical and mining machinery. This led to a sharp increase in consumption of new types of materials with special physical and mechanical properties, with high corrosion and heat resistance, which processing by the traditional mechanical methods was associated with certain difficulties. These materials are generally difficult to treat and cutting tool wear is very high. One way of saving expensive tool material is the application of new technologies, one of which is a combined method of parts processing of body of rotation by turn-milling. One of the main differences of the developed method is the use of special friction mill that is not from the tool material instead of standard mills. Results of the study of this method have shown the possibility and efficiency of machining of the rotation body type parts by turn-milling using mill made of steel HARDOX as a cutting tool.
It is revealed that after processing by turn-milling under various cutting conditions and combinations of cutting tool and workpiece movement, the surface hardness values obtained before and after treatment are not significantly different, which affects successfully on performing of the following operations. The authors suggest that the main effect of the investigated cutting method is the occurrence of the current layer in sufficiently plastic state, perhaps even close to the melting state under certain temperature conditions.
Key Words: TURN-MILLING, FLOW CHIPS, CHIP FORMATION, CURRENT LAYER, FRICTION MILL, SUBCONTACT LAYER, TEMPERATURE, SURFACE ROUGHNESS, HARDNESS, FEED MOTION

Scientific and technological progress in mechanical engineering necessitates the use of new materials with special properties. Typically, these materials have higher strength characteristics, high heat resistance and corrosion resistance. When processing parts made of such materials, tool wear is intense. There are close links between the intensity of tool wear and the surface layer quality parameters of the parts processed by cutting [1].

The most significant metalworking reserves, which have not been mastered yet, are disclosed from the relationship of cutting methods establishing the transition from one method to another as change of kinematics and technological characteristic. This relationship allows us to improve the classic and develop entirely new complex methods [2]. The turn-milling is a kind of turning with multiblade revolving pick. Insignificant differences lie in the use of standard mills and rotation axes location of workpiece and tool [2, 3].

The research results of the titanium alloy processing by turn-milling are given in [4]. As processed material, the round rolled product made of titanium alloy VT 1-0 was used. The end mill was taken as tool. BK8 was cutting part material. The treatment was carried out at the counter and passing scheme of tool advance without using of LCTF (lubricant cooling technological facility). It was found that the surface quality differs slightly when the processing of titanium alloy with a cutting speed of 15 m/min at the counter and passing scheme of the tool advance. With increasing cutting speed when counter scheme of the tool advance, the surface quality is reduced by the chip pickup on the surface processed. When passing turn-milling the surface quality is improved and there is a reliable removal of chips from the cutting zone. Also, the chip samples have been researched when the counter scheme of the tool advance, which have been strongly deformed and, with an increase in cutting speed, this deformation magnifies. When passing processing scheme the chips obtained have less deformed condition [5, 6]. At the department of "Technological equipment, mechanical engineering and standardization" the following grant topic is performed: "Development of a special machine constructions enabling a pulsed cooling feed and replacement of cutting tool made of hard alloy on the tool made of structural steel when thermal friction cutting of metal workpieces"(contract No723-2015). As a part of this topic, a series of experimental studies of the combined turn-milling method using special cutting tool (friction mill) have been carried out. One of the main differences of the developed method is the use of special friction mill, which is not made of the tool material, instead of standard mills. The basis for the research and development of this process were the results obtained by the authors in the development of resource-saving ways of thermal friction processing at low speeds [7, 8]

Experimental tests were carried out in a special unit mounted on lathe. Samples (round rolled pro- ducts) prepared for processing were made of the following materials: steel 30KhGSA and steel 3. Friction mill was made of steel HARDOX 400. Also, the standard angular cutter made of material P18 was used for processing.

Figure 1 shows a picture of the special friction mill.Experimental studies were carried out in three stages.

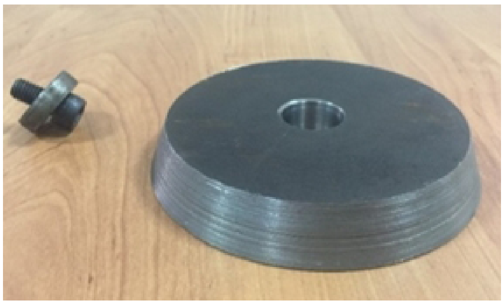
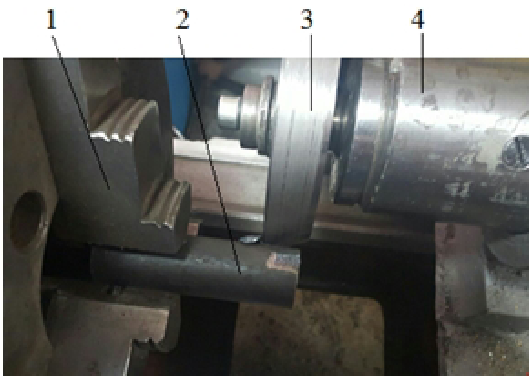


Figure 1. Special friction mill

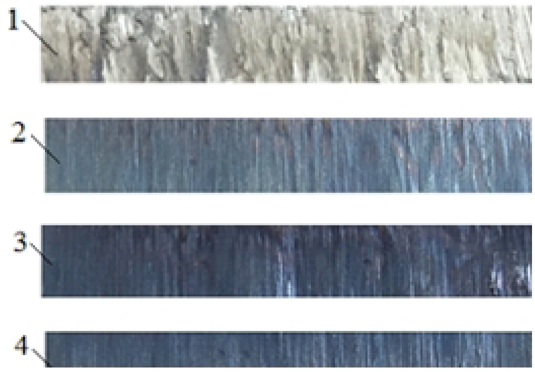


1. three-jawed chuck; 2. workpiece made of steel 30KhGSA; 3. friction mill made of steel HARDOX 400; 4. special unit spindle

Figure 2. The processing of steel 30KhGSA

At the first stage, the special friction mill is connected with rotary motion and feed motion, wherein the workpiece is fixed. At the second stage, the friction special mill and workpiece are simultaneously interconnected with rotation movement, wherein the tool additionally comprises a feed motion. At the third stage, angular cutter made of P18 was used as a cutting tool. Tool and workpiece at the same time were connected with rotation movement, and the tool further has a feed motion.

Figure 3 shows the surface of the processed steel 30KhGSA and types of chips obtained when different tool feeds.



a)

b)

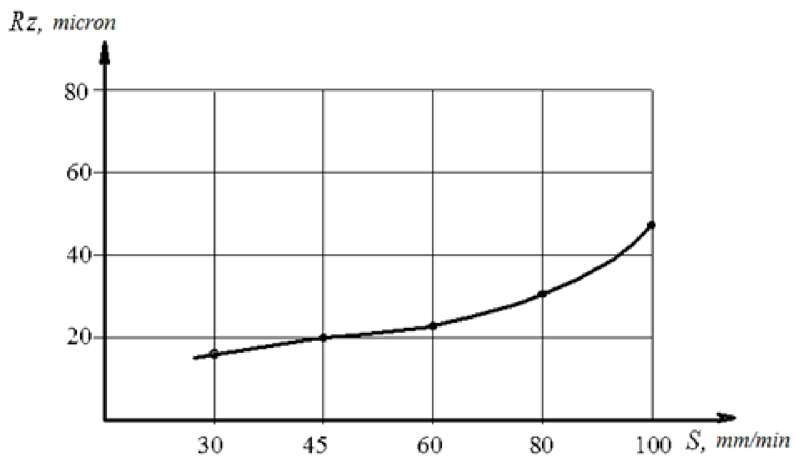
c)

a - processed surface at a magnification of 20 times; b - processed workpiece; c - types of chips obtained when different tool feeds;
1 - S = 100 mm/min; 2 - S = 80 mm/min; 3 - S = 60 mm/min; 4 - S = 45 mm/min;
5 - S = 30 mm/min; t = 1.5 mm; n_{sr} = 2000 rev/min; v_u = = 250 m/min

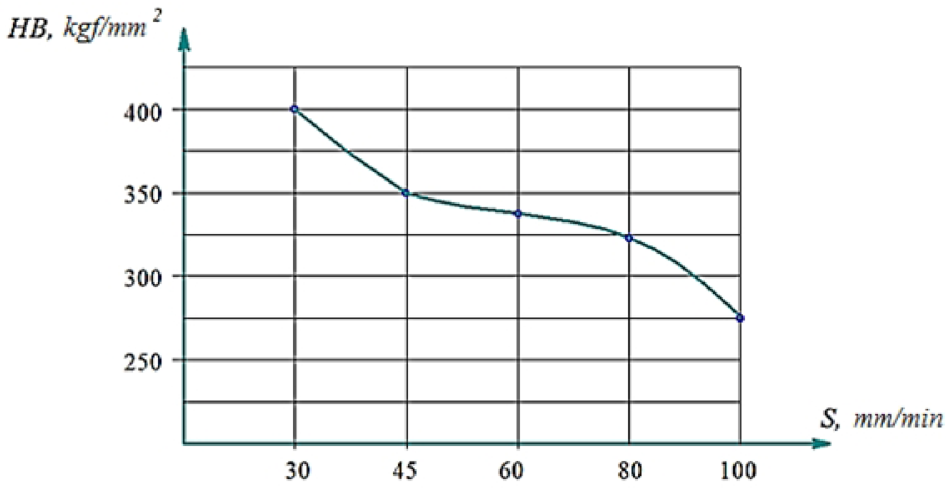
Figure 3. The processed surfaces of steel 30KhGSA and chips types

When processing steel 30KhGSA the flow shearing chips were formed (Fig. 3, *c*). The chip surface contacting with the cutting edge of the tool was smooth, and the opposite side was rough. After completion of the tests, when inspecting the cutting part of the friction mill the signs of wear, scratches, and the presence of burnt areas and scale pickup were not observed. This can be explained by the fact that when the high temperature (θ>600°) chip layer softens, becomes very ductile and acquires certain mobility. So-called active layer is appeared [9,10] and it can be assumed that there is a chip sliding relative to the current stagnant layer that protects the surface of the friction mill from wear. It can be concluded that the main effect of the test cutting method is the occurrence of the current layer in sufficient plastic state, possibly even close to the melting state under certain temperature conditions. The appearance of this layer reduces the friction on the workpiece-tool surface, and consequently, reduces wear and improves surface quality. Further scientific conclusions can be drawn from a study of the chip section in deformed state.

Figure 4 shows the feed charts impact on the roughness and hardness of the cutting surface during processing of steel 30KhGSA.



a)



b)

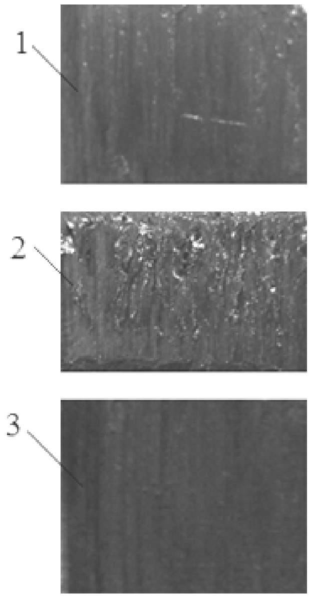
a – chart of feed impact on roughness; b – chart of feed impact on hardness t = 1.5 mm; n_{sr} = 2000 r/min; v_u = 250 m/min

Figure 4. Feed impact charts on the roughness and hardness of the cutting surface

While conducting tests, feed values ranged *S* = 30 ÷ ÷ 100 mm/min. Measurement of surface roughness was carried out using a device (profilometer) TR 100. Measurement of hardness of the treated surface was carried out using a dynamic device TDM-2. The results of experimental studies have shown that the feed impact on the roughness of the cutting surface is monotonic, i. e. with the feeding increase the surface quality deteriorates. The increase feeding has a monotonous impact on the hardness of the cutting surface. According to the chart (Fig. 4b), it can be seen that the hardness value decreases when feeding increase.

Conducted initial experimental studies indicate the possibility of mechanical processing by the proposed method of turn-milling using the tool made of steel HARDOX 400.

Figure 5 shows the processed workpiece made of steel 3 and types of chips obtained.



a)

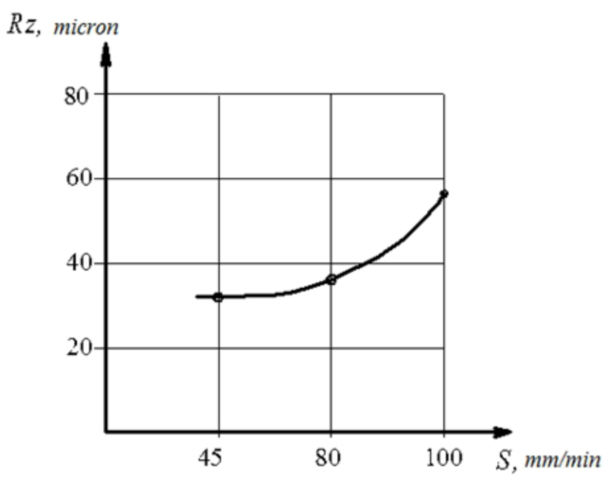
b)

c)

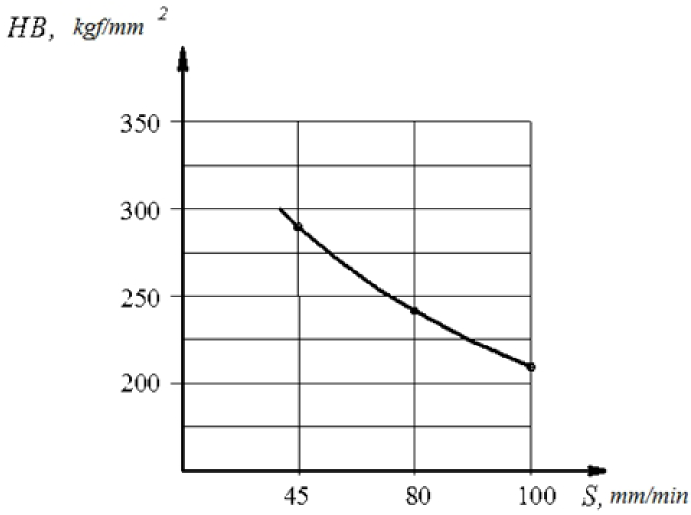
a - processed surface at a magnification of 20 times; b - processed workpiece; c - the types of chips obtained when processing with various feeds
1 - S = 100 mm/min; t = 1.0 mm; 2 - S = 80 mm/min; t = 2.0 mm; 3 - S = 45 mm/min; t = 4.0 mm; n_{sr} = 2000 r/min; v_u = 250 m/min

Figure 5. The processed surfaces of steel 3 and chips types

During the processing of steel 3 at various feedings, a sharp change in the character of chip formation process is observed. A temperature has a great influence on chip formation process. This temperature occurs in tool-workpiece subcontact layer that provides high ductility of the shear layer. Increasing the feed facilitates the chip formation and output. Fig. 6 shows the feed charts impact on roughness and hardness of the cutting surface when processing the steel 3.



a)



b)

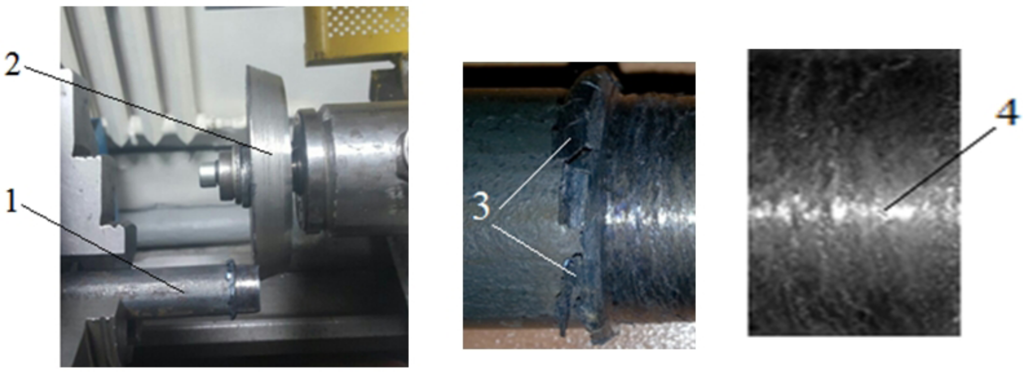
a – the chart of feed impact on roughness; b – the chart of feed impact on hardness
t = 1.0 mm; n_{sr} = 2000 r/min; v_u = 250 m/min

Figure 6. Feed impact charts on the roughness and hardness of the cutting surface

The results obtained show (Fig. 6 *a*), that when feed increasing the microroughnesses height rises and the hardness decreases (Fig. 6 *b*). In both cases, it is observed that the feed increasing has a monotonous impact.

The experiments on study the possibility of processing by turn-milling were carried out when simultaneous rotating of workpiece and tool.

Figure 7 shows the processing of steel 30KhGSA when simultaneous rotation of workpiece and tool.



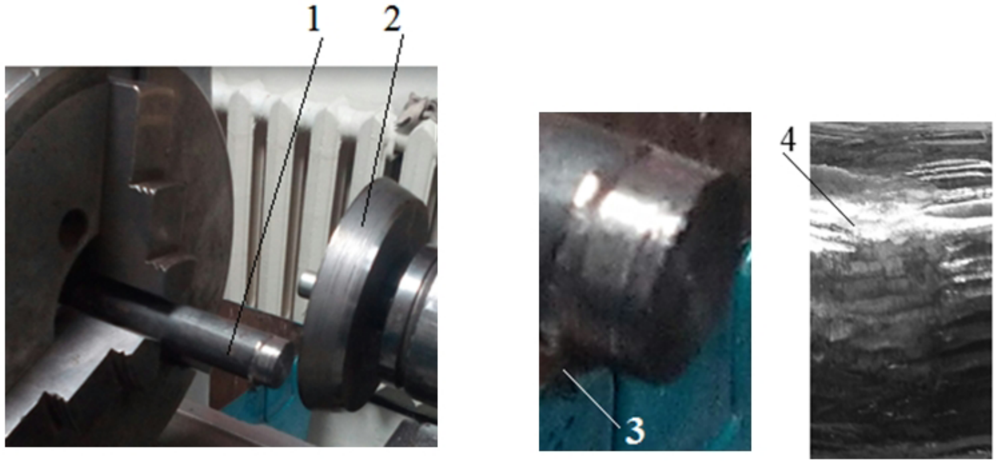
a) b) c)

a – processing; b - processed workpiece; c - machined surface roughness
S = 45 mm/min; t = 1.5 mm; n_{sr} = 2000 r/min; v_u = 250 m/min
1-workpiece; 2 – friction mill made of steel HARDOX 400; 3- chips;
4- processed surface at a magnification of 20 times;

Figure 7. The processing of steel 30KhGSA in case simultaneous rotation of workpiece and tool

The experiment on the processing of workpiece made of steel 30KhGSA was conducted when simultaneous rotating of workpiece and tool. The workpiece with following dimensions was processed: ø30mm, *l* = 25 mm. The treatment process has roughing character and the chips output is not observed during the cutting process. The surface hardness was measured before and after processing that was HB217 before treatment and HB220 after treatment respectively. The surface roughness corresponded to R_z 40.

Figure 8 shows the processing of steel 3 when simultaneous rotating of workpiece and tool.



a) b) c)

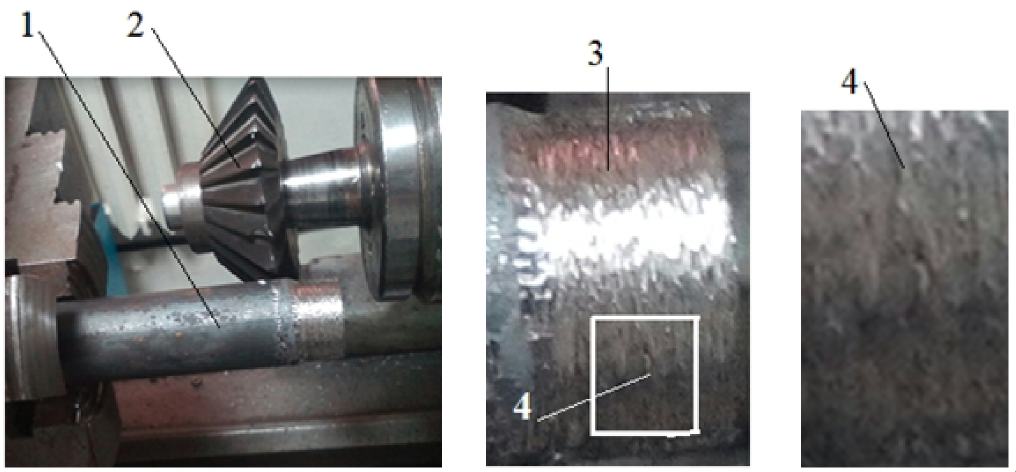
a – processing; b - processed workpiece; c - machined surface roughness
S = 60 mm/min; t = 1.0 mm; n_{sr} = 2000 r/min; v_u = 250 m/min
1 - workpiece; 2 - friction mill made of steel HARDOX 400; 3 - chips;
4 - machined surface at a magnification of 20 times

Figure 8. The processing of steel 3 on case of simultaneous rotation of workpiece and tool

Processing of steel 3 when simultaneous rotating of workpiece and tool has been performed under the same cutting conditions as when the processing of steel 30KhGSA. The workpiece ø26mm was selected for processing, length of treated surface was *l* = 32 mm. The surface roughness corresponded to R_z60. The hardness of the surface was HB131 before the processing and HB148 – after processing. After treatment, surface hardness increased slightly.

To investigate the turn-milling, method the standard angular cutter was used.

Figure 9 shows processing of steel 3 by angular cutter when simultaneous rotation of workpiece and tool.



a) b) c)

a – processing; b - processed workpiece; c - machined surface roughness
S = 40 mm/min; t = 1.5 mm; n_{sr} = 2000 r/min; v_u = 250 m/min
1- workpiece; 2- angular cutter; 3- machined surface; 4- machined surface at a magnification of 20 times

Figure 9. The processing of steel 3 by angular cutter when simultaneous rotating of workpiece and tool

During processing of steel 3 by angular cutter in case of simultaneous rotation of workpiece and tool, the previously selected modes of cutting were not changed. The workpiece with following dimensions ø30mm, *l* = 28 mm was subjected to processing. During the processing, there was crushing of chips and their removal from the treatment zone. These chips were severely deformed. Surface hardness was measured before and after treatment that was HB131 before and HB137 after the processing respectively. The surface roughness corresponded to R_z 80.

The aim was to obtain experimental data showing the possibility of mechanical processing by turn-milling using the mill made of steel HARDOX as cutting tool, as well as to get general information regarding chip formation process, the surface quality forming and feed impact on the quality indicators.

The results show the possibility of processing by the proposed method. It is necessary to conduct further experimental studies for more extensive study of the processes occurring in the course of treatment and technological capabilities of turn-milling.

Conclusion

1. The possibility of mechanical processing of parts such as body of rotation by turn-milling using a mill made of steel HARDOX as a cutting tool has been shown.

2. It has been found that the feed impact on the roughness and hardness of the cutting surface is monotonic, i. e. with feed increasing the surface quality deteriorates, and the hardness of the surface is reduced.

3. It has been revealed that after processing by turn-milling when simultaneous rotating of workpiece and tool the surface hardness value before and after treatment differs slightly, which successfully affects the performance of the following operations.

4. The results obtained when processing of steel 3 by standard angular cutter when simultaneous rotation of workpiece and tool confirm the conclusions of [4], namely that for the implementation of high-quality grinding of chips, a number of tool rotations n_t should be greater than the number of part rotations n_p.

5. We can assume that the main cutting effect of the investigated method is the occurrence under certain temperature conditions of the current layer in sufficient plastic state, probably even close to the melting state. The appearance of this layer reduces the friction on the workpiece-tool surface, and consequently, reduces wear and improves surface quality. However, to obtain reliable results, further scientific researches of the chip section in deformed state are needed.

References

1. Makarov A. D. (1989) *Optimizatsiya protsessov rezaniya* [Optimization of cutting processes]. Moscow: Mashinostroenie. 278 p.
2. Ermakov Yu. M. (2005) *Kompleksnyie sposobyi effektivnoy obrabotki rezaniem: Biblioteka tehnologa* [Complex methods for efficient processing by cutting: Technologiest Library]. Moscow: Mashinostroenie, 272 p.
3. Kovshov A. N., Nazarov Yu F., Yaroslavtsev V. M. (2007) *Netraditsionnyie metodyi obrabotki materialov* [Nontraditional methods of mate- rials processing]. Moscow: MSOU. 211 p.
4. Selivanov A. N. (2011) *Povyishenie proizvoditelnosti i kachestva obrabotki tel vrascheniya iz titanovyih splavov metodom vyisokoskorostnogo frezerovaniya i frezotocheniya: dissertatsiya kandidata tehnicheskih nauk* [Increasing the productivity and quality of processing bodies of revolution made of titanium alloys by high-speed milling and turn-milling: the dissertation of the candidate of technical sciences]. Saratov. 141 p .
5. Nasad T. G., Selivanov A. N. (2011) Eksperimentalnyie issledovaniya struzhkoobrazovaniya pri obrabotke titanovogo splava marki VT 1-0 metodom vyisokoskorostnogo okruzhnogo frezerovaniya [Experimental studies of chip formation during the processing titanium alloy VT 1-0 by high-speed circumferential milling]. *Vestnik Saratovskogo gosudarstvennogo tehnicheskogo universiteta* [Bulletin of Saratov State Technical University]. No 2 (56). p.p.138 - 144.
6. Selivanov A. N., Nasad T. G. (2010) Obespechenie kachestva obrabotki valov iz titanovyih splavov metodom vyisokoskorostnogo frezerovaniya i frezotocheniya [Quality assurance of rolls made of titanium alloys processing by high-speed milling and turn-milling]. *Vestnik Saratovskogo gosudarstvennogo tehnicheskogo universiteta* [Bulletin of Saratov State Technical University]. No 3 (46). p.p.55 - 61.
7. Patent of Kazakhstan 22998. Bulletin No10 of 15.10.2010. The method of thermal frictional processing of plane and friction disc structure by Sherov K .T., Alikulov D.E., Imasheva K. I.
8. Patent of Kazakhstan 25649. Bulletin No4 of 16.04.2012. The method of thermal frictional cutting-hardening processing of cylindrical surfaces and friction disc structure by Sherov K. T., Buzauova T. M., Sherov A. K.
9. Loladze T. N. (1982) *Prochnost i iznosostoykost rezhuschego instrumenta* [The strength and durability of the cutting tool]. Moscow: Mashinostroenie. 320 p.
10. Reznikov A. N. (1983) *Teplofizika protsessov mehanicheskoy obrabotki materialov* [Thermal physics processes of materials mechanical processing]. Moscow: Mashinostroenie. 279 p.

Numerical method to calculate coal strata surface curvature, predetermined by discreet points of the irregular grid

Vorob'ev A.E.

Doctor of Technical Sciences, Professor,
Head of Department of Oil-Field Geology, Mining and Oil-Gas Business,
Peoples' Friendship University of Russia, the Russian Federation

Khodzhaev R.R.

Doctor of Technical Sciences,
Director of LLP "Research & Engineering Center "GeoMark"

Gabaydullin R.I.

PhD in Technical Sciences,
Deputy Director for Science
LLP "Research & Engineering Center "GeoMark"

Isabek T.K.

Doctor of Technical Sciences, Professor,
Head of the Department of Development of Mineral Resources Deposits
Karaganda State Technical University, Karaganda, Kazakhstan

Khuangan N.

Master in Mining Engineering, Assistant Professor,
Department of Development of Mineral Resources Deposits
Karaganda State Technical University, Karaganda, Kazakhstan

Vorob’ev K.A.

Bachelor of Department of Oil-field Geology,
Mining and Oil-Gas Business, Peoples’ Friendship University of Russia,
the Russian Federation

Abstract
This article reports on implementation of the numerical method for surface curvature calculation at random point; it is determined by discreet set of points on the irregular grid. The results of this work were used for the research of structural failures of coal strata evidenced by the data obtained from the exploration wells.
Key words: MINING PRODUCTION, COAL STRATUM, NUMERICAL METHOD, METHOD, ELASTICITY MODULUS, CURVATURE SURFACE, EXPLORATION WELL

The necessity to calculate the curvature surface *z=F(x,y)* (or radius of curvature, as these notions are reciprocal) occurs, particularly, when we need the solution of the calculation problems for tensile or compressive stresses at the points of the curvature surface. It is known that [1] stresses acting at the instant of the pure bend of the stress within the material are calculated according to the formula below:

$$\left.\begin{aligned}\sigma_x &= Ezk_x,\\ \sigma_y &= Ezk_y,\end{aligned}\right\}, \qquad (1)$$

where

E is the elasticity modulus (Young’s modulus) of the material (kg/cm²);

k_x, k_y – the curvature surface with respect to the directions of X and У axes at the points under study;

z – the distance from the neutral axis at bending (m);

σ_x, σ_y – the stresses on X and У axes (kg/cm²).

When the calculations are carried out, the numerical value of the material elasticity modulus *E* is, as a rule, taken as standard reference data, which have been earlier found based on the special laboratory tests, or defined by the appropriate empirical dependence on the mechanical and physical properties.

The value of the distance from the neutral axis is set by the researcher and depends on whether the calculations of the stresses at the point under interest are required or, in other words, it is determined by the certain initial value. The only issue that we need to calculate is the curvature surface at the point under analysis.

Theatrically, the curvature at any point (x_j,y_i) of the surface *z=F(x,y)* is directed by the arrangement of axes and is calculated by formula [2]

$$k_{x_j} = \left| d^2\varphi(x_j)/dx^2 \right| / \left[(1 + d\varphi(x_j)/dx)^2\right]^{3/2} \qquad (2)$$

or

$$k_{y_i} = \left| d^2\psi(y_i)/dy^2 \right| / \left[(1 + d\psi(y_i)/dy)^2\right]^{3/2} \qquad (3)$$

where *φ(x), ψ(y)* are the equations of lines, derived from the intersection with the surface by *XOZ* plane at the fixed y_i and YOZ plane at the fixed x_j respectively.

Unfortunately, when the surface is set by the discreet points, there exist the difficulties with the analytic expressions for $\varphi(x)$ line and $\psi(y)$ line, which are to be developed with the objective to calculate the derivatives of the first and second order.

Therefore, for the practical solution of this problem we offered the following procedure. Firstly, we produce the two-dimensional interpolation of the values for points z_{ji} with respect to both directions of X and Y axes with the equal step h (this simplifies the calculations); the interpolation results in the range of numerical values $\{\varphi(x_j)\}=\{z(x_j)\}$ at fixed y_i and $\{\psi(y_i)\}=\{z(y_i)\}$ at fixed x_j. After this, we use the method of numerical differentiation for the function with a constant step by the function values at these points. This method is based on the use of the Lagrange interpolation polynomial formula for equidistant points. The general formula for calculation of the derivative of the first order with Lagrange interpolation polynomial $L_{xz}(x_j)$ for the equidistant points x_j is expressed as [3]:

$$\phi'(x_j)=z'(x_j)\approx L_n'(x_j)=\frac{1}{n}\sum_{j=0}^{n}\frac{(-1)^{n-j}z_j}{j(n-j)}\frac{d}{dq}\left\{\frac{q^{[n+1]}}{q-j}\right\},\ j=0,\ldots,n, \qquad (4)$$

where $q=(x-x_0)/h$ is the new variable of differentiation.

The similar structure is seen in the formula for the calculation of the first order derivative with the use of Lagrange interpolating polynomial $L_{yz}(y_i)$ for the equidistant points y_i.

From the general formula (3), we can develop the specific formulae for the derivatives of the first and second order for each of n points belonging to x_j (or y_i). The further algorithm is as follows.

Let us consider the case, when with the two-dimensional interpolation of the values belonging to function $z(x_j,y_i)$, we receive NxN matrix of numerical values z_{ji} (without intervention into generality, we assume that the number of the points of interpolation by both axes is identical and equal to N). For calculation of the derivatives and the curve by formulae (3) and (2), it is necessary to define subset $\{n\}\subset\{N\}$, where n is the number of points, for which the derivatives are calculated. Methodically, this implies that by Lagrange interpolating polynomial $L_{xz}(x_j)$ (or $L_{yz}(y_i)$) of degree n, we can make a piecewise approximation of the equation for the flat line, which passes through n of points.

When calculating the derivatives and further the curvature surface, the choice of interpolation step and number of points are essential (the method is used only for the equidistant points). The most important thing here is that this procedure envisages the error, value of which is inevitable due to approximate numerical methods.

For points x_0, x_1, x_2, x_3, x_4 (n=4), positioned in the succession with the step h, the derivative of the first order at midpoint x_2 is calculated by approximation formula as follows:

$$z_2'\approx\left(z_0-8\cdot z_1+8\cdot z_3-z_4\right)/12\cdot h, \qquad (5)$$

while the derivative of the second order – by formula [6]:

$$z_2''\approx\left(-2\cdot z_0+32\cdot z_1-60\cdot z_3+32\cdot z_4\right)/24\cdot h^2 \qquad (6)$$

where z_0, z_1, z_3, z_4 are the values of the function at points x_0, x_1, x_3, x_4.

If the number of points is uneven (n - even) and the derivative is taken from the midpoint, then the appropriate formula for the numerical differentiation is expressed much simpler and is highly accurate. For such central points, the first derivative is calculated by formula [7]. In order to observe the symmetry, the indices are enumerated in this order: -2, -1, 0, +1, +2:

$$z'(0)\approx\frac{2}{3h}\left(z_1-z_{-1}\right)-\frac{1}{12h}\left(z_2-z_{-2}\right) \qquad (7)$$

Moreover, the calculation of the derivatives by the numerical method always bears the possibility of an error existence and the general expression of this error for the first derivative is written as:

$$R_n(x_j)\approx(-1)^{n-j}h^n\frac{j(n-j)}{(n+1)}z^{(n+1)}(\xi),\ \xi\neq x_j,\ j=0,1,2,\ldots n \qquad (8)$$

Furthermore, for central point x_2 at n=4 (we take the subset of 5 points) the error expression is the following:

$$R_5(x_2) \approx \frac{h^4}{30} z^{(5)}(\xi) \qquad (9)$$

It becomes obvious from formula (9) that the error value is influenced by the distance between the points or the interpolation step and the choice of point ξ from interval (x_0…x_5), provided that point ξ does not coincide with any of points x_0…x_5. If the value of the interpolation step h can be given with quite high accuracy in a definite way, then the choice of point ξ is not so explicit and as the practice shows it is reasonable to take it in the vicinity of the central point.

Eventually, the method we described above finds the application for processing on exploration wells and the authors use it for detecting tectonic fractures in coal strata, caused by accumulation of stresses as a result of abrupt changes of stratum hypsometry [4]. The algorithms of the method are implemented in the medium of integrated mathematical package MATLAB 7.01, which has the predefined functions of two-dimensional interpolation. The techniques applied for this are the methods of nearest neighbor, cubic and linear. We would like to note here that well-developed software programming language is suitable for the matrix data processing and EXCEL system spreadsheet is a convenient way of information exchange.

Since the well network is irregular, we first develop the two-dimensional interpolation with 25 m step on both X and Y coordinates, which stand for the values of depths from the surface to the stratum top and stratum bottom. This results in the matrix of depth values in the interpolation nodes. Leaving aside the issues of determining the physical and mechanical properties of different rocks, namely the elasticity modulus values, in each exploration well and the areas chosen for the stresses analysis (these are distances from the stratum top and the stratum bottom), let us concentrate our attention on the details how the calculations for surface curvature of the coal stratum are to be performed with the objective to calculate further the stresses at the interpolation points.

The calculations for the derivatives of the first and second order by formulae (5) and (6) are made with respect to the 5-point scheme (n = 4), at that the derivatives are calculated only for central point. The first five neighboring points x_j (j = 0,1,2,3,4) are selected with the fixed coordinate value y_i (i = 1, .., N) while the derivatives at point (y_i,x_2) are calculated by function values at point (y_i,x_2). Then, the set of 5 points is shifted with one interpolation step forward and the derivatives for another central point are calculated. With the help of this "shifting" method, we calculate the derivatives at all the points of a matrix row at the fixed coordinate y_i. After that, coordinate y_{i+1} is fixed and the above described is repeated for the new values of function $z(x,y)$.

A similar procedure is performed for fixed values x_j with the 5-point subsets y_j (i=0,1,2,3,4). Thus, with the completion of the cyclic procedures, we obtain the calculated numerical curvature values at all points of interpolation $k_{j,i}$, except the two outermost columns and two outer rows of the matrix created by interpolated values of functional $z(x_j,y_i)$.

Eventually, based on the data of exploration of wells irregular grid and physical and mechanical properties of the rocks in them, the calculations performed by the described method allow us to predict zones of tectonic curvature or stratum strains for the conditions of d_6 strata of Karaganda basin mines and with strain stress calculations to determine the locations of possible discontinuity of tectonic faults.

Conclusions

On condition that the analytical formula is applied to calculate the curvature at any point of the surface and this curvature is defined by a discrete set of points, then there is no need to write an explicit expression of interpolation polynomials, which approximate the surface intersections by the planes parallel to reference axis.

The derivatives of the first and second order in the formula of the curvature line at arbitrary points can be calculated by the numerical differentiation methods, based on the Lagrange's interpolation formula for equidistant points by the function values at these points.

The implementation of the described numerical method has proved its suitability for applicative calculations on the rupture stress of strain in coal strata under the influence of tectonic forces.

References

1. Darkov A.V, Shpiro G.S. (1989) *Soprotivlenie material*ov [Material Stregnth]. Moscow: Vysshaja shkola. 622 p.
2. Vygodskij M.Ja. (1969) *Spravochnik po vysshej matematike* [Higher mathematics reference book]. Moscow: Nauka. 870 p.
3. Demidovich V.P., Maron I.A. (1968) *Osnovy vychislitel'noj matematiki* [Fundumentals of numerical mathematics]. Moscow: GI FML. 659 p.
4. Metodika vyjavlenija zonal'nosti metanovyde-

lenija po priznakam strukturnoj geologii (na poljah shaht «Tentekskaja» i im. Lenina, plast d6). (Zakljuchitel'nyj). Otchet po NIR. [Methodology to reveal zonation by the signs of tectonics (mines of Tentekskaja named after V. Lenin, d6 stratum). Scientific and research work report]. Karaganda, 2011. 42 p.

Steel casting speed in suspended cast-rolling with roll-mold for thin bars production

Victoria Chubenko

Candidate of Technical Sciences (Ph. D.), Docent,
Krivoy Rog National University, Ukraine
e-mail: victoria_4@rambler.ru

Alla Khinotskaya

Senior Lecturer,
Krivoy Rog National University, Ukraine

Valeriy Chubenko

Student,
Krivoy Rog National University, Ukraine
victoria_4@rambler.ru

Abstract
This article is devoted to the research of suspension casting speed dependence on reduction value and gripping angle under conditions of cast-rolling of thin steel bars production. In order to determine the casting speed, we used foundry and rolling mill of improved design. It enabled us to increase the rate of metal crystallization and to diminish metal loss. The operations were performed with suspension, made from particulate low carbon steel chips. In the research, the impact of the reduction value and gripping angle on the speed of steel casting in the process of casting-rolling was analyzed and the reasonable reduction ratio of 15% with the steel casting was found. The dependence of the suspension casting speed in the foundry and rolling mills on the exit thickness of bar and the gripping angle was defined. The dependency graphs allowing us to trace the change of steel casting speed with different gripping angles for thin bar manufacture by cast-rolling method were developed. This dependence was defined as the exponential one. In order to determine the speed of steel casting under conditions of suspension casting, we expressed the dependency in the form of an equation. This permitted us to determine reasonable modes of thin bars manufacturing.
Keywords: SUSPENDED STEEL CASTING, CAST-ROLLING, FOUNDRY AND ROLLING MILL, MOLD, CASTING SPEED, GRIPPING ANGLE, REDUCTION VALUE, THIN BAR, PRODUCTION PROCESS, LIQUID STEEL

Introduction

The modern metallurgical industry places high requirements for the performance of machines and production units, for saving of materials and energy resource and for the quality of manufactured products. Meeting these requirements becomes possible thanks to the development of cast-rolling with roll-molds. Manufacturing of bar by continuous casting-rolling process enables us to increase productivity, to reduce energy consumption and to improve the quality of the product. Therefore, further improvement on the manufacture processes of the cast-rolling and the choice of optimal modes are crucial tasks, which open up new opportunities in the steel industry.

Analysis of recent researches and publications

The unit of continuous direct casting of liquid steel into thin sheets is an important step forward in innovations in metallurgy. The main advantage of this process is the elimination of the hot rolling operations in the production scheme and the corresponding reduction in equipment, as well as decrease in labor and energy costs [1 – 6]. In the units of the direct casting of a thin sheet, the mold is composed of two rolls, which are arranged directly beneath the intermediate ladle and rotate in opposite directions. During the casting, liquid steel enters the space between the rolls and crystallizes in contact with the surface of the rolls. At that, the cooled solid layers are formed, they move together with the surface and exit from the rolls in the form of the sheet. The sheet thickness is determined by the distance between the rolls and the width is made by the side walls of the mold [1].

In cast-rolling, there are two combined processes employed: crystallization of the liquid steel and plastic deformation carried out first for the crystallized part of the metal and then for the whole mass of metal [5]. Soft reduction takes place while crystallization [6].

Compared against the conventional rolling, we would like to note that in cast-rolling, molten metal serves as the initial product and the parameters of plastic deformation zones are formed as a result of a complex interaction of the material with the tool [7].

The most important parameter of the cast-rolling technology, which determines the quality of the bar and the roll performance, is the rotation speed of the roll-molds and the speed of steel casting. According to the commonly established ideas[8, 9], there are three zones distinguished for the metal in the gap between the rolls in the casting-rolling process (Figure 1).

The process of cast-rolling with roll-mold involves a lot of complex interactions of physical phenomena such as fluid flow, heat exchange, solidification, air gap between the rolls for bar forming and mechanical deformation. A very important task is to evaluate the influence of these process parameters on the production rate and quality of the final product.

Moreover, if we discuss the production of 10 mm thick bar from low-melting metals with low resistance to deformation, for example, aluminum [8], the deformation area length is 0.6-0.8 of the total three zones length due to the lowered casting speed. The reduction of the bar reaches 40-60% in the deformation zone.

Furthermore, when casting steel bars, the roll-molds are not able to provide greater reduction because of the insufficient strength and stiffness of the roll-molds. Therefore, the speed of steel bars casting is practically much higher than that of aluminum bars. Increased speed of steel bars casting leads to the reduction of the relative length of the deformation zone down to 10%, and the reduction of bar in the deformation zone does not exceed 15%.

An important characteristic of the bar forming process in the roll-mold is position of solidification final point regarding to the plane of the rolls axis («S» point) [9].

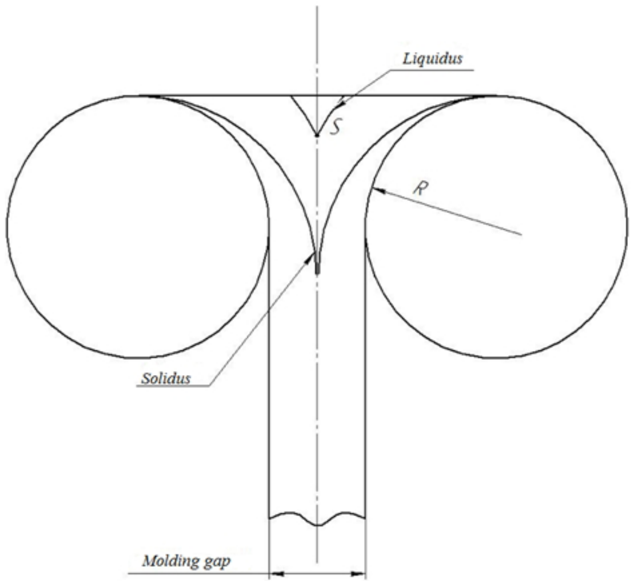


Figure 1. Scheme of the gap between the rolls in cast-rolling for the thin bars manufacturing: *R* – radius of roll-molds

The research results were analyzed and evaluated with A. Kasama's research data and the co-authors [8], while those for the steel cast-rolling – with the data obtained by S. Berkovich [10] and for aluminum cast-rolling – with A.Y. Gridin's results [11]. Utilizing the outcomes of the earlier researches [12], we accept that the degree of deformation able to provide a good quality of steel during its processing is to be not less than 15%.

There is the suggestion to apply a new design of foundry and rolling stand with the objective to reduce metal consumption during casting [13]; in order to decrease the overheating of steel coming between the rolls, we can use the additional crystallization centers in the form of steel chips which are able increase the speed of liquid steel casting.

The purpose of the current work is to make the research on the steel casting speed increase in suspended cast-rolling for thin bars manufacturing.

To achieve the stated purpose, it is necessary to perform the following **tasks**:

- to analyze the impact of gripping angle and reduction value on the speed of steel casting in the foundry and rolling stands in order to select the optimal mode of casting;
- to determine the dependence of suspension casting speed for the liquid steel on the bar thickness and its gripping angle; to develop the dependency graphs and to determine the formula for the casting speed calculation.

The Research Methods

Low-carbon constructional steel was used as the material for the research of the suspension casting speed of metal into roll-mold. The rolls had a radius of 500 mm while the degree of deformation was equal to 15 %. The experimental production resulted in manufacture of bars with the width of 2 mm, 3 mm and 4 mm. The angle of gripping was equal to 10°, 20° and 30°. The rolls were with collars. [13]. For creating suspension, steel chips were used.

Based on the experiment, we carried out a research analysis on dependence of predicted maximum speed of steel bar casting (4 mm/s) on the crystallization-deformation angle α for the rolls with radius of *R* = 500 mm. The research was made with varying bars thickness and deformation degrees. [6].

Research results of steel casting speed with suspended cast-rolling

The research results of steel cast-rolling in thin bars production without the suspension are shown in Table 1.

Table 1. The research results of influence of the gripping angle on the casting speed without suspension use (original development by the article author).

.*α*,°	*υ*, m/min		
	h=2, mm	*h*=3, mm	*h*=4, mm
10	42	20	10
20	91	43	15
30	160	80	40

The table 1 marks: α – gripping angle; h – exit thickness of a bar; *υ* – steel casting speed.

As the research results evidence, with the exit bar thickness increase, we observe the casting speed decrease, while with the gripping angle increase allows the casting speed increase.

In accordance with technology [13], the use of suspended casting is provided where it is obvious that the crystallizing and cooling rate of the metal increases up by 20 % with the use of suspension. Owing to this, we offer to increase steel casting speed into roll-mold up by 20 %. The corresponding research results are given in Table 2.

Table 2. The research results of the gripping angle influence on the casting speed with the use of suspension (original development by the article author).

.α,°	υ, m/min		
	h=2 mm	h=3 mm	h=4 mm
10	50.4	24	12
20	109.2	51.6	18
30	192	96	48

To follow up more precisely, the gripping angle influence on the steel casting speed in the foundry and rolling stand on condition of suspension use, we consider it is necessary to build up dependency graphs (Figure 2).

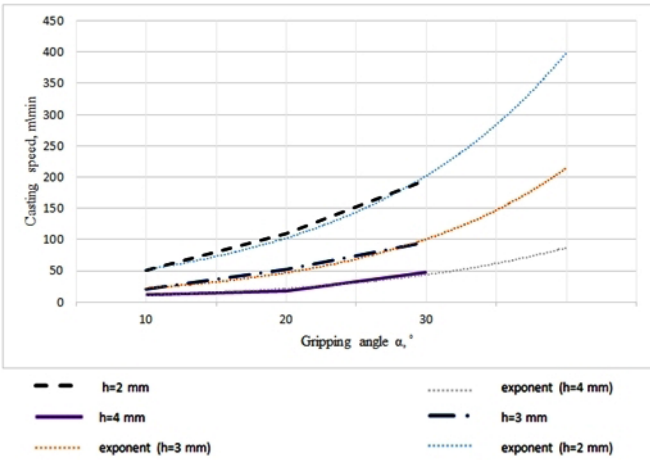


Figure 2. The influence of the gripping angle on the casting speed when suspended cast-rolling of carbon steel (original development by the article author)

It is clear from the graph that with increasing the gripping angle it is possible to increase the steel casting speed under conditions of suspended cast-rolling. For the experiment reported in the current paper, the maximum steel casting speed was achieved with the exit bar thickness of 2 mm and the gripping angle of 30°.

The research results show that there is an exponential dependency of steel casting speed on the gripping angle which is reflected in an equation below:

$y = a \cdot e^{kx}$, (original development by the article author),

where *a* and *k* are coefficients, which depend on the following conditions of steel casting: the bar thickness, the gripping angle, *e* – exponent, *e*=2.718.

Thus, the above written can prove that the equation of dependency of steel casting speed on the gripping angle under suspended cast-rolling is found.

Conclusions

The researches on the stated theme resulted in the analysis on the influence of the gripping angle and percentage reduction of product cross-sectional area on the steel casting speed in foundry and rolling stand. This analysis has been performed with the aim of choosing the optimal casting modes, defined as those where the optimal reduction for a steel bar is 15 % while the gripping angle is 10-30°.

The dependency of liquid steel suspension casting speed on the exit bar thickness and the gripping angle is defined; this dependency is expressed in the graphical form. Moreover, it has been found out that there is an exponential dependency between the bar gripping angle and the steel casting speed. The dependency equation has been made, which allows us to define the steel casting speed provided by the conditions of suspended casting for thin bars production.

References:

1. Hubin H.V. (2010) *Suchasni promyslovi sposoby bezkoksovoi metalurhii zaliza* **[**Modern industrial ways of coke-free ferrous metallurgy**]**. Kryvyi Rih: Vydavnychyj dim. 366 p.
2. Ghubin Gh.V., Kalinichenko Ju.P., Tkach V.V., Ghubin Gh.Gh. (2012) Pro pererobku vidpracjovanykh avtomobilej [On recycling for cars with expired service lives]. *Visnyk Kryvorizjkogho tekhnichnogho universytetu* [Journal of Kryvyi Rih National University]. No. 31, p.p. 3 – 8.
3. Danchenko V. N. (2011) Progressivnye processy obrabotki metallov davleniem **[**Advanced processes of metal forming**]**. *Metallurgicheskaja i gornorudnaja promyshlennost'* [Metallurgical and mining industry]. No.7, p.p. 1-8.
4. Minaev A. A. (2011) Vozrozhdenie metallurgii na Ukraine nevozmozhno bez prioritetnogo razvitija prokatnogo proizvodstva **[**The revival of metallurgy in Ukraine is impossible without prioritized development of rolling production**]**. *Metallurgicheskaja i gornorudnaja promyshlennost'* [Metallurgical and mining industry]. No.7, p.p. 143-144.
5. Alzetta F. Luna **(**2002) The Danicli ECR Endless Casting Rolling Plant for Specialty Steels-Technology, Innovation and Benefits. *Iron and Steelmaker*. No.7, p.p. 41-49
6. Danchenko V.M. (2008) *Teorija procesiv obrobky metaliv tyskom* [Theory and practice of metal working]. Dnipropetrovsjk: Poroghy. 370 p.
7. Ghridin O. Ju. (2014) *Rozvytok naukovykh ta tekhnologhichnykh osnov procesiv valovoji rozlyvy-prokatky z intensyvnoju formozminoju metalu pry vyrobnyctvi tonkyj shtab z pidvyshhenym rivnem mekhanichnykh vlastyvostej*. avtoref. dys. na zdobuttja nauk. stupenja dokt. tekhn. nauk: spec. 05.03.05 “Procesy ta mashyny obrobky tyskom” [Development of scientific and fabrication fundamentals for cast-rolling with intensive metal working for thin products production with enhanced mechanical properties. Thesis paper for the doctors degree. Speciality 05.03.05. Processes and production units for metal working]. 40 p.
8. Chernjak P. N. (1976) *Besslitkovaja prokatka aljuminievoj lenty* [Endless casting rolling of aluminum bars]. Moscow: Metalyrgy. 136 p.
9. Nogovicyn A. V. (2013) Skorost' lit'ja aljuminievyh i stal'nyh polos na dvuhvalkovyh mashinah processy lit'ja [Casting speeds for aluminum and steel bars in two-high mills for casting]. Processy lit'ja. No.2 (98), p.p. 54-59.
10. Berkovici S. J. (1985) Optimisation of 3C Roll Caster by Automatic Control. *Proc. of Conference “Light Metals”*. p.p.1285-1299.
11. Gridin A. Ju. (2010) Jeksperimental'nyj metod opredelenija dliny zony deformacii pri nepreryvnoj valkovoj razlivke-prokatke [Experimental method to determine the deformation length zone in continuous cast-rolling]. *Vestniknacional'nogo tehnicheskogo universiteta* [National technical university]. No. 42. p.p. 48 58.
12. Brovman M. Ja. (2007) Protjazhennost' zony plasticheskoj deformacii i dopustimaja skorost' pri besslitkovoj prokatke [The length of plastic deformation and the allowable speed in endless casting]. *Metally* [Metals]. No.1, p.p. 44-49.
13. Viktoriya Chubenko, Alla Khinotskaya, Valeriy Chubenko (2016). Study of cooling rate, crystallization duration and metal discharge coefficient in case of continuous casting into foundry and rolling mills, Metallurgical and Mining Industry, No 6, p.p. 96-102.

UDC 389.14:621.317

Evaluation of experts competence on the measurement of electrical power using the method of analytic hierarchy

Velychko O. N.

D. Sc., Professor,
The State Enterprise "Ukrmetrtectstandart"

Gordienko T. B.

D. Sc., senior researcher, Associate Professor,
Odessa State Academy of Technical Regulation and Quality

Karpenko S. R.

Ph.D.,
The State Enterprise "Ukrmetrtectstandart"

Kolomiets L. V.

D. Sc., Professor,
Odessa State Academy of Technical Regulation and Quality

Abstract
The application of the process of analytic hierarchy for evaluating the experts competence on the measurement of electrical power is considered. The results of calculation of generalized priorities for each of the experts compared and global priorities for each experts competence range are given;

as well the most competent experts using special software have been identified.
Key words: EXPERT COMPETENCE, EVALUATION, MEASURING, METHOD OF ANALYTIC HIERARCHY

Making substantiated decisions in all fields (spheres) of activity should be based on experience, knowledge and intuition of experts. This requires carrying out the expert evaluation i. e. a procedure for determining the specific problems (questions) on the basis of expert opinions for further decision making.

For this evaluation, the correct approaches to the selection of experts (qualified specialists of a particular area, who are engaged in research, consulting, development of opinions, conclusions, scientific and technical expertise proposals on specific issues) should be applied. On the basis of practical experience, many researchers have attempted to develop methods for the selection of experts. However, in practice, to select experts who have the necessary qualities is difficult [1-3].

Methods of expert selection are based on two main approaches: subjective and objective. However, current methods can not completely solve the problem of a certain selection of experts, so the method of their selection should be based on a combination of different approaches (techniques). In any case, the level of experts competence is one of the main selection criteria.

Using analytic hierarchy process (AHP) [4-6], the several variants of expert competence evaluation can be implemented: the competence of any expert in any sphere (industry); the dynamics of improving competence of experts for many years for every single specialist.

Tasks for determining the competence of the expert with AHP are carried out in three hierarchical levels (Fig. 1). The first (top) level of the hierarchy appropriates for the purpose of evaluation, i.e. to determine the experts competence; the second level contains the criteria to determine the experts competence; the third (lower) level includes experts (expert group), for which it is necessary to define or compare the competence.

In general, the list of criteria (components) must be such as to display more complete the level of experts competence. Each criterion of experts competence can be estimated by using data on education, work experience in a particular field (sphere), specific position and other available information.

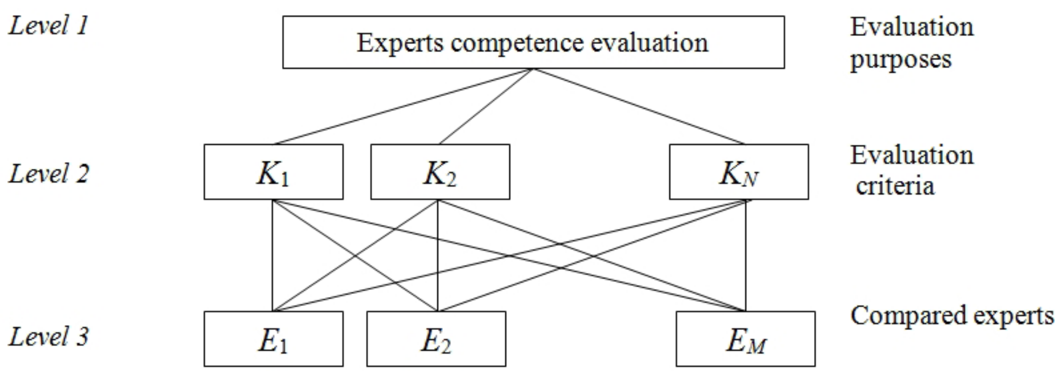


Figure 1. Structure of the simplest model of AHP implementation for evaluating the competence of the experts

In evaluating of the competence of experts, all the components that are compared and grouped as the criteria for an appropriate comparison should be taken into account. Each of the criteria is assessed by individual and pairwise comparison according to certain criteria and includes all the following steps using AHP.

Fig. 2 shows the competence of experts evaluation algorithm and Table 1 shows the formulas for calculating the numerical values of the components required to identify the most competent expert.

The numerical values a_{ij} $(i, j = 1, 2, ..., N)$ of therelative importance, components are determined directly for each performing of the expert competence comparative analysis. In this case, the analysis of the expert available data, which describe their level for the individual components and determine the number of any dimension, is carried out.

The implementation of AHP provides specific criteria for expert evaluation and their components, which are shown in Table 2. Also the matrix values of pairwise comparisons determined for specific indexes A with normalized eigenvectors Ki (priority vector) for the selected criteria (Table 3), and the weighting coefficients for selected evaluation criteria (Table 4) are presented.

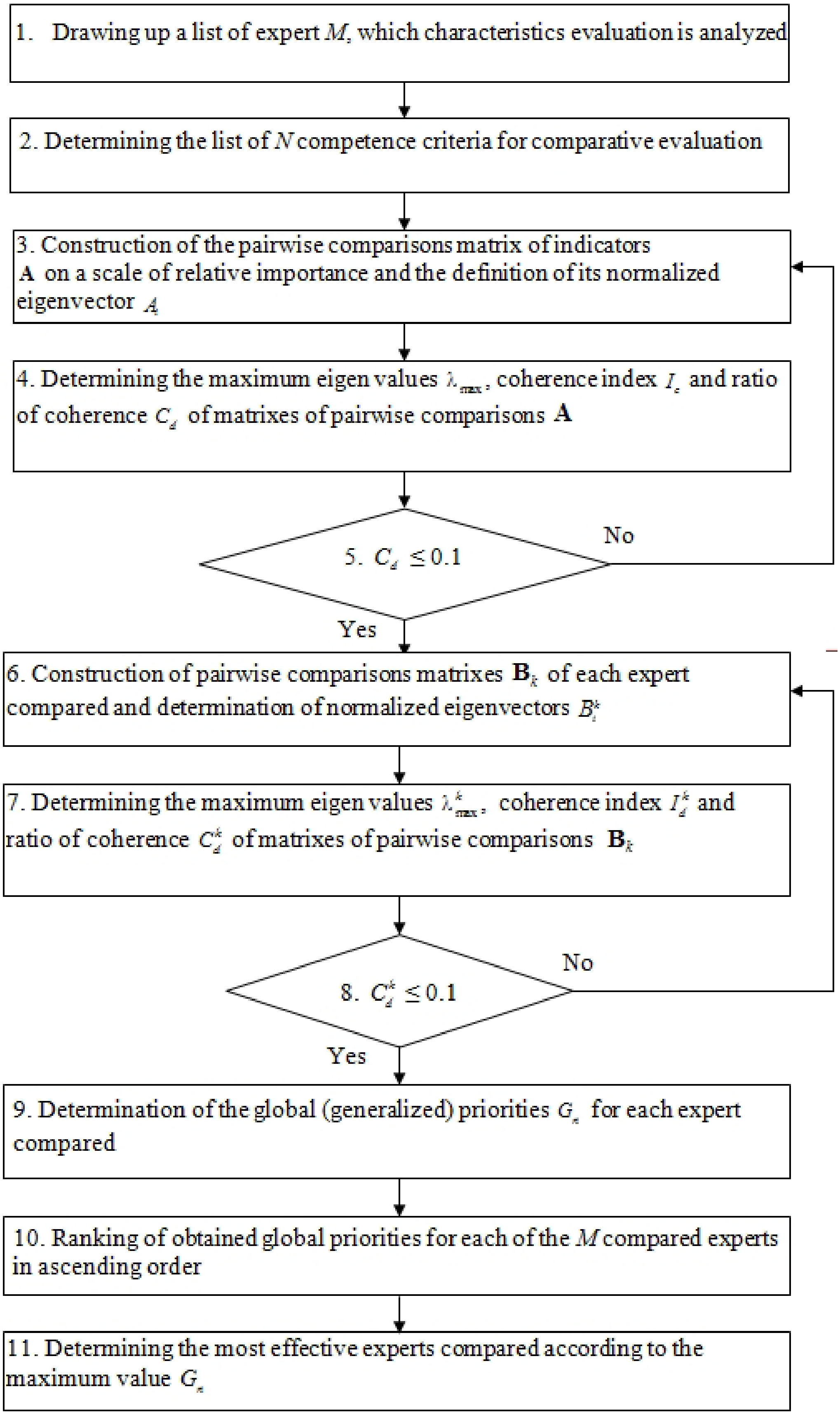


Figure 2. The algorithm for assessment of the expert competence for AHP

Table 1. Formulas for calculating the numerical values of the components

Algorithm element	Symbol	Calculation formula
The matrix of pairwise comparisons of criteria	$\mathbf{A}$	$\mathbf{A}=\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1N} \\ a_{21} & a_{22} & \dots & a_{2N} \\ \dots & \dots & \dots & \dots \\ a_{N1} & a_{N2} & \dots & a_{NN} \end{pmatrix}$ (1)
The normalized eigenvector of the matrix $\mathbf{A}$	A_i	$A_i = \sqrt[N]{\prod_{j=1}^{N} a_{ij}} \Big/ \sum_{i=1}^{N} \sqrt[N]{\prod_{j=1}^{N} a_{ij}}$ (2)
The ratio of the matrix coherence $\mathbf{A}$	C_d	$C_d = I_c / R_c$, (3) where: R_c – tabulated depending on the dimension of the matrix random coherence index
The coherence index of initial data of matrix $\mathbf{A}$	I_c	$I_c = \frac{\lambda_{\max} - N}{N-1}$ (4)
The largest eigenvalue of the matrix $\mathbf{A}$	$\lambda_{\max}$	$\lambda_{\max} = \sum_{j=1}^{N} \sum_{i=1}^{N} a_{ij} \cdot A_i$ (5)
The matrix of pairwise comparisons of experts according to established criteria	$\mathbf{B}_k$	$\mathbf{B}_k = \begin{pmatrix} b_{11}^k & b_{12}^k & \dots & b_{1M}^k \\ b_{21}^k & b_{22}^k & \dots & b_{2M}^k \\ \dots & \dots & \dots & \dots \\ b_{M1}^k & b_{M2}^k & \dots & b_{MM}^k \end{pmatrix}$ (6)
The normalized eigenvectors for matrices $\mathbf{B}_k$	B_i^k	$B_i^k = \sqrt[M]{\prod_{j=1}^{M} b_{ij}^k} \Big/ \sum_{i=1}^{M} \sqrt[M]{\prod_{j=1}^{M} b_{ij}^k}$ (7)
The ratio of matrices coherence $\mathbf{B}_k$	C_d^k	$C_d^k = I_c^k / R_c$ (8)
The coherence index of matrices $\mathbf{B}_k$	I_c^k	$I_c^k = \frac{\lambda_{\max}^k - M}{M-1}$ (9)
The largest eigenvalues for matrices $\mathbf{B}_k$	$\lambda_{\max}^k$	$\lambda_{\max}^k = \sum_{j=1}^{M} \sum_{i=1}^{M} b_{ij}^k \cdot B_i^k$ (10)
Global (generalized) priorities for each of M comparable experts	G_n	$G_n = \sum_{i=1}^{N} B_i^0 \cdot B_n^i$, (11) where: B_i^0, ..., B_n^i – components of the normalized eigenvectors of the local priorities are determined by the ratio(6)

For the proposed criteria of competence expert evaluation, the most eigenvalues of the matrix of pair-wise comparison of criteria **A** determined by ratios (1) and (5) are $\lambda_{max} = 5.35$.

Table 2. Specific criteria for the evaluation of the expert competence and their components

Evaluation criterion	Criterion component
K_{1i} – education and scientific level in the field of metrology	K_{11} – undergraduate higher education (Bachelor) K_{12} – higher education (Specialist / Master); K_{13} – postgraduate (specialization); K_{14} – postgraduate study; K_{15} – doctoral studies
K_{2i} – total work experience	K_{21} – less than 5 years; K_{22} – from 5 to 10 years; K_{23} – from 10 to 15 years; K_{24} – from 15 to 20 years; K_{25} – from 20 to 25 years; K_{26} – from 25 to 30 years; K_{27} – from 30 to 40 years; K_{28} – more than 40 years
K_{3i} – work experience in the field of metrology	K_{31} – less than 1 year; K_{32} – from 1 to 3 years; K_{33} – from 3 to 5 years; K_{34} – from 5 to 8 years; K_{35} – from 8 to 10 years; K_{36} – from 10 to 15 years; K_{37} – from 15 to 20 years; K_{38} – more than 20 years
K_{4i} – work experience as an expert in the field of metrology	K_{41} – less than 1year; K_{42} – from 1 to 2 years; K_{43} – from 2 to 4 years; K_{44} – from 4 to 6 years; K_{45} – from 6 to 8 years; K_{46} – from 8 to 10 years; K_{47} – more than 10 years
K_{5i} – work at position	K_{51} – engineer; K_{52} – leading engineer; K_{53} – research associate; K_{54} – head (deputy head) of the sector as part of the department; K_{55} – head (deputy head) of department of the institute; K_{56} –head (deputy head) of the institute as part of the enterprise or organization; K_{57} – head (deputy head) of the enterprise, organization

Table 3. Values of the matrix of pairwise comparisons for the selected criteria

	K_1	K_2	K_3	K_4	K_5	A_i
K_1	1	0.333	0.2	0.143	2	0.068
K_2	2	1	0.333	0.333	0,5	0.106
K_3	5	3	1	0.333	3	0.260
K_4	7	3	3	1	5	0.478
K_5	0.5	2	0.333	0.2	1	0.088

Table 4. The weighting coefficients for the selected criteria for evaluation

i	W_{1i}	W_{2i}	W_{3i}	W_{4i}	W_{5i}
1	2	1	2	3	1
2	5	3	3	4	3
3	6	4	4	5	5
4	7	5	5	6	6
5	9	6	6	7	7
6	–	7	7	8	8
7	–	8	8	9	9

Checking the coherence of the input data used to construct the matrix **A** obtained by the coherence index I_c = 0.088 and ratio (3), and coherence ratio C_d = 0.079 defined by the expression (4) have shown that the coherence ratio meets the requirements of inequality $(C_d \leq 0.1)$. The coherence of criteria established for the evaluation of experts is shown.

In order to assess the competence of the experts, it should be determined the specific input data for the calculation of the matrix elements $\mathbf{B}_k$ using the statement (6) for the pairwise comparison of experts' competence for each of these criteria. In addition to determining the normalized eigenvectors for each pairwise comparison matrix $\mathbf{B}_k$ using the statements (7) and checking the consistency of local priorities included in the matrix of pairwise comparisons $\mathbf{B}_k$ using the statements (8)–(10) for C_d^k, I_c^k and $\lambda_{\max}^k$.

A figure determined in accordance with the scale of the Saaty relative importance[4] should be existed in matrices elements $\mathbf{B}_k$ for pairwise comparisons of experts for each *k*-th criterion. For the transition from the current quantitative criteria values evaluation for these numbers, we use a special procedure, which basic steps are shown below.

For each (*k*-th) criterion the possible range of variation was evaluated and the maximum value of this range was attributed to the number 9 from the Saaty scale, and number 1 to the minimum. For these criteria, the real current values of each expert compared were obtained.

Quantitative characteristics of experts obtained for the *k*-th criterion are ranked in the ascending order. The result is a sequence of real numbers, which is used in subsequent calculations. The obtained numbers sequences in full scale are associated with numbers in sequence of Saaty scale.

Calculating the ratio of the generalized *k*-th criterion value in Saaty scale for the first expert to other specialists is carried out using specialized mathematical software. This relation is used as the first line matrix elements of pairwise comparisons $\mathbf{B}_k$ for *k*-th analyzed criterion.

The same action is performed for the second, third, ..., the *M*-th expert and the elements of the second, third, ..., *M*-th line of the matrix of pairwise comparisons $\mathbf{B}_k$ are obtained. All these operations are performed for each of the *k* criteria and all the necessary data for analysis of pairwise comparison matrix $\mathbf{B}_k$ are obtained.

When estimating the total priorities G_p are determined by using the statement (11) for each of the *M* compared experts. Global priorities for each expert ($n = 1, 2, ..., M$) rank and identify the most competent specialist – an expert who has received the maximum value G_p or the most competent group of experts with the highest values G_p for a particular expert evaluation. As one of the options to determine the group of experts the Pareto method can be applied. It is based on the results of analysis of global priorities G_p of the experts.

AHP is used as a useful tool for comparative evaluation of experts' competence on the basis of data on the above criteria for various industries (sectors), associated or related sectors (industries), as well as to determine the dynamics of the competence increasing for years for each expert individually.

For a comparative analysis of metrological support of the organizations engaged in measuring of electrical power, the group expert evaluation (questionnaire) according to the specially designed criteria was conducted. In this reviewing 26 experts working in the field of metrology participated. Quantitative characteristics of the competence of these specialists were evaluated using special software "Competence AHP 1.0" ("Kompetentnost MAI 1.0").

The results of the experts' competence evaluation with using the software are shown in Table 5 (the least competent experts are indicated by shading). Software window with the evaluation of the final results is shown in Fig. 3.

Table 5. Results of experts competence evaluation

Expert	01	02	03	04	05	06	07	08	09	10
Global priority	0.013	0.015	0.047	0.013	0.009	0.048	0.053	0.024	0.046	0.055
Place	24–25	22–23	13	24–25	26	11–12	5–6	18–20	14	2
Expert	11	12	13	14	15	16	17	18	19	20
Global priority	0.052	0.054	0.053	0.042	0.038	0.024	0.052	0.051	0.048	0.015
Place	7–8	3–4	5–6	15	17	18–20	7–8	9	11–12	22–23
Expert	21	22	23	24	25	26	Total			

Global priority	0.054	0.040	0.024	0.059	0.020	0.049	Unsatisfactory (amount /%)
Place	3–4	16	18–20	1	21	10	10/38

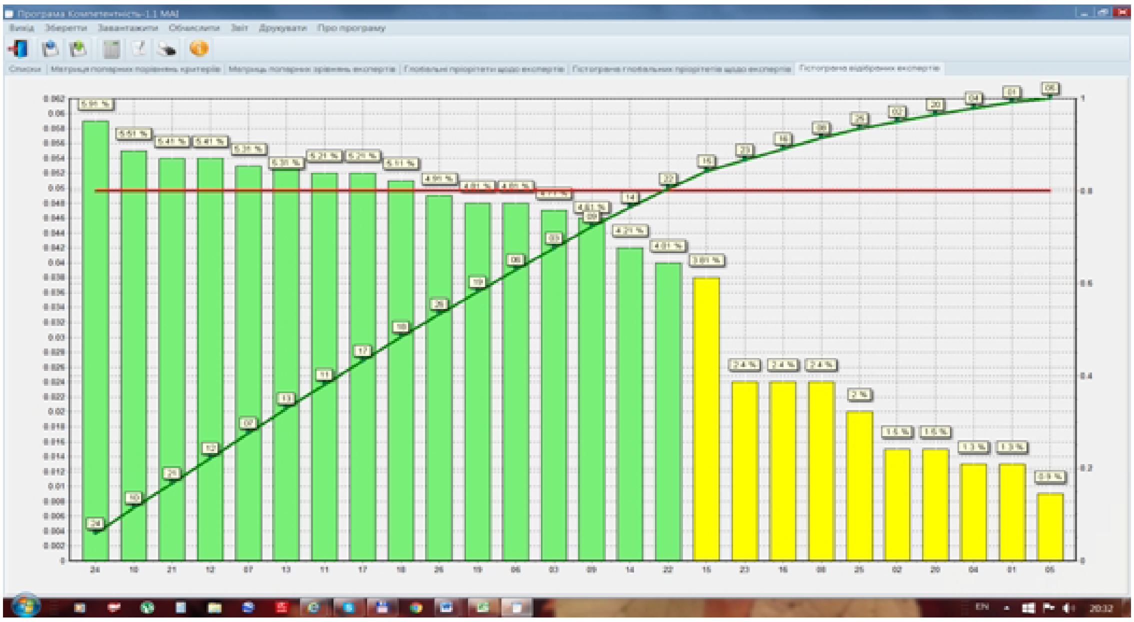


Figure 3. Software Window “Competence AHP 1.0” with the final results of the evaluation

For the obtaining evaluation results from the total number of experts 28% of experts have been rejected (ten specialists: 05, 01, 04, 20, 02, 25, 08, 16, 23 and 15).

References

1. Velychko O. M., Gordiyenko T. B., Kolomiets L. V. (2015) Methodologies of expert’s competence evaluation and group expert evaluation. *Metallurgical and Mining Industry*. No 2. p.p. 262–271.
2. Litvak B. G. (1996) Expert estimations and making decision. Moscow: Patent, 271 p.
3. Orlov A. I. (2002) Expert estimations. Moscow. 31 p.
4. Saaty T. L. (1992) The Hierarchon: A Dictionary of Hierarchies. Pittsburgh, Pennsylvania: *RWS Publications*.
5. Drake P. R. (1998) Using the Analytic Hierarchy Process in Engineering Education. *International Journal of Engineering Education*, No 14 (3). p.p. 191–196.
6. Navneet Bhushan (2004) Strategic Decision Making: Applying the Analytic Hierarchy Process. London: *Springer-Verlag*.

The group expert evaluation of the state of metrological assurance of capacitance measurements

Oleh Velychko

D.Sc. in engineering, professor
SE «Ukrmetrteststandard»
E-mail: velychko@hotmail.com

Sergiy Shevkun

Ph.D. in Engineering Science
SE «Ukrmetrteststandard»
E-mail: shevkunsn@yandex.ru

Stanislav Karpenko

Ph.D. in Engineering Science
SE «Ukrmetrteststandard»
E-mail: s.r.karpenko86@gmail.com

Abstract
The measurement of the impedance of devices and transmission lines is a practical problem in technology and other fields. Measurements of capacity are used in metallurgical and mining industry. The results of group expert evaluation of metrological assurance of capacitance measurements with evaluated expert's competence are considered. Special and universal statistical software is used for processing of expert data obtained. Priority problematic questions for improvement of the metrological assurance of capacitance measurements are established.
Key words: MEASUREMENT, IMPEDANCE, CAPACITANCE, METROLOGICAL ASSURANCE, GROUP EXPERT EVALUATION, EXPERT COMPETENCE

The scope and application of a measurements are dependent on the context and discipline. In the natural sciences and engineering, measurements are not applied to nominal properties of objects. Measurement is a cornerstone of science, technology, trade, and quantitative research in many disciplines. Measurement of electrical quantities may be done to measure electrical parameters of a system. Applied measurements are required every day in industrial practice.

Electrical impedance is the measure of the opposition that a circuit presents to current when voltage is applied. The measurement of the impedance of devices and transmission lines is a practical problem in technology and other fields. A capacitor has purely reactive impedance, which is inversely proportional to the signal frequency. A capacitor consists of two conductors separated by an insulator, also known as dielectric.

Measurements of such electrical quantity as capacity are used at the high-fidelity measurement of change of geometrical sizes of wares from a metal to the coefficient of specific temperature expansion of substance (capacity dilatometer), high temperature measuring of level of liquid metal in stoves, express controls of quality of the inflicted coverages from a metal and thickness of metal-roll, properties of intermetalloids and alloys, level of cooling and lubricating liquid in a flatting mill and others like that.

The increase of requirements to quality of eventual products of metallurgy envisages the increase of requirements to exactness of measuring instruments that, in turn, envisages the presence of national standard base of certain physical quantities, and also row of measures from providing of the metrological traceability measurements from international standards to every measuring instruments.

Metrological assurance (MA) of capacitance measurements should be considered in two approaches:conventional approach (verification and calibration of measuring instruments with the definition of the metrological characteristics) [1] and non-conventional approach (group expert evaluation of state of MA). The group expert evaluation (GEE) is widely used in various fields [2-10]. They are intended to resolve problematic issues concerning certain activities to find solutions (or ways of solving them). In this case, it is expedient to consider the opinions of qualified experts with special skills or knowledge in particular field [5, 8-10]. Considering the practical competence, each expert is involved for GEE taking into account their objective professional data allows increasing the reliability and accuracy of such GEEs. MA is the establishment and application of metrological rules and regulations and also the development, production and application of technical means needed to achieve the necessary unity and accuracy of certain measurements [1]. Authentic knowledge of the real status of MA of certain physical quantity measurements is very important. GEE involves experts on metrology, i.e. highly qualified metrology specialists can be one of the useful means of solution of noted issue.

The main aim of GEE in metrological activity is to assess the quality of a metrological work and specialists on metrology. This aim is implemented by the method of GEE, the essence of which is to set out a quality level on the basis of common criteria for quality evaluation and expert questionnaires (prepared for the particular measurements).

1. National standard base of electrical capacitance measurements

National Standard of the unit of capacitance and loss factor (Figure 1) is the most precision measurement standard of the unit of capacitance in Ukraine (DETU 08-06-01), which is kept in State Enterprise “Ukrmetrteststandard” (Kyiv).

Figure 1. General view of National Standard of the units of capacitance and loss factor

Transfer of the unit of capacitance is performed by the State verification scheme in accordance with national standard GOST 4064. Each year from 40 to 70 working standards (measures of capacitance and loss factor, RLC-meters) are verified and calibrated by using National Standard DETU 08-06-01.

The evaluation of state of MA of capacitance on national level is of extreme importance. An important issue for calibration of measuring instruments of capacitance is provision metrological traceability to National Standard DETU 08-06-01. Ukraine has internationally recognized calibration and measurement capabilities (CMC) for calibration of measuring instruments of capacitance. This CMC on measurement of capacitance were obtained by positive results of international comparisons of National Standard DETU 08-06-01 in project of Euro-Asian regional metrology organizations (COOMET.EM-S13).

2. Main results of expert competence evaluation

In [11], there suggested methodology of evaluation of expert competence taking into account descriptions of data uncertainties that belong to the sphere of comparative evaluation of level of expert competence in various fields of activities. For implementation of suggested methodology, corresponding criteria are set for the numerical score of expert competence of certain field.

Within the framework of realization of GEE of the metrological assurance of capacitance measurements on the specially worked out criteria, the evaluation of competence was also conducted for 14 attracted experts on issues of metrology. Quantitative descriptions of competence of these experts were appraised by means of universal (Microsoft Excel 2010) and special (Competence ND 1.1) statistical software. All evaluations were done on the same criteria: K1 – education; K2 – total work experience; K3 – experience in field of metrology; K4 – experience of expert work in field of metrology; K5 – work status.

Windows of the marked special software with final evaluation results are shown in Figure 2 (Competence ND 1.1).

Figure 2. Appraised expert competence with the use of the software Competence ND 1.1

On the basis of all present results, it is possible to talk about a rejection on the whole 3 experts (declined even by one of the program). Percent of the declined experts on evaluation results folds these programs: 29 % (4 experts out of 14 for software Microsoft Excel 2010) and 21 % (3 experts out of 14 for software Competence ND 1.1). In general, it is possible to establish the high consistency of evaluation results.

The values of the obtained evaluation results of expert competence in the rationed average values (in a range from 0 – minimum to 1 – maximal) for all 14 experts are presented in Table 1.

Table 1. Competence coefficients for all experts

Expert	01	02	03	04	05	06	07
Relative average value	0.72	0.67	1.00	0.92	0.74	0.90	0.90
Expert	08	09	10	11	12	13	14
Relative average value	0.87	0.97	1.00	0.90	1.00	0.97	0.77

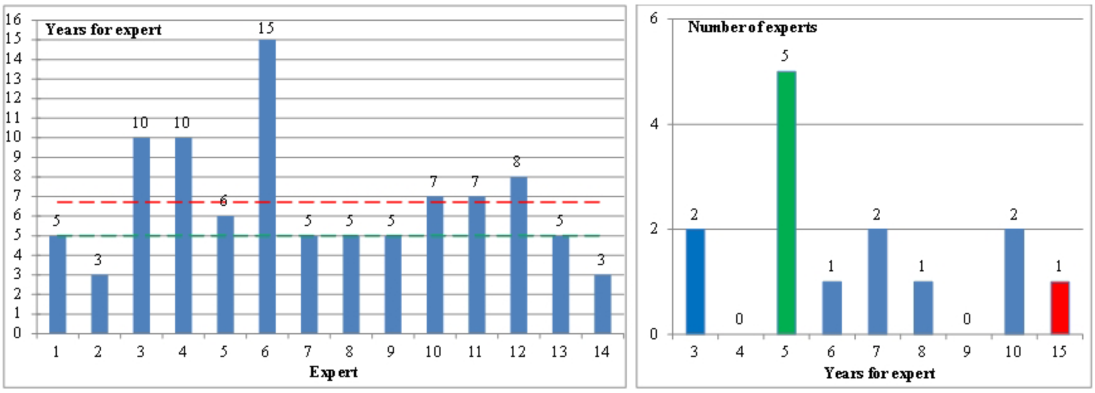
These coefficients were obtained by using the methodology described in [11]. Also experts were asked to make their own assessment of their competence during conducting mentioned questionnaire.

In framework of the carried out questionnaire, questioning took place also in relation to work experience in the field of metrology. Mostly there was the answer (mode) – 5 years (5 experts, 36 %), following by the amount of the answers – 3, 7 and 10 years (2 experts, 14 %), and all the rest – 22 % (3 experts), and less than (Figure 3, reference value is 6.71 and mode is 5.00). The results obtained allowed specifying some quantitative evaluation on the criterion of "K4 – experience of expert in field of metrology".

3. Main results of group expert evaluation

Group expert evaluation (GEE) of MA conducted by the methodology described in [11]. For GEE involved a group of 14 experts in field of metrology whose competence was previously estimated (Table 1).

Evaluation was carried out for 6 problematic questions of MA: personnel involved in metrology works (X1); conditions of implementation of metrology works (X2); normative and methodical documents (X3); standard base and adjuvant equipment (X4); procedures and documents for implementation of metrology works (X5); metrological traceability (X6), which contain 38 sub-questions total, taking into account the established grade evaluations. It was calculated by using universal (Microsoft Excel 2010) and special (Competence ND 1.1) statistical software taking into account the competence of experts.

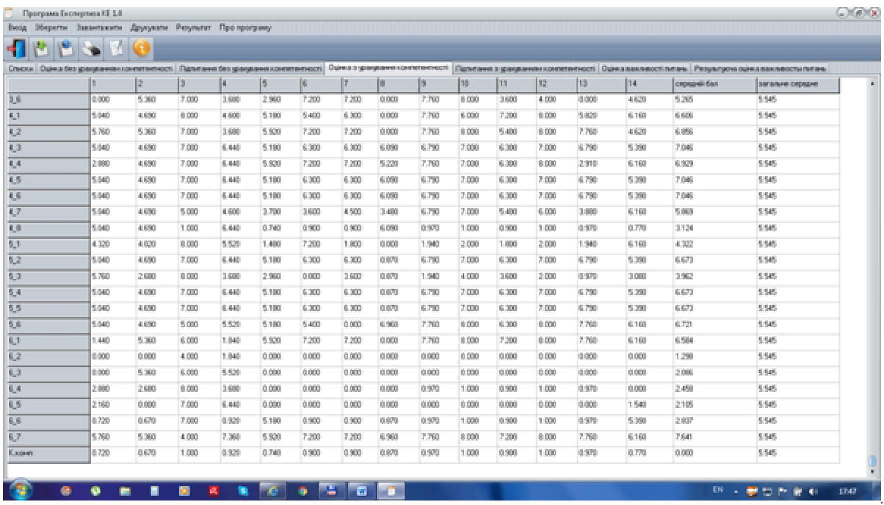


a) b)

Figure 3. Results of exper's level estimation

(a – years for each expert estimation; b – number of experts by years)

Statistical data of a group of 14 experts in the field of metrology is shown in Figure 4. Special software (Expertise CE 1.0) and universal software (Microsoft Excel 2010) were used to process the obtained data.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	середній бал	загальне середнє
3_6	0.000	5.360	7.000	3.680	2.960	7.200	7.200	0.000	7.760	8.000	3.600	4.000	0.000	4.620	5.265	5.545
4_1	5.040	4.690	8.000	4.600	5.180	5.400	6.300	0.000	7.760	6.000	7.200	8.000	5.820	6.160	6.606	5.545
4_2	5.760	5.360	7.000	3.680	5.920	7.200	7.200	0.000	7.760	8.000	5.400	8.000	7.760	4.620	6.056	5.545
4_3	5.040	4.690	7.000	6.440	5.180	6.300	6.300	6.090	6.790	7.000	6.300	7.000	6.790	5.390	7.046	5.545
4_4	2.880	4.690	7.000	6.440	5.920	7.200	7.200	5.220	7.760	7.000	6.300	8.000	2.910	6.160	6.929	5.545
4_5	5.040	4.690	7.000	6.440	5.180	6.300	6.300	6.090	6.790	7.000	6.300	7.000	6.790	5.390	7.046	5.545
4_6	5.040	4.690	7.000	6.440	5.180	6.300	6.300	6.090	6.790	7.000	6.300	7.000	6.790	5.390	7.046	5.545
4_7	5.040	4.690	5.000	4.600	3.700	3.600	4.500	3.480	6.790	7.000	5.400	6.000	3.880	6.160	5.869	5.545
4_8	5.040	4.690	1.000	6.440	0.740	0.900	0.900	6.090	0.970	1.000	0.900	1.000	0.970	0.770	3.124	5.545
5_1	4.320	4.020	8.000	5.520	1.480	7.200	1.800	0.000	1.940	2.000	1.800	2.000	1.940	6.160	4.322	5.545
5_2	5.040	4.690	7.000	6.440	5.180	6.300	6.300	0.870	6.790	7.000	6.300	7.000	6.790	5.390	6.673	5.545
5_3	5.760	2.680	8.000	3.680	2.960	0.000	3.600	0.870	1.940	4.000	3.600	2.000	0.970	3.080	3.962	5.545
5_4	5.040	4.690	7.000	6.440	5.180	6.300	6.300	0.870	6.790	7.000	6.300	7.000	6.790	5.390	6.673	5.545
5_5	5.040	4.690	7.000	6.440	5.180	6.300	6.300	0.870	6.790	7.000	6.300	7.000	6.790	5.390	6.673	5.545
5_6	5.040	4.690	5.000	5.520	5.180	5.400	0.000	6.960	7.760	8.000	6.300	8.000	7.760	6.160	6.721	5.545
6_1	1.440	5.360	6.000	1.840	5.920	7.200	7.200	0.000	7.760	8.000	7.200	8.000	7.760	6.160	6.584	5.545
6_2	0.000	0.000	4.000	1.840	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.298	5.545
6_3	0.000	5.360	6.000	5.520	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.086	5.545
6_4	2.880	2.680	8.000	3.680	0.000	0.000	0.000	0.000	0.970	1.000	0.900	1.000	0.970	0.000	2.458	5.545
6_5	2.160	0.000	7.000	6.440	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.540	2.105	5.545
6_6	0.720	0.670	7.000	0.920	5.180	0.900	0.900	0.870	0.970	1.000	0.900	1.000	0.970	5.390	2.837	5.545
6_7	5.760	5.360	4.000	7.360	5.920	7.200	7.200	6.960	7.760	8.000	7.200	8.000	7.760	6.160	7.641	5.545
Кконп	0.720	0.670	1.000	0.920	0.740	0.900	0.900	0.870	0.970	1.000	0.900	1.000	0.970	0.770	0.000	5.545

Figure 4. Statistical data of group of 14 experts in the field of metrology (horizontal – expert number; vertical – sub-question number)

The view of these software windows is shown in Figures 5 (Expertise CE 1.0) with evaluated results for sub-questions. Reference values of expert evaluations (evaluated average grade is 5.55) are shown as dashed lines in Figure 5 as well.

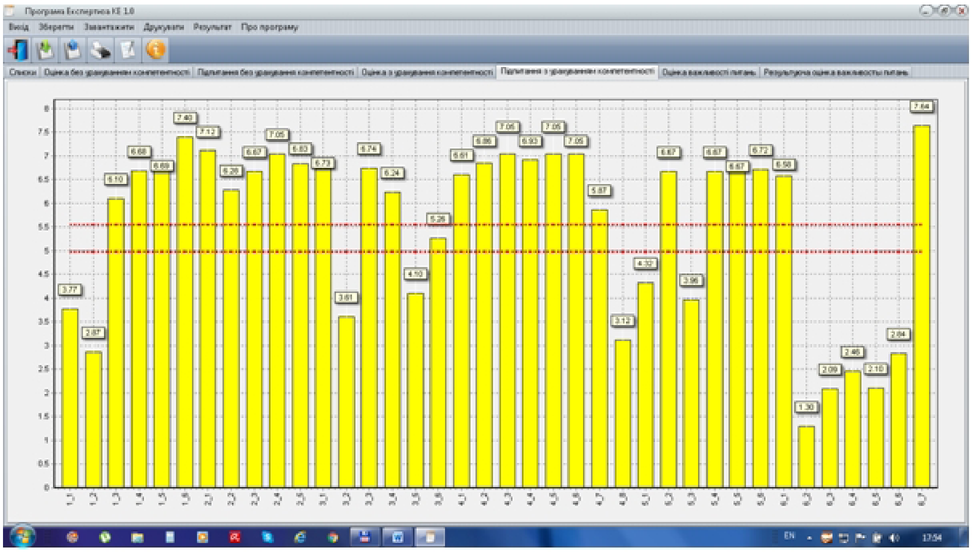
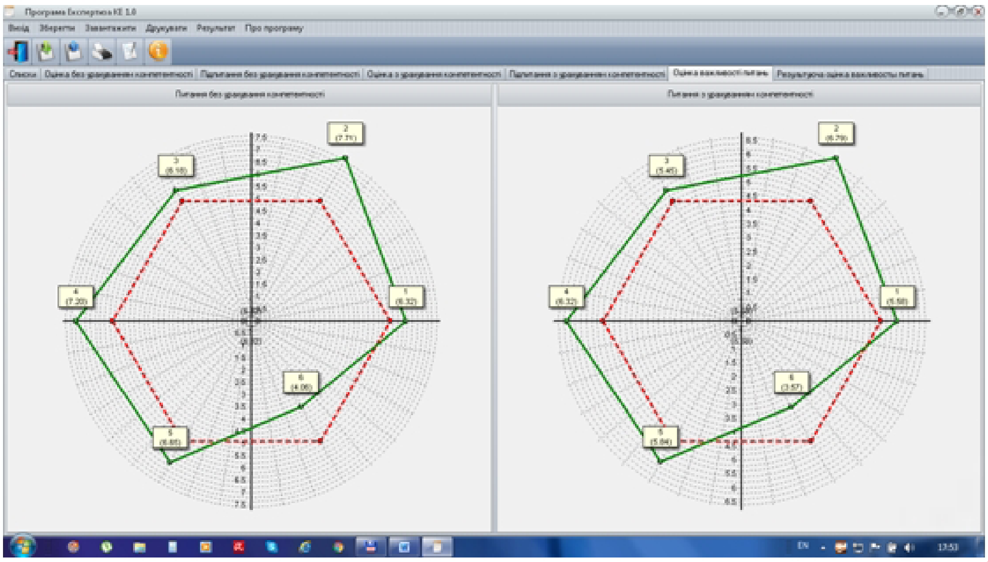


Figure 5. Evaluated average grades by using special software (Expertise CE 1.0) taking into account the competence of experts

Also analysis of these results showed that in all cases 12 sub-questions (32 %) were priority for further detailed analysis in order to take necessary decisions. But 26 sub-questions (68 %) did not have priority or matter at all for their further analysis.

By the results of analysis of resulting evaluation of the importance of questions there was built chart for average grades of expert evaluations with and without taking into account the competence of experts by using universal (Microsoft Excel 2010) and special (Competence ND 1.1) statistical software (Figure 6).

Overall analysis of these results showed that the least important questions for consideration are the following: X2 (average grade with/without taking into account the competence of experts are 7.71/6.79); X4 (7.20/6.32); X5 (6.65/5.84); X1 (6.32/5.58); X3 (6.18/5.45). However, the most important question is X6 (4.06/3.57).



a) b)

Figure 6. The chart for average grades of expert evaluations by using special software (Expertise CE 1.0)

(a – without taking into account the competence of experts; b – with taking into account the competence of experts)

The total evaluation results of the importance of questions are shown in the Table 2.

The results obtained show small variation of average grades of expert evaluation for questions (X1–X6) that testifies to its quite good consistency. Considering competence coefficient of experts did not influence the result of evaluation on problematic questions that were discussed.

Table 2. The total evaluation results of the importance of questions

Question	Without taking into account the competence of experts			With taking into account the competence of experts		
	Average value	Reference value	Degree of deviation	Average value	Reference value	Degree of deviation
X2	7.71	6.30	1.41	6.79	5.55	1.25
X4	7.20		0.89	6.32		0.77
X5	6.65		0.35	5.84		0.29
X1	6.32		0.02	5.58		0.04
X3	6.18		-0.12	5.45		-0.10
X6	4.06		-2.24	3.57		-1.97

4. Priority problematic questions for improvement of the metrological assurance of capacitance measurements

Only the problematic question of MA (X6) is attributed for further more detailed researching by the results of GEE on problematic questions of MA of capacitance.

The following sub-questions are attributed for further more detailed researching by the results of GEE (in order of importance):

- calibration of working standards (X6_2);
- correlation between the number of verified and calibrated measuring instruments by the enterprise (X6_3);
- status of evaluation uncertainty during calibration of measuring instruments (X6_5);
- the use of calibration methodologies of measuring instruments (X6_4);
- estimation of suitability of software for the automated collection and processing of the obtained data at the verification (calibration) of measuring instruments (X6_6);
- number of experts who conduct or participate in testing (X1_2);
- availability on the enterprise of the movable laboratories manned by working standards, measuring instruments and equipment (X4_8);
- used methodologies of verification of measuring instruments (X3_2);
- total amount of specialists that work in metrology (X1_1);
- use of verification protocol forms (X5_3);
- availability of methodologies that require development or review (X3_5);
- authority or accreditation of enterprise on implementation of metrology activities (X5_1).

The other problematic questions of MA are referred to the ones that have no primary importance.

Conclusion

The increase of requirements to quality of eventual products of metallurgy envisages the increase of requirements to exactness of measuring instruments. The capacitance measurement is a practical problem in metallurgical and mining industry. The group expert evaluation with evaluated expert competence for establishment of the real state of metrological assurance for specific measurements is very useful tool in different fields of industry. Special and universal software can be used for mathematical processing of obtained expert data.

The status of metrological assurance for capacitance measurements by the results of group expert evaluation can be stated generally. Some problematic questions should be established which need take into account calibration of working standards; correlation between the number of verified and calibrated measuring instruments by the enterprise; status of evaluation uncertainty during calibration of measuring instruments; the use of calibration methodology of measuring instruments.

References

1. Velichko O. N. (1999) Metrological activity in Ukraine. *Measurement Techniques*. Vol. 42, No 12, p.p.1109–1115
2. Saaty T. L. (1992) *The Hierarchon: A Dictionary of Hierarchies*. Pittsburgh, Pennsylvania: RWS Publications.
3. Litvak B. G. (1996) *Ekspertnaya informatsiya:*

Metody polucheniya i analiza [Expert estimations and making decision]. Moscow, Patent. 271 p.
4. Drake P. R. (1998) Using the Analytic Hierarchy Process in Engineering Education. *International Journal of Engineering Education*. No 14 (3), p.p. 191–196.
5. Orlov A. I. (2002) *Ekspertnye otsenki* [Expert estimations]. Moscow, 31 p.
6. Navneet Bhushan (2004) *Strategic Decision Making: Applying the Analytic Hierarchy Process*. London: Springer-Verlag,
7. Grabovetskii B. E. (2010) Metody ekspertnykh otsinok: teoriia, metodolohiia, napriamy vykorystannia [Methods of expert estimations: theory, methodology, directions of the use]. Vinnytsia: Vinnytsia National Technical University. 171 p.
8. Kalinina I. O., Gozhiy O. P., Musenko G. O. Vrakhuvannia kompetentnosti ekspertiv u metodakh bahatokryterialnoho analizu v zadachakh ratsionalnoho vyboru [Taking into account of competence of experts in the methods of multi-criterion analysis in the tasks of rational choice]. *Naukovi pratsi Chornomorskoho derzhavnoho universytetu. Kompiuterni tekhnolohii* [Scientific works of Bleak Sea State University. Computer technology]. Vol. 191, No 179, p.p. 116–123
9. Chernyshova T. Y. (2009) Ierarkhicheskaya model' otsenki i otbora ekspertov [Hierarchical model of estimation and selection of experts]. *Doklady TUSUR. Upravleniya, vychislitel'naya tekhnika i informatika* [Reports of TUSMR. Managements, computing engineering and informatics]. No 1 (19). Part 1, pp. 168–173
10. Kolpakova T. A. (2011) Opredelenie kom-petentnosti ekspertov pri prinyatii gruppovykh resheniy [Determination of competence of experts at the acceptance of group decisions]. Radioelektronika, informatyka, upravlinnja [Radioelectronics, informatics, management]. No 1, pp. 40–43
11. Velychko O. M., Gordiyenko T. B., Kolomiets L. V. (2015) Methodologies of expert's competence evaluation and group expert evaluation. *Metallurgical and Mining Industry*. No 2, pp. 262–271

The expert evaluation by the use of group of experts with established competence of the state of inductance measurements

Oleh Velychko

D.Sc. in engineering, professor
SE «Ukrmetrteststandard»
E-mail: velychko@hotmail.com

Sergiy Shevkun

Ph.D. in Engineering Science
SE «Ukrmetrteststandard»
E-mail: shevkunsn@yandex.ru

Stanislav Karpenko

Ph.D. in Engineering Science
SE «Ukrmetrteststandard»
E-mail: s.r.karpenko86@gmail.com

Abstract
Measurement of inductance is widely used in metallurgical industry, therefore requirements to measurement accuracy and data accuracy is very important for industrial process. The results of expert evaluation of the real state of inductance measurements group of experts with established competence are considered. The self-assessment of expert competence was conducted that showed that all less competent experts over-estimated own qualification. Special and universal software is used for processing obtained expert data. The obtained results show small variation of expert evaluation and quite good consistency.
Key words: GROUP EXPERT EVALUATION, EXPERT EVALUATION, METROLOGICAL ASSURANCE, MEASUREMENT, INDUCTANCE

In science and industry, measurements are one of the main means for extraction of measurement information. The science of measurement is pursued in the field of metrology. The measurement of a property may be categorized by the following criteria: type, magnitude, unit, and uncertainty. The magnitude is the numerical value of the characterization usually obtained with a suitably chosen measuring instrument. Accurate measurement is essential in many fields therefore a great deal of effort must be taken to make measurements as accurate as possible.

Measurement of such electric quantities is used as inductance at determination of specific fate of metal in ore, conductivity of liquid metals, corn-floors of Foucault, high temperature measuring, express control of quality of weld-fabricated wire, products of powder-like metallurgy, inflicted coverages from a metal, properties of intermetalloids and alloys and others like that.

Electrometallurgy is industry of metallurgy, which embraces the processes of receipt, affinage and treatment of metals and alloys from ores and concentrates by means of electric energy. The electric measurements are widely used in this industry, in particular measurements of the impedance. In the technological processes of receipt of metals from ores, the changes of chemical composition, structure, aggregate state and properties of metallic alloys, are widely used for control methods, including, and noncontact, that is based on measurements of electrical quantities.

The increase of requirements to quality of eventual products of metallurgy envisages the increase of requirements to exactness of measuring instruments that, in turn, envisages the presence of national standard base of certain physical quantities, and also row of measures from providing of the metrological traceability measurements from international standards to every measuring instrument.

Metrological assurance of inductance measurements should be considered in two approaches: traditional approach (verification and calibration of equipment with the determination of the metrological characteristics) [1] and not traditional approach (group expert evaluation of state of inductance measurements). The expert evaluation is widely used in the various spheres of activity with the aim of receipt of decisions in relation to overcoming of certain problem on the basis of opinion of skilled experts that have the special skills or knowledge in the concrete sphere of activity [2-10].

Methodology of evaluation of expert competence in group taking into account the data uncertainty is expedient to apply as useful instrument for the comparative estimation of expert competence on the basis of their objective data on the set criteria for the different fields of activity. This allows us to carry out more reasonable selection of the most competent experts for forming of group from the evaluation of certain problem questions in certain fields of activity and to decline experts, and objective data that does not confirm the certain level of set criteria.

The main aim of expert evaluation in metrological activity is to assess the quality of a metrological work and specialists on metrology. This aim is implemented by the method of expert evaluation, the essence of which is to set out a quality level on the basis of the common criteria for quality evaluation and expert questionnaires (prepared for the particular measurements).

1. Measurement standards base of inductance measurements

National Standard of the unit of capacitance and loss factor (Figure 1) is the most precision measurement standard of the unit of inductance (DETU 08-09-09), which is kept in State Enterprise “Ukrmetrteststandard” (Kyiv).

Figure 1. General view of National Standard of the units of inductance and tangent of loss

Transfer of the unit of inductance is going by the State verification scheme in accordance with national standard GOST 7161. Each year from 20 to 50 working standards (measures of inductance and tangent of loss, RLC-meters) are verified and calibrated by using National Standard DETU 08-09-09.

The evaluation of real conditions of the state of inductance measurements on national level is of extreme importance. An important issue for calibration of measuring instruments of inductance is of provision metrological traceability to National Standard DETU 08-09-09. Ukraine has internationally recognized calibration and measurement capabilities for calibration of measuring instruments of inductance. Those capabilities on inductance measurement were obtained by positive results of international comparisons of National Standard DETU 08-09-09 in project of European regional metrology organizations [11].

2. Results of expert's competence evaluation

In [12], the offered methodology of evaluation of expert competence is taking into account descriptions of data uncertainties that belong to the sphere of comparative evaluation of level of expert competence in various fields of activities. For implementation of the suggested methodology corresponding criteria are set for the numerical score of expert competence of certain field.

Within the framework of implementation of GTT of the metrological assurance of inductance measurements on the specially worked out criteria, the evaluation of competence was also conducted for 14 attracted experts on questions of metrology. Quantitative descriptions of competence of these experts were appraised by means of universal (Microsoft Excel 2010) and special (Competence ND 1.1) statistical software. All evaluations were done on the same criteria: K1 – education; K2 – total work experience; K3 – experience in field of metrology; K4 – experience of expert work in field of metrology; K5 – work status.

Windows of the marked special software with final evaluation results are shown in Figure 2 (Competence ND 1.1).

Figure 2. Appraised expert competence with the use of the software Competence ND 1.1

On the basis of all present results it is possible to talk about a rejection on the whole 4 experts (declined even by one of the program). Percent of the declined experts on evaluation results folds these programs: 29 % (4 experts out of 14 for software Microsoft Excel 2010 and Competence ND 1.1). On the whole it is possible to establish the high consistency of evaluation results.

The values of the got evaluation results of expert's competence in the rationed average values (in a range from 0 – minimum to 1 – maximal) for all 14 experts are shown in the Table 1.

Table 1. Competence coefficients for all experts

Expert	01	02	03	04	05	06	07
Relative average value	0.72	0.67	0.67	0.92	0.69	0.85	0.90
Expert	08	09	10	11	12	13	14
Relative average value	0.87	0.97	1.00	0.56	1.00	0.54	0.77

9 experts from 14 involving experts in field of metrology (64 %) have overestimated their competence according to the results as compared with the specific objective estimates and including 4 the least competent experts (100 %). 5 experts from 14 involving experts in field of metrology (36 %) have underestimated their competence according to the results as compared with the specific objective estimates and including 4 the most competent experts (57 %). Lighter column on a diagram shows the data uncertainty for a concrete expert.

Also experts were asked to make their own assessment of their competence during conducting mentioned questionnaire (Figure 3).

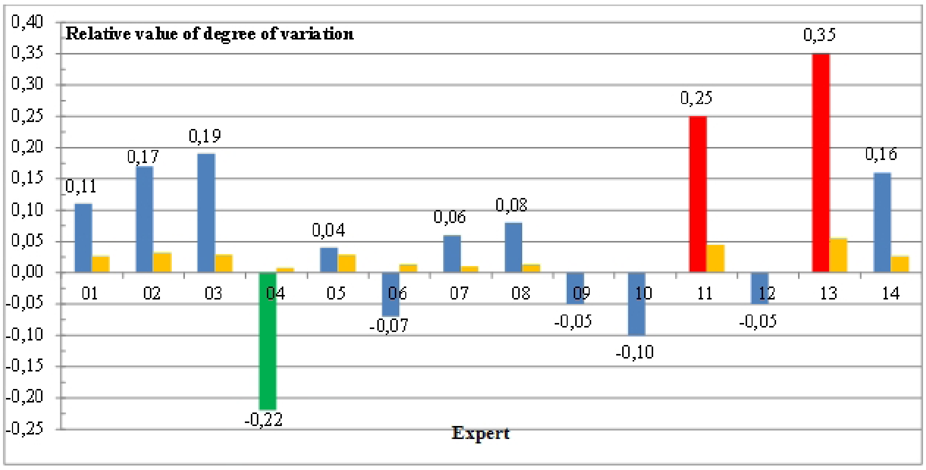


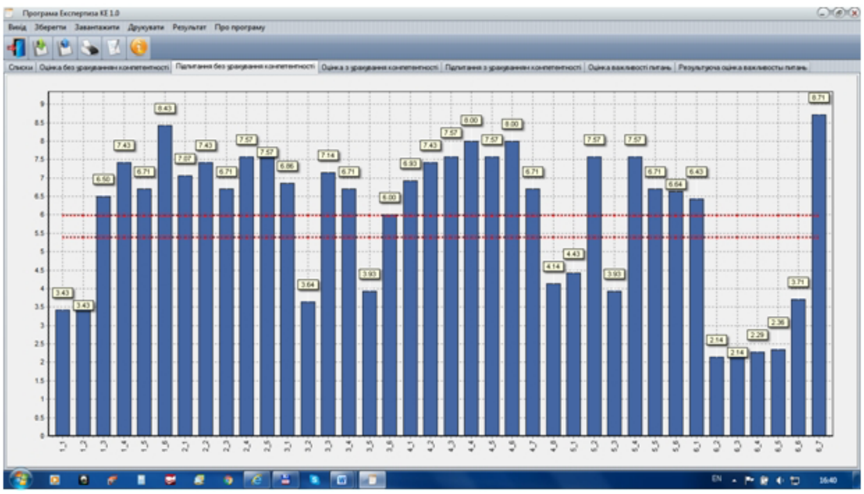
Figure 3. Self-assessment of expert competence

3. Results of expert evaluation

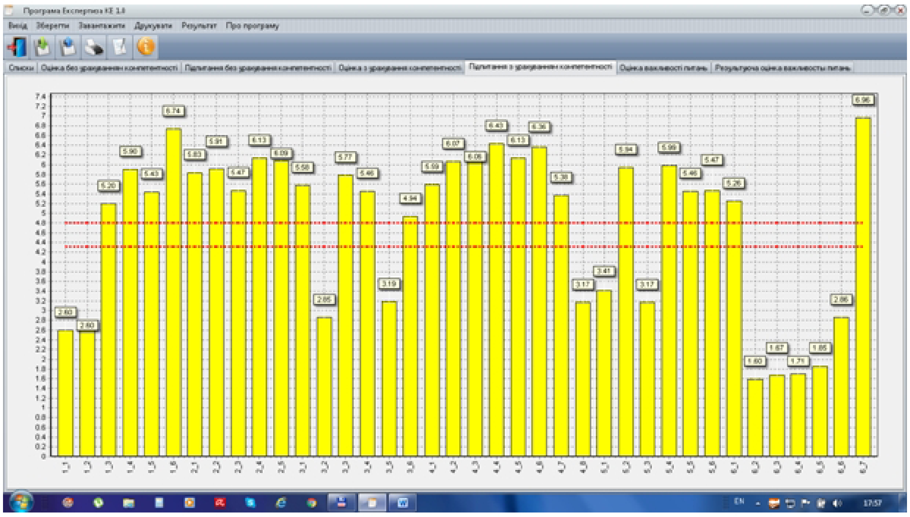
The expert evaluation of the state of inductance measurement was conducted by the methodology described in [12]. For expert evaluation involved a group of 14 experts in field of metrology whose competence was previously estimated (Table 1).

Evaluation was conducted for 6 problematic questions of the state of inductance measurement: personnel involved in metrology works (X1); conditions of implementation of metrology works (X2); normative and methodical documents (X3); standard base and adjuvant equipment (X4); procedures and documents for implementation of metrology works (X5); metrological traceability (X6), which contain total 38 subquestions taking into account the established grade evaluations. It was calculated by using universal (Microsoft Excel 2010) and special (Competence ND 1.1) statistical software taking into account the competence of experts.

These software windows are shown in Figures 4 (Expertise CE 1.0) with evaluated average grades. Reference values of expert evaluations (evaluated average grade without/with taking into account the competence of experts are 5.99/4.80) are shown as dashed lines in Figure 4 (a, b).



a)



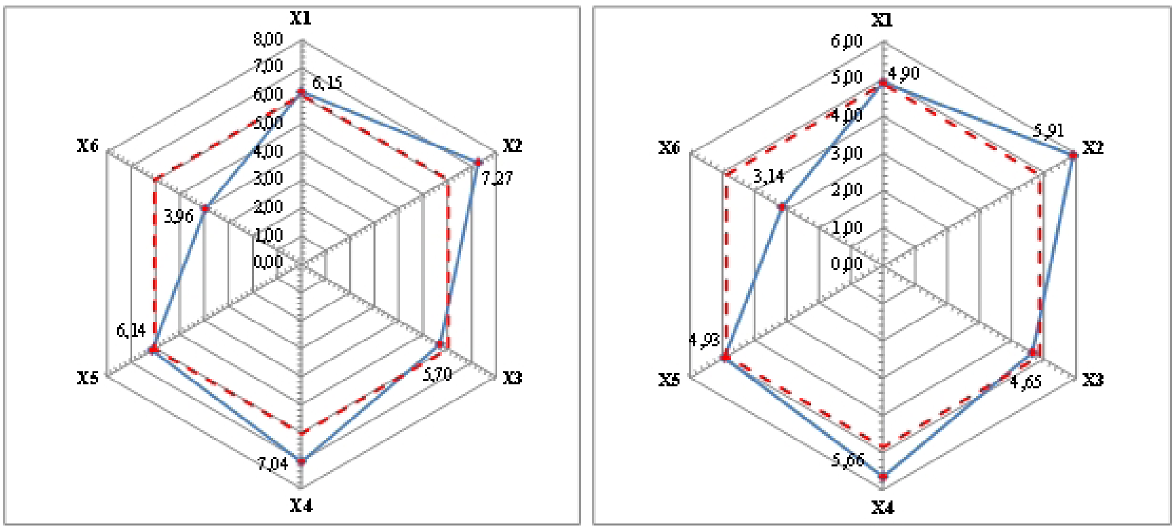
b)

Figure 4. Evaluated average grades by using special software (Expertise CE 1.0) without (a) and with (b) taking into account the competence of experts

Also analysis of the results (Figures 4) showed that in all cases 12 sub-questions (32 %) were priority for further detailed analysis in order to take the necessary decisions. But 26 sub-questions (68 %) did not have priority or not matter at all for their further analysis.

By the results of analysis of the resulting evaluation of the importance of questions, chart for average grades of expert evaluations for with and without taking into account the competence of experts was built by using universal (Microsoft Excel 2010) and special (Competence ND 1.1) statistical software (Figure 6).

Overall analysis of these results has shown that the least important questions for consideration are: X2 (average grade without/with taking into account the competence of experts are 7.27/5.91); X4 (7.04/5.66); X1 (6.15/4.90); X5 (6.14/4.93). Without and with taking into account the competence of experts, questions X1 and X5 switch places. But the most important questions are: X6 (3.96/3.14) and X3 (5.70/4.65).



a) b)

Figure 6. The chart for average grades of expert evaluations by using special software (Microsoft Excel 2010) (a – without taking into account the competence of experts; b – with taking into account the competence of experts)

By the results of analysis, degrees of deviation of the evaluated average grades from the reference value with/without taking into account the competence of experts were also evaluated for questions (X1–X6) by using special software (Expertise CE 1.0) (Figure 7). The least important questions for consideration are: X2 (degrees of deviation without/with taking into account the competence of experts are 1.28/1.09); X4 (1.06/0.85) and X5 (0.15/0.11). The most important questions are: X6 (-2.02/-1.67), X3 (-0.27/-0.16) and X1 (-0.001/-0.05).

The results obtained show small variation of average grades of expert evaluation for questions (X1–X6) that testifies to its quite good consistency. Considering competence coefficient of experts did not influence the result of evaluation on problematic questions that were discussed.

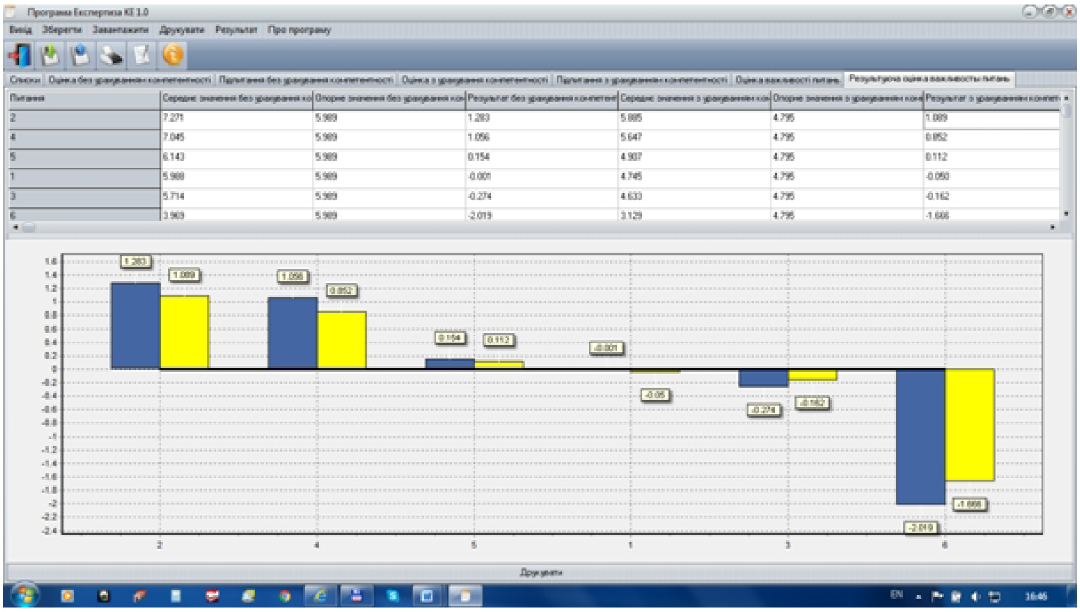


Figure 7. Degrees of deviation of evaluated average grades from the reference value with/without taking into account the competence of experts by using special software (Expertise CE 1.0)

4. Problematic questions for improvement of the state of inductance measurements

Only the problematic question of the state (X6) is attributed for further more detailed researching by the results of expert evaluation on problematic questions of the state of inductance measurements.

The following sub-questions are attributed for further more detailed researching by the results of expert evaluation (in order of importance):

- calibration of working standards (X6_2);
- correlation between the number of verified and calibrated measuring instruments by the enterprise (X6_3);
- the use of calibration methodologies of measuring instruments (X6_4);
- status of evaluation uncertainty during calibration of measuring instruments (X6_5);
- total amount of specialists that work in metrology (X1_1);
- number of experts who conduct or participate in testing (X1_2);
- used methodologies of verification of measuring instruments (X3_2);
- estimation of suitability of software for the automated collection and processing of the obtained data at the verification (calibration) of measuring instruments (X6_6);
- availability on the enterprise of the movable laboratories manned by working standards, measuring instruments and equipment (X4_8);
- use of verification protocol forms (X5_3);
- availability methodologies that require development or review (X3_5);
- authority or accreditation of enterprise on implementation of metrology activities (X5_1).

The other problematic questions of the state of inductance measurements are referred to the ones that have no primary importance.

Conclusion

Inductance measurement is widely used in metallurgical industry, therefore requirements to measurement and data accuracy is very important. The expert evaluation by the use of group of experts with established competence of the real state of specific measurements, for example inductance measurements, can be established. Special software (for example, Expertise CE 1.0) and universal software (for example, Microsoft Excel 2010) can be used for mathematical processing of obtained expert data.

The real state of inductance measurements by the results of the expert evaluation can be stated generally. However, it should be noted that there are some problematic questions regarding calibration of working standards; correlation between the number of verified and calibrated measuring instruments by the enterprise; the use of calibration methodologies of measuring instruments.

References

1. Velichko O. N. (1999) Metrological activity in Ukraine. *Measurement Techniques*. Vol. 42, No 12, pp.1109–1115.
2. Saaty T. L. (1992) *The Hierarchon: A Dictionary of Hierarchies*. Pittsburgh, Pennsylvania: RWS Publications.
3. Litvak B. G. (1996) *Ekspertnaya informatsiya: Metody polucheniya i analiza* [Expert estimations and making decision]. Moscow, Patent. 271 p.
4. Drake P. R. (1998) Using the Analytic Hierarchy Process in Engineering Education. *International Journal of Engineering Education*. No 14 (3), pp. 191–196.
5. Orlov A. I. (2002) *Ekspertnye otsenki* [Expert estimations]. Moscow, 31 p.
6. Navneet Bhushan (2004) *Strategic Decision Making: Applying the Analytic Hierarchy Process*. London: Springer-Verlag,
7. Grabovetskii B. E. (2010) *Metody ekspertnykh otsinok: teoriia, metodolohiia, napriamy vykorystannia* [Methods of expert estimations: theory, methodology, directions of the use]. Vinnytsia: Vinnytsia National Technical University. 171 p.
8. Kalinina I. O., Gozhiy O. P., Musenko G. O. Vrakhuvannia kompetentnosti ekspertiv u metodakh bahatokryterialnoho analizu v zadachakh ratsionalnoho vyboru [Taking into account of competence of experts in the methods of multi-criterion analysis in the tasks of rational choice]. *Naukovi pratsi Chornomorskoho derzhavnoho universytetu. Kompiuterni tekhnolohii* [Scientific works of Bleak Sea State University. Computer technology]. Vol. 191, No 179, p.p. 116–123
9. Chernyshova T. Y. (2009) Ierarkhicheskaya model’ otsenki i otbora ekspertov [Hierarchical model of estimation and selection of experts]. *Doklady TUSUR. Upravleniya, vychislitel’naya tekhnika i informatika* [Reports of TUSMR. Managements, computing engineering and informatics]. No 1 (19). Part 1, pp. 168–173
10. Kolpakova T. A. (2011) Opredelenie kompetentnosti ekspertov pri prinyatii gruppovykh resheniy [Determination of competence of experts at the acceptance of group decisions]. Radioelektronika, informatyka, upravlinnja [Radioelectronics, informatics, management]. No 1, pp. 40–43
11. Dierikx E., Nestor A., Melcher J., Kölling A., Callegaro L. (2011) EURAMET.EM-S26 Supplementary Comparison Inductance measurements of 100 mH at 1 kHz (EURAMET project 816). *Final Report*, December 2011, VSL, Dutch Metrology Institute, 119 p.
12. Velychko O. M., Gordiyenko T. B., Kolomiets L. V. (2015) Methodologies of expert’s competence evaluation and group expert evaluation. *Metallurgical and Mining Industry*. No 2, pp. 262–271.

A review of definitions of Zero Energy Buildings

Kuznetsova E. A.

PhD in engeeniring, Associate Prof.
Departament of Tecnological Safety, Heat and Mass Transfer Processes
Kyiv National University of Technologies and Design, Ukraine, Kyiv
E-mail: ekyznec@yandex.ua

Abstract
Zero energy buildings (ZEB) are regarded as an integrated solution of problems of energy saving, environmental protection, and CO_2 emission reduction in the building section. ZEB could be even possible with electricity production if enough renewable energy could be used. Moreover, various building-service systems with renewable energy sources have been widely considered for potential applications in ZEB. All of these new features extend the technical boundary of the conventional energy-efficient buildings, attach a more profound implication to the sustainable development of building technology, and therefore pose a challenge to evaluation works on ZEB performance.
The paper presents a review of ZEB definitions. It outlines discrepancies between different definitions and issues to be solved in order to develop a consistent and robust ZEB definition, which can facilitate the development of the energy calculation procedure.
The approaches concerning the units applied in ZEB definitions, the period of time over which the building calculation is performed, types of energy used, types of energy balances as well as renewable supply options are considered.
Key words: ZERO ENERGY BUILDING, NET ZERO ENERGY BUILDING, DELIVERED ENERGY, EXPORTED ENERGY, ENERGY BALANCE

Introduction

Commercial and residential buildings consume about one-third of world's energy. Owing to the energy crisis, increased emissions of wastes and the depletion of fossil fuels, research and development in building technologies and integrated processes have attained greater and renewed interest among stakeholders worldwide.

In order to reduce the dependence of the buildings on the primary energy, a number of studies on energy-saving technologies have been carried out worldwide. On the other hand, renewable energy utilization was regarded as reasonable solutions to global warming, air pollution, and energy security. Through integrating the technologies of energy-efficient and renewable energy utilization in building, zero energy buildings (ZEB), which are an innovative concept for high-performance building, are suggested. Zero energy building (ZEB) is a building with considerably reduced annual energy consumption by saving as much energy as possible via better heat insulation, solar shading, natural energy and high-efficiency equipment as well as creating energy (e.g., with photovoltaic (PV) power generation), while maintaining comfortable environments.

A zero energy building (ZEB) produces enough renewable energy to meet its own annual energy consumption requirements. There are a number of long-term advantages of moving toward ZEB, including lower environmental impacts, lower operating and maintenance costs, better resiliency to power outages and natural disasters, and improved energy security.

Reducing building energy consumption in new building construction or renovation can be accomplished through various means, including integrated design, energy efficiency retrofits, reduced plug loads and energy conservation programs. Reduced energy consumption makes it simpler and less expensive to meet the building energy requirements with renewable sources of energy.

Private commercial property owners are interested in developing ZEB to meet their corporate goals, and some have already constructed buildings designed to be zero energy.

However, nowadays definitions of ZEB differ from region to region and from organization to organization leading to confusion and uncertainty around the term.

The paper provides an overview of the different approaches to ZEB definitions with the emphasis on their similarities and peculiarities as well as considers the problems to be discussed further.

The zero energy/emission building is a complex concept, thus the development of one ZEB definition applicable for all case is not a simple task. There are many approaches to the ZEB definition and each of them spotlights different aspects of ZEB. Those issues have served to create a list of the main topics, which should be considered, when developing a new ZEB definition.

Review of literature on ZEB definitions

The study of the approaches concerning ZEB definitions shows that they differ on the applied unit for energy balance, period of the balance, type of energy use, type of balance, renewable energy supply options, connection with the energy infrastructure.

First and probably the most important is the issue of unit of balance between consumed and generated energy from renewables by the building.

The applied units for the “zero” balance can be the final or delivered energy, primary energy, CO_2 equivalent emissions, the cost of energy or some other parameters.

In [1], four types of metrics are considered: site energy (delivered or final energy), source energy (primary energy), energy costs and energy emissions.

According to [1], pluses and minuses of each metrics are as follows.

The use of *site energy* as metric has such advantages:

- Easy to implement;
- Verifiable through on-site measurements;
- Conservative approach to obtaining ZEB;
- No externalities affect performance, can track success over time;
- Easy for the building community to understand and communicate;
- Encourages energy-efficient building designs.

The shortcomings of the use of the *site energy* as metric:

- Requires more PV export to offset natural gas;
- Does not consider all utility costs (can have a low load factor);
- Not able to equate fuel types;
- Does not account for nonenergy differences between fuel types (supply availability, pollution).

The use of *source energy* as metric has such pluses as:

- Able to equate energy value of fuel types used at the site;
- Better model for impact on national energy system;
- Easier to reach ZEB.

Minuses of the use of the *source energy* as metric:

- Does not account for nonenergy differences between fuel types (supply availability, pollution);
- Source calculations are too broad (do not account for regional or daily variations in electricity generation rates);
- Source energy use accounting and fuel switching can have a larger impact than efficiency technologies;
- Does not consider all energy costs (can have a low load factor).

As an additional issue to be considered is the need to develop site-to-source conversion factors, which require significant amounts of information to define.

When energy is consumed on-site, the conversion to source energy must account for the energy consumed in the extraction, processing and transport of primary fuels such as coal, oil and natural gas; energy losses in thermal combustion in power generation plants; and energy losses in transmission and distribution to the building site. Source energy is calculated from delivered energy and exported energy for each energy type using source energy conversion factors.

Cost ZEB may be characterized as having such advantages:

- Easy to implement and measure;
- Market forces result in a good balance between fuel types;
- Allows for demand-responsive control;
- Verifiable from utility bills.

But, at the same time, such shortcomings are inherent to the *cost ZEB*:

- May not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid;
- Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges;
- Highly volatile energy rates make for difficult tracking over time.

As additional issues to be considered are:

- Offsetting monthly service and infrastructure charges require going beyond ZEB;

- Net metering is not well established, often with capacity limits and at buyback rates lower than retail rates.

Advantages of *emissions ZEB*:

- Better model for green power;

- Accounts for nonenergy differences between fuel types (pollution, greenhouse gases);

- Easier to reach ZEB.

At the same time, the *emissions ZEB* need appropriate emission factors.

Mertz, et al. [2] address the issue of net-zero CO_2 buildings and distinguish two approaches towards the ZEB: a net-zero energy building or a net-zero CO_2 (CO_2 neutral) building. They are the result of resource limitation and environmental impact, respectively. Mertz, et al. [2] describe the net-zero energy home as *"… a home, that over the course of year, generates the same amount of energy as it consumes"*. Furthermore, *"In a CO_2 neutral home, no CO_2 is added to the atmosphere due to the operation of the building"*.

For the first time Mertz, et al. [2] has mentioned a possibility for a building to be a part of the CO_2 credits exchange market. Moreover, in the definition for net zero CO_2 building authors indicate, that net-zero energy building is at the same time a CO_2 neutral home; however, CO_2 neutral home does not necessarily have to be a net-zero energy home.

Other possible metrics are exergy and some others. So, Kilkis [3] states that the metric of the balance in ZEB definition should address both the quantity as well as the quality of energy, if the complete building impact on the environment must be assessed. He explains that: "*(...) although ZEB definition seems logical, it falls short recognize the importance of exergy in assessing the complete impact of buildings on the environment*". Therefore, the author proposes a new definition for the ZEB concept, in particular a *Net-Zero Exergy Building* and defines it as "*a building, which has a total annual sum of zero exergy transfer across the building-district boundary in a district energy system, during all electric and any other transfer that is taking place in a certain period of time*".

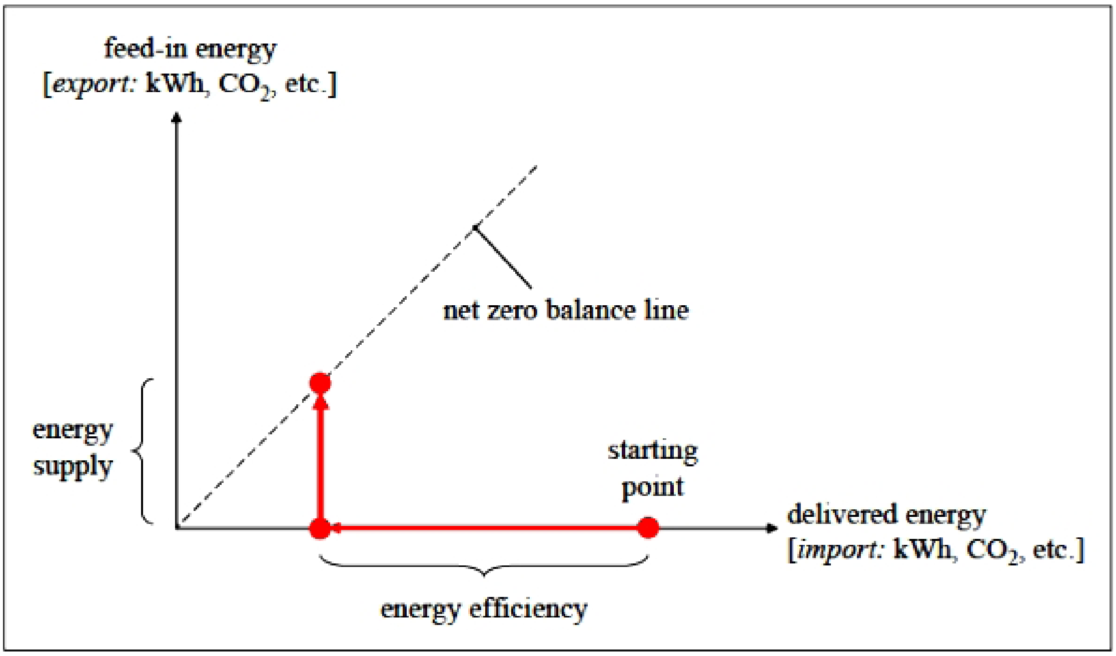


Figure 1. The net zero balance of a Net ZEB [9]

The primary energy is obviously the most favoured metric of the ZEB balance. This is in line with the latest EPBD recast [4] and common practice in many energy calculation methodologies.

The grid connected ZEB definitions from the existing literature are inconsistent in the type of balance that should be used. The most favoured is the balance between the energy needs or consumption and the renewable energy generation [1, 5, 6, 7]. However, in the papers of Lausten [8] and Mertz et. el. [2] the energy balance reflects the status of energy flows between the building and energy infrastructure, i.e. the overall energy delivered to the building from the utility grid has to be offset by the overall energy feed to the grid. Torcellini et al. [9] represent the net zero balance of a net ZEB (grid connected ZEB) graphically (Fig. 1), plotting the import (delivered energy) on the *x*-axis and the export (feed-in energy) on the *y*-axis.

The starting point may represent the performance of a new building built according to the minimum requirements of the building code or the performance of an existing building prior to renovation work. The general pathway for obtaining a Net ZEB consists of two steps: firstly, reduction in energy demand (*x*-axis) by means of energy efficiency measures; secondly, generation of electricity, or other energy carriers, by means of energy supply options to get enough credits (*y*-axis) to achieve the balance.

However, the study shows that the most accepted energy balance takes place between the energy use of building and the renewable energy generation.

The period of time over which the building calculation is performed can vary very much. In the existing literature on the issues considering ZEB definitions, the annual balance is the most favoured period of the balance [2, 10]. However, Hernandez and Kenny [11] states that the full life cycle of the building could be more appropriate period of time for the energy balance. Alternatively, a seasonal or monthly balance could also be considered.

The next important question is: what type of energy use should be included in the balance. Should it be only the energy required for operating the building i.e. building related (heating, cooling, ventilation, lighting, pumps and fans, other technical service systems) or user related (domestic hot water, cooking, appliances, lighting) or should also the embodied energy in the building construction and used technical equipment as well as in the construction and demolition of the building be accounted in the balance? This issue does not have an unambiguous answer and the opinions are divided as the countries practices are very different.

Based on the literature review, the most common approach is to include only the operating energy in the balance, and at this moment the embodied energy is not considered as the input for the balance. However, Hernandes and Kenny [11] suggest that the energy balance should not only be focused on the energy used by building in the operation phase, but as well include the energy embodied with building construction and systems. However, it should be noted that in the prevailing publications the type of energy use included in the balance is not specified [1, 4, 5, 6, 8]. The renewable energy sources (RES) can either be available on the site e.g. sun, wind or need to be transported to the site e.g. biomass. Therefore, there are two renewable energy supply options: on-site supply and off-site supply respectively. Thus, our attention is turned to the question: how and where the renewable energy is produced. Some of the proposed methodologies even do not address the issue of various supply options. The opinions are divided, one claim that only building footprint and site should be used, others accept the possibility of buying carbon credits in the carbon market in order to offset the energy use of a building. Even, the recent recast of the Directive on Energy Performance of Buildings [4] gives unclear answer to the above questions by stating: "(…) *energy should be covered to a very significant extent by energy from renewable sources produced on-site or nearby.'* Taking Torcellini's definition, the EPBD term "nearby" logically belongs to "off-site".

According to Torcellini, et al. [1] there are two options: on-site supply or off-site supply. Within the on-site supply authors distinguish building footprint and building site. Within the off-site supply, the building either uses RES available off-site to produce energy on-site, or purchase off-site RES. Tocellini, et al. [1] suggest ranking of preferred application of renewable energy sources (Table 1).

Table 1. ZEB Renewable Energy Supply Options [1]

Option number	ZEB supply-side options	Examples
0	Reduction of site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On-site supply options		
1	Use of renewable energy sources available within the building footprint	PV, solar hot water, and wind located on the building
2	Use of renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building
Off-site supply options		
3	Use of renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol or biodiesel that can be imported from off site, or waste streams from on-site processes to generate electricity and heat
4	Purchase of off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other 'green' purchasing options. Hydroelectric is sometimes considered

Moreover, Torcellini, et al. [1] indicate: "*Rooftop PV and solar water heating are the most applicable supply-side technologies for widespread application of ZEBs. Other supply-side technologies such as parking lot-based wind or PV systems may be available for limited applications.*"

Marszal et. al. [12] attempt to represent graphically the possible renewable energy supply options suggested in different energy calculation methodologies (Fig. 2).

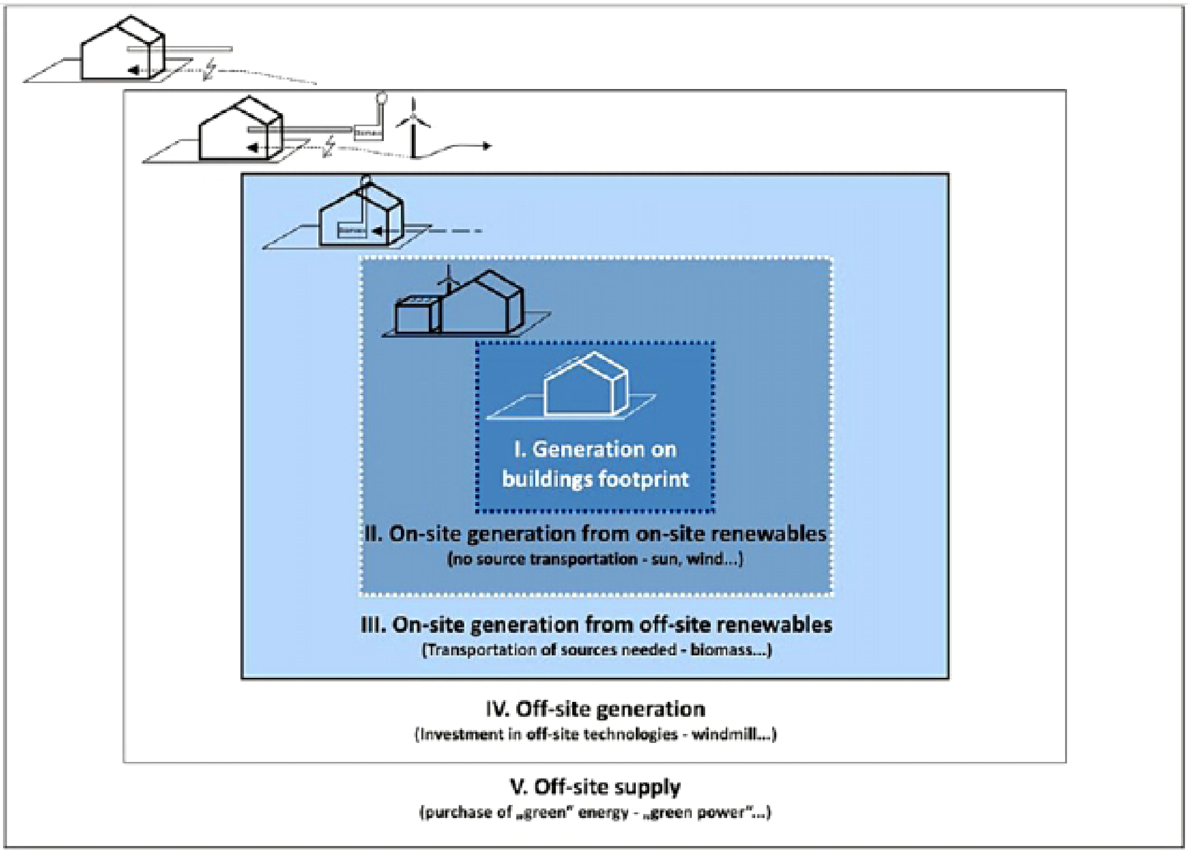


Figure 2. Overview of possible renewable supply options [12]

Next issue that requires clear answer is: if the ZEB definition should include specific requirements in terms of energy efficiency. In the review of existing ZEB approaches a very similar path to achieve ZEB can be noticed. Firstly, the reduction of energy demand using energy efficient technologies is applied, and afterwards the renewable energy sources to supply the remaining energy demand are utilized. The above strategy is the most logical approach to reach ZEB. Nevertheless, Laustsen, [8] points out that: "*In principle ZEB can be a traditional building, which is supplied with very large solar collector and solar photo voltage systems. If these systems deliver more energy over a year than the use in the building it is a zero net energy building.*" In order to avoid and eliminate this 'low-quality' ZEB a fixed value of maximum allowed energy use could be a good solution.

Moreover Torcellini, et al. [1] state: "*A good ZEB definition should first encourage energy efficiency, and then use renewable energy sources available on site. A building that buys all its energy from a wind farm or other central location has little incentive to reduce building loads, which is why we refer to this as an off-site ZEB.*"

Sartori at. al. [13] states that a Net ZEB definition may set mandatory minimum requirements on energy efficiency. Such requirements may be either prescriptive or performance requirements, or a combination of the two. Prescriptive requirements apply to properties of envelope components and of ventilation systems, while performance requirements apply to energy needs (e.g. for heating, cooling, lighting) or total (weighted) primary energy demand.

The paper [14] provides an overview of prescriptive and performance based energy efficiency requirements adopted in existing national or commercial certification systems.

Mandatory requirements on energy efficiency may be determined on the basis of cost-optimality considerations as in the plans of the Energy Performance of Buildings Directive [4]; such methodology is still under development [15]. Alternatively, mandatory efficiency targets could simply require a demand reduction (e.g. 50%) compared to a reference building of the same category (e.g. detached house, office, school). In absence of explicit requirements on energy efficiency it is left to the designers to find the cost-optimal balance between energy efficiency measures and supply options, eventually considering embodied energy too, if in the balance boundary.

However, the analysis of a large number of already existing ZEB underlines the priority of energy efficiency as the path to success.

In the ZEB definitions, the topic of indoor environment quality is almost fully neglected, though it is an important issue. On the one hand, it would be very beneficial from general point of view, that all ZEB would use the same values. It would be much easier to evaluate and compare ZEB from different location worldwide. On the other hand, giving so detailed criteria in the ZEB definition could significantly limit its usefulness in many cases. As different values can be used depending on building type, country, applied standard and local climate conditions. A good solution could be guidance or suggestion which standards or values should be used.

Monitoring procedure of ZEBs is an issue to be considered as well. Torcellini at.al. [9] address the issue about monitoring procedure: "*The meters displaced should allow to measure the effective balance, the temporal match indices and preferably also the actual separate loads, e.g. heating, cooling, plug loads etc. The monitoring procedure should also check the comfort to avoid that a Net ZEB is mistaken for a not consuming building due to a low fulfillment of comfort requirements.*"

Thus, as for the definition of ZEB, until now there is no consensus on a common expression, which can be satisfied by all participators in this research field. However, through research works, ideas exchange, and discussion during recent years, a common view is emerging that a widely-accepted definition of ZEB should be a definition framework which contains different elements, such as: boundary, metrics, criteria etc. Inside this common framework, various participators can choose elements in different levels to form a specific definition, based on individual considerations on cost, local climate, environmental protection demand, or the feasibility of on-site renewable energy source. In this way, the definition frame, which contains different levels of ZEB for different scenarios, can be helpful to put forward roadmap or guideline for countries, regions, associations or design groups based on their specific demands.

Through the definitional framework, a basis for legislations and action plans to promote ZEB development effectively can also be created.

Conclusions

While the concept of ZEB is understood, an internationally agreed definition is still lacking. From the information presented, it may be seen that a lot of discrepancies exist between the different approaches to ZEB definition.

The zero energy building is a complex concept thus the development of one ZEB definition applicable for all cases is not a simple task. There are many approaches to ZEB definition, and each of them spotlights different aspects of ZEB. Those issues have served to create a list of the main topics, which should be considered, when developing a consistent and robust ZEB definition.

The known approaches concerning the units applied in ZEB definitions, the period of time over which the building calculation is performed, type of energy use, type of balance as well as renewable supply options have been analyzed.

A lot of issues need to be discussed further. Among them are the issues connected with the determination of mandatory minimum requirements on buildings energy efficiency and what type of energy use should be included in the balance. In the ZEB definitions, the topic of indoor environment quality is almost fully neglected, though it is an important issue. These issues do not have an unambiguous answer and the opinions are divided.

A commonly accepted definition and corresponding methods of measurement for ZEB would have a significant impact on the development of design strategies for the buildings and spur greater market uptake of such projects.

References

1. Torcellini P., Pless S., Deru M., Crawley, D. (2006). *Zero energy buildings: a critical look at the definition*. National Renewable Energy Laboratory and Department of Energy, USA.
2. Mertz G. A., Raffio G. S., Kissock K. (2007). Cost optimization of net-zero energy house. *ASME 2007 Energy Sustainability Conference*. American Society of Mechanical Engineers, p.p. 477-487.
3. Kilkis S. (2007) A new metric for net-zero carbon buildings. *ASME 2007 Energy Sustainability Conference*. American Society of Mechanical Engineers, p.p. 219-224
4. Recast E.P.B.D. (2010) Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). *Official Journal of the European Union*. No 18 (06).
5. Noguchi M., Athienitis A., Delisle V., Ayoub J.,

Berneche, B. (2008) Net zero energy homes of the future: A case study of the EcoTerraTM house in Canada. *Renewable Energy Congress, Glasgow, Scotland,* p.p. 2008-112.
6. Gilijamse W. (1995) Zero-energy houses in the Netherlands. *Building Simulation*, Wisconsin, USA.
7. Rosta S., Hurt R., Boehm R., Hale M. J. (2008) Performance of a zero-energy house. *Journal of Solar Energy Engineering*. No 130(2), p.p. 021006.
8. Laustsen J. (2008). Energy efficiency requirements in building codes, energy efficiency policies for new buildings. *International Energy Agency (IEA)*, p.p. 477-488.
9. Sartori I., Napolitano A., Marszal A. J., Pless S., Torcellini P., Voss, K. (2010) Criteria for definition of net zero energy buildings. *International Conference on Solar Heating, Cooling and Buildings*.
10. Crawley D., Torcellini P. (2006) Understanding Zero-Energy Buildings. *ASHRAE Journal*. No *48*, p.p. 9-62.
11. Hernandez P., Kenny, P. (2010) From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings*. No 42(6), p.p. 815-821.
12. Marszal A. J., Bourrelle J. S., Musall E., Heiselberg P., Gustavsen A., Voss K. (2010) Net zero energy buildings-calculation methodologies versus national building codes. *Proceedings of EuroSun*.
13. Sartori I., Napolitano A., Voss K. (2012) Net zero energy buildings: A consistent definition framework. *Energy and buildings*. No 48, p.p. 220-232.
14. Sartori I., Candanedo J., Geier S., Lollini R., Athienitis A., Garde F., Pagliano L. (2010) Comfort and energy performance recommendations for net zero energy buildings. *Proceedings of EuroSun*.
15. Wittchen K. B., Thomsen K. E. Aggerholm S., Kluttig-Erhorn H., Erhorn H., Poel B., Hitchin R. (2011) *Cost optimal levels for energy performance requirements: Executive summary*. European Commission.

Determination of energy parameters of technology of thermal pore formation

Pavlenko A.M.

Doctor of Technical Sciences
Professor Department of Building Physics and Renewable Energy
Kielce University of Technology, Poland,
E-mail: am.pavlenko@i.ua

Shumska L.P.

Postgraduate
Poltava National Technical Yuri Kondratyuk University

Abstract
Research porosity thermal insulation of refractory materials is the important task of power engineering, because the thermal conductivity of porous materials depends on the shape and especially location of pore.
Analytical review of existing technologies shows that research in this area is focused on the study of a process separately and generalized theories are not sufficient to clear analysis and model building process heat mass transfer of alumina porous material.
Key words: THERMAL CONDUCTIVITY, POROSITY, SWELLING, HEAT INSULATION

Introduction

The thermal insulating products are among the most efficient materials for protecting elements of various purposes. Low density, fire resistance, low thermal conductivity and at the same time sufficiently high structural strength allow considering the porous ceramic material as one of the most promising materials for construction [1,2].

It is possible to determine three groups of technologies covering all known methods for obtaining porous structures. In the first group of technologies, the porous structure is created by using artificial or natural pore-forming materials and low-melting clays via volumetric method or contact concreting – ceramic pores; the second method is the pore forming of slip mass with different ways of foam-forming, dry mineralizing of foam, aeration, low-temperature gas forming; the third method is high-temperature pore-forming of light-alloy raw materials.

Let us consider the third method of structure formation occurring during the hydration of raw material composition [3 - 6].

Carrying out the practical research into raw mass, we added the chamotte clay or pure structural clay, the composition of which is shown in the Table1.

Table 1. The chemical composition of fire-clay

Clay	The content of oxides, %									
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	SO_3	Lost on ignition
Structural clay	44.59-54.14	27.13-35.85	1.48-2.47	1.14-1.97	0.38-0.81	0.23-0.42	0.21-0.60	0.25-0.45	1.34-3.62	11.48-13.86
Chamotte clay	46.80	36.80	1.58	-	0.20	0.76	0.34	0.18	-	13.6

The research objective is to determine the optimal ratio of additives` masses in accordance with energy consumption to implement the thermal bloating process, strength of the obtained material, porosity and thermal conductivity.

Obviously, thermal conductivity and energy consumption should be minimal.

The research was performed by the use of differential thermal analysis (DTA) of the thermal bloating process for the raw mixture.

Trails are performed at a constant rise of temperature with recording the temperature difference on the chart paper as a function of temperature. The result is a curve DTA (Fig. 1-4). At processing the experiment's results, the horizontal axis should be graded by temperature. According to the position of peak of the endothermic process, the temperature interval of phase transitions can be found.

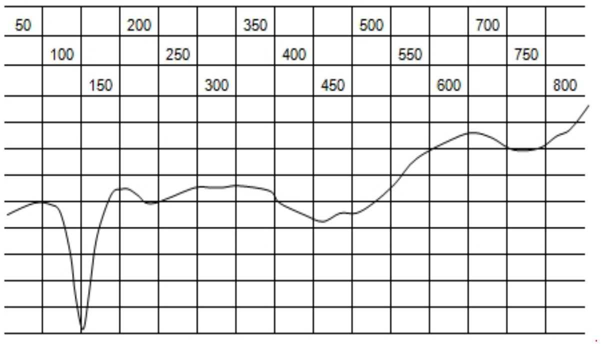


Figure1. DTA of raw material mixture with a content of 75 mass fractions of clay No 1 (Table1)

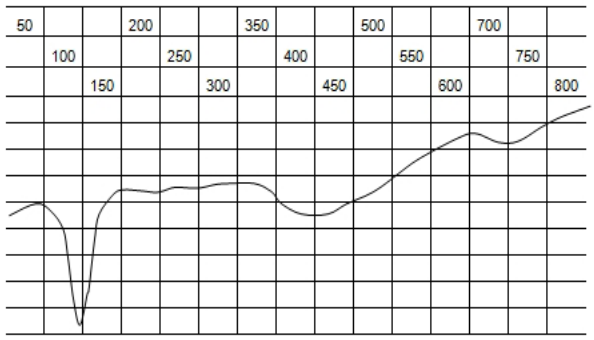


Figure 2. DTA of raw material mixture with a content of 75 mass fractions of clay No 2 (Table 1)

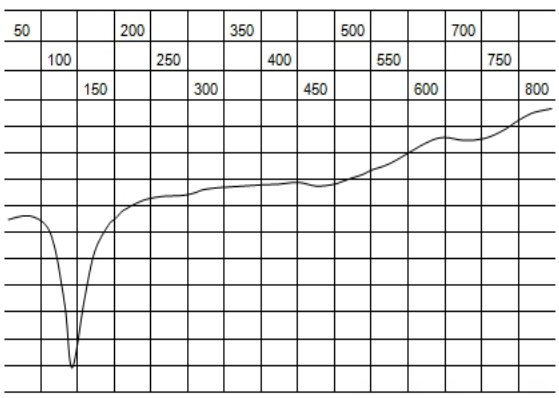


Figure 3. DTA of raw material mixture with a content of 160 mass fractions of clay No 1 (Table 1)

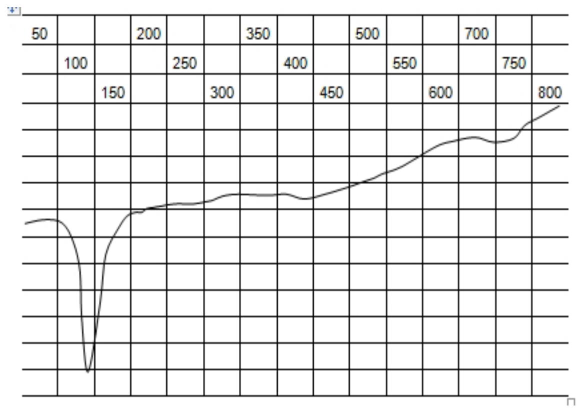


Figure 4. DTA of raw material mixture with a content of 160 mass fractions of clay No 2 (Table 1)

There is no significant difference in thermal evidence of phase transformations of clays of samples No 1 and No 2 in the charts. However, at increasing the alumina content, the exotherm of moisture removal has a higher minimum, which is a consequence of higher water saturation of the raw material mixture.

On DTA curves the low-temperature endothermic peak of 146 °C is recorded, which is due to the removal of adsorbed water; the presence of water is caused by high specific surface area of particles that is directly dependent on disorder of mixture.

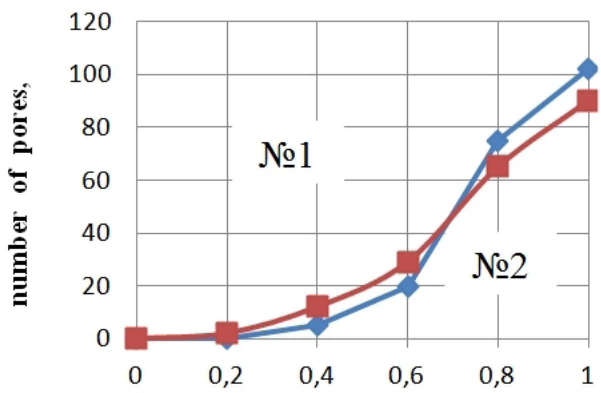
Changes, which took place during the heating, showed three endothermic effects: 146, 500, and 720 (average temperature intervals in Fig. 1-4). A large endothermic effect due to the removal of absorbed water is observed at 146 °C, and the step observed on the curve at 300 °C indicates removal of interpacket water. The second effect (450-550 °C) corresponds to the removal of the constitutional water (bound into the form of OH). The endothermic effect at 720 °C explains the removal of OH-ions. As it can be seen from the data chart, the optimum temperature range for dehydration of the mixture is within 146-720 °C. It should be defined the connection of temperature intervals with the structure of bloated material, and, consequently, with the useful application properties (strength, conductivity, heat resistance, water absorption). For this, changing the composition of the initial mixture, the measurements were repeated under method presented above.

In the obtained DTA curves for all experimental samples in the investigated temperature intervals, a number of phenomena associated with thermal effects are observed: 1) up to 100 °C — evaporation of chemically unbound water; 2) 100...170°C — a sudden loss of mass and strongly expressed endothermic effect that is related to the partial dehydration of gel and phases of different composition; 3) 450...550 °C — endothermic effect that corresponds to the decomposition of portlandite with water vapor emission 4) 700...900 °C — a minor loss of mass and weak endothermic effect, which is related to the decomposition of carbonate minerals (calcite, dolomite), and late-stage dehydration of gel and hydro aluminates.

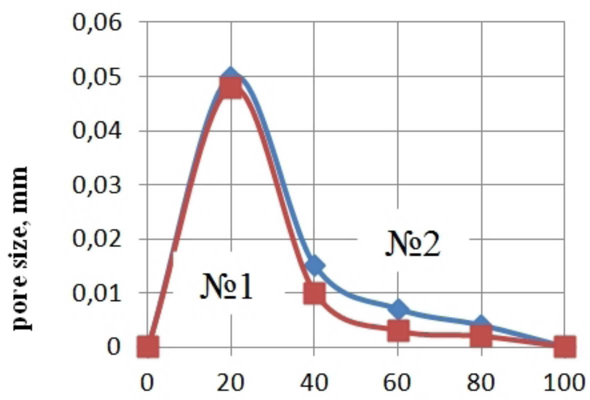
Studies of the pore structure

The morphology and porosity of the samples were determined by optical methods. According to this method, the macroscopic parameters of porosity inside metric interval with a lower bound of 10 mμ and upper bound of 5 mm are determined. The specified interval characterizes the strength parameters of the substance and parameters of heat and mass transfer.

To analyze the structure a polished thin section of bloated material was made and preliminary analysis was carried out at the installation consisting of a projection optical system, television camera and computer with the interface. The general view of thin section in visible light in gray with 256 shades of gray was recorded at 10-times increase. Visualization of pores was carried out by methods of shadow contrast, which is based on applying a system of lighting the surface of a sample, which consists of lights directed at small angles to the surface. When using the method of luminous contrasting the luminophore layer was applied on the surface of the thin section. Thickness of luminophore was preliminary rated by the method of water sedimentation with reveal of luminophore particles of submicron size. Excess luminophore is removed from the surface by blowing, after what a specialized film is applied on the surface to remove the remaining luminophore particles. The sample's surface was controlled via a binocular microscope. In the plane of granules and inter-granules planes the pores with a minimum size of 150 mμ were recorded. The object marker lay-out defined by the contours of particles of the fired granules was built. The resulting scene is analyzed with determining the size (Fig. 5-10).

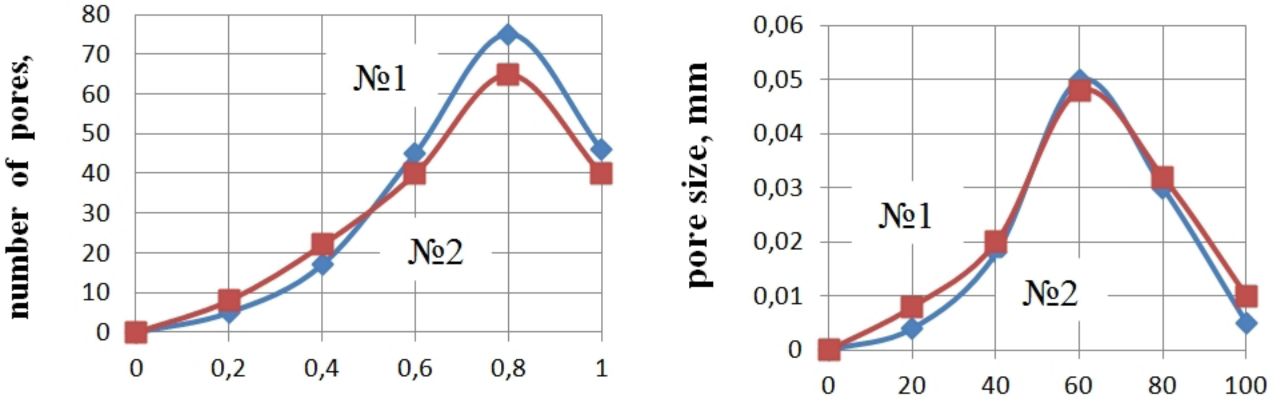


The interval factor of form



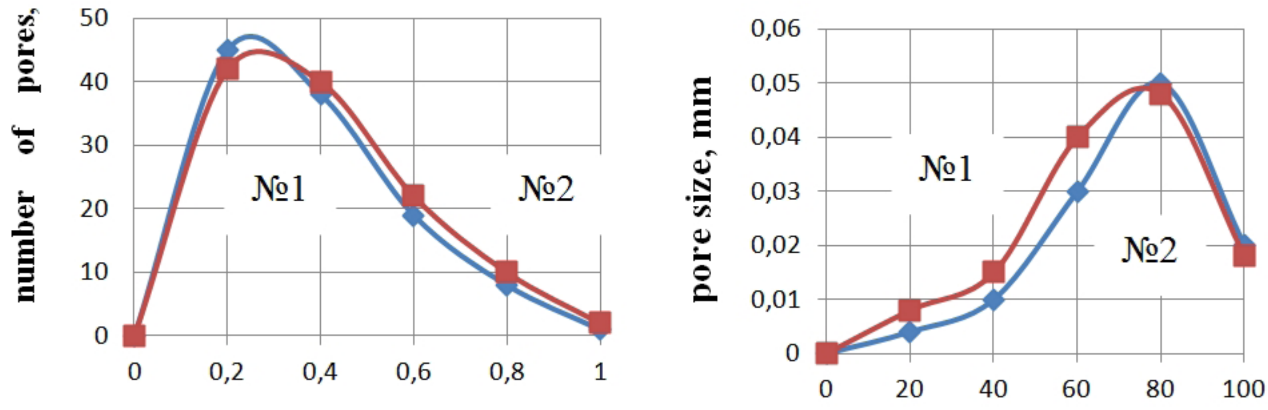
The distribution of pores by size

Figure 5. The parameters of total porosity of the samples No 1 and No 2 (75 mass fractions) bloated at temperature of 160 °C (the first endothermic minimum)



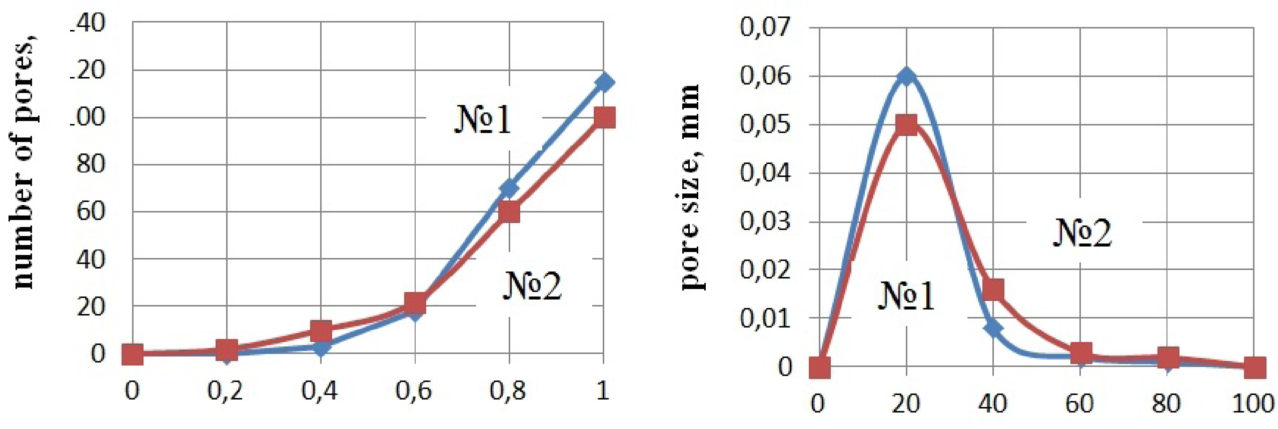
The interval factor of form The distribution of pores by size

Figure 6. The parameters of total porosity of the samples No 1 and No 2 (75 mass fractions) bloated at temperature of 300 °C (the first endothermic minimum)



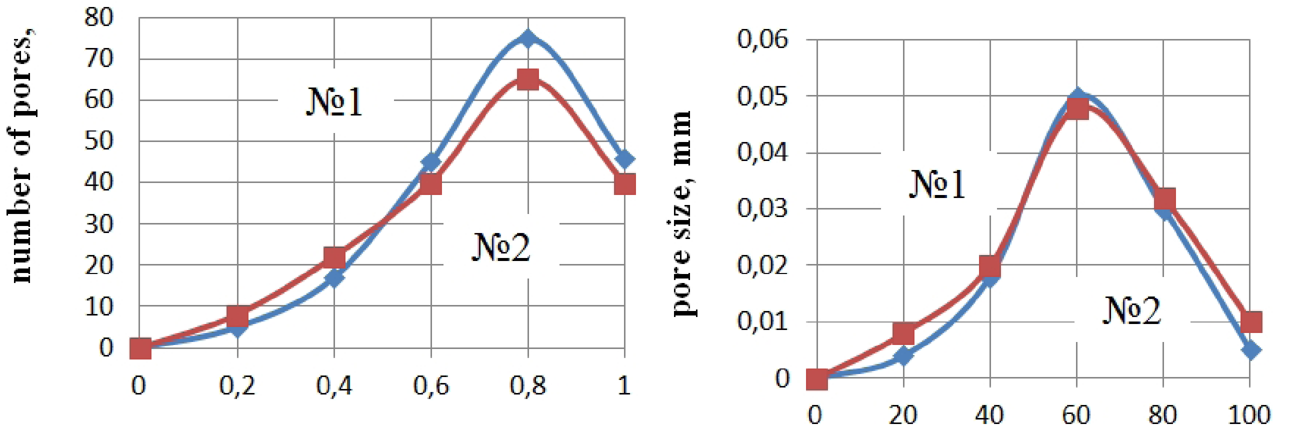
The interval factor of form The distribution of pores by size

Figure 7. The parameters of total porosity of the samples No 1 and No 2 (75 mass fractions) bloated at temperature of 700 °C (the first endothermic minimum)



The interval factor of form The distribution of pores by size

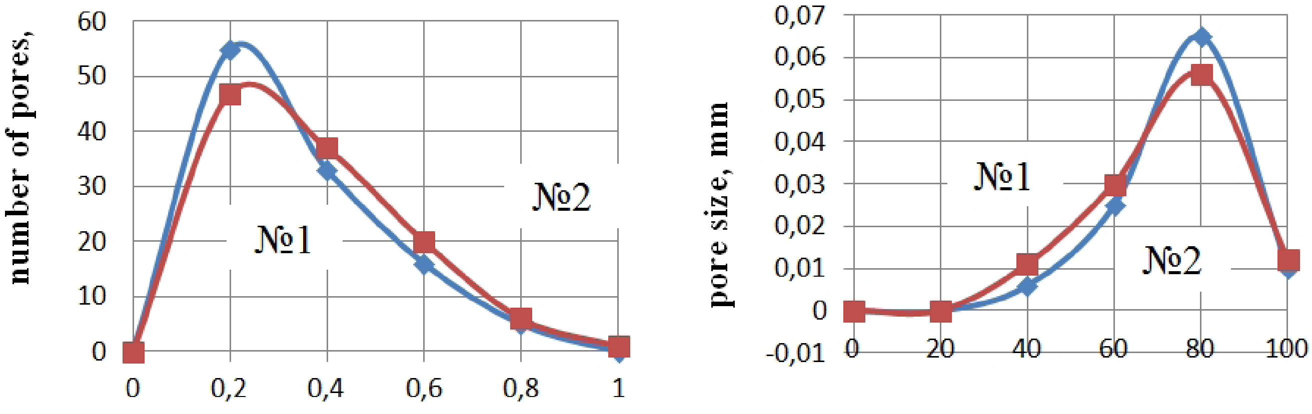
Figure 8. The parameters of total porosity of the samples No 1 and No 2 (160 mass fractions) bloated at temperature of 160 °C (the first endothermic minimum)



The interval factor of form

The distribution of pores by size

Figure 9. The parameters of total porosity of the samples No 1 and No 2 (160 mass fractions) bloated at temperature of 300 °C (the first endothermic minimum)



The interval factor of form

The distribution of pores by size

Figure 10. The parameters of total porosity of the samples No 1 and No 2 (160 mass fractions) bloated at temperature of 700 °C (the first endothermic minimum)

In figures 5-10, the porosity parameters of samples No 1 and No 2 for the mixture with different content of 75 and 160 mass fractions are shown. The characteristic feature of the obtained data is that graphs for different types of clay are almost the same. Significant differences are in reading for different temperature minimums. So, for the first endothermic minimum, we obtained the bloated material with small and almost spherical pores [7-9]. Most of them had a minimum size. The bloating of the raw material mixture in the second endothermic minimum provides a mixed porosity (spherical cellular and channel). The material becomes less solid. When there is bloating in the conditions of the third endothermic minimum the channel porosity is mainly formed. This material has the lowest strength. The reducing in thermal conductivity with increasing temperature of bloating should be expected.

Conclusions

The solution of task of creating new porous thermal insulation materials and technologies of their production is inextricably related to scientific research in energy transferring of porous structure during the stages of bloating, hardening and drying under the condition of providing the lowest thermal conductivity and density.

The indicated material properties are determined by a rate of their porosity, the ratio of micro and macro porosities, properties of interporous material that form a kind of supporting structure, which in its turn is determined by the production technology, type of raw materials and conditions of their preparation. All mentioned above impose the special requirements to the formation of material structure to ensure its relatively high strength and durability.

With the help of differential thermal analysis, the modes of heat treatment have been studied; the rational parameters of thermal bloating has been defined that allows to implement the process with minimal energy consumption with predicted thermal properties of obtained materials.

References

1. Pavlenko A., Koshlak H. (2015) Design of processes of thermal bloating of silicates. *Metallurgical and Mining Industry*. No 1, p.p.118-122.
2. Eom, J.-H., Kim Y.-W., Raju S. (2013) Processing and properties of macroporous silicon carbide ceramics: A review. *Journal of Asian Ceramic Societies*. Vol. 1, No 3. p.p. 220–242.
3. Komissarchuk O., Xu Z., Hao H. (2014) Pore structure and mechanical properties of directionally solidified porous aluminum alloys. *China Foundry* (electronic source). Vol. 11, No 1. p.p. 1–7. Available at: https://doaj.org/article/002c72e2e0 1345db8bf4fef190113057.
4. Bajare D., Kazjonovs J., Korjakins A. (2013) Lightweight Concrete with Aggregates Made by Using Industrial Waste. *Journal of Sustainable Architecture and Civil Engineering*. Vol. 4, No 5.
5. Lopez-Pamies O., Ponte Castaneda P., Idiart M. I. (2012) Effects of internal pore pressure on closed–cell elastomeric foams. *International Journal of Solids and Structures*. Vol. 49, No 19-20. p.p. 2793–2798.
6. Gunasegaram D. R., Farnsworth D. J., Nguyen T. T. (2009) Identification of critical factors affecting shrinkage porosity in permanent mold casting using numerical simulations based on design of experiments. *Materials Processing Technology*. Vol. 209, p.p. 1209-1219.
7. Grunsven W. (2014) Porous metal implants for enhanced bone ingrowth and stability. *Thesis submitted to the University of Sheffield for the degree of Doctor of Philosophy. Department of Materials Science and Engineering*. September 2014.
8. Lepeshkin I. A., Ershov M. Ju. (2010) Vspenennyj aljuminij v avtomobilestroenii [The foam aluminum in automotive industry]. *Avtomobil'naja promyshlennost*' [Automotive industry]. No 10, p.p. 36-39.
9. Krushenko G. G. (2012) Poluchenie i primenenie poristyh metallicheskih materialov v tehnike [Obtaining and application of porous metal materials in the technique]. *Vestnik Sibirskogo gosudarstvennogo ajerokosmicheskogo universiteta imeni akademika M. F. Reshetneva. Tehnologicheskie processy i materialy*. [Journal of Siberian State Aerospace University. Technological processes and materials]. p.p. 181-184.

Calculation of heat transfer in fluid around gas-vapour bubbles

Pavlenko A.M.

Doctor of Technical Sciences, Professor Department of Building Physics and Renewable Energy
Kielce University of Technology, Poland,
E-mail: am.pavlenko@i.ua

Koshlak H.V.

PhD, Associate Professor Department of heat and gas supply, ventilation and heat power engineering Poltava national technical Yuri Kondratyuk university
E-mail: annready@yandex.ua

Abstract
Marine gas hydrates are considered the most probable alternative fuel in many countries. Their exploration actively engages specialists from France, Germany, the USA, Canada and Japan [1-9]. The Japanese plan to start commercial production of methane from the "Ice fuel" around their islands in the basin Nyanhay in 2016. However, effective technology acquisition, storage and transport of methane gas hydrates is still in the development stage [10-15]
Key words: HEAT AND MASS TRANSFER, MATHEMATICAL MODEL, THERMAL CONDITIVITY, HEAT INSULATION

Introduction

There are a number of technological processes which are based on the use of gas-vapor bubbles, surface cleaning, cavitation, homogenization fuel mixing colloidal solutions, water degassing, distillation of petroleum products, foaming in the food industry and in the manufacture of thermal insulation materials, transportation of natural gas as a hydrate and many others. Typically the formation and existence of gas-vapor bubbles are accompanied by intense heat and mass transfer processes at phase interface. The small size surfaces and significant speed of these processes led to the widespread use of mathematical modeling for their research. Mathematical models can determine the most influential factors and optimize technological processes. For an exact description of the various hydrodynamic, heat exchange and mass transfer processes, a mathematical model must take into account the heat transfer in the fluid that surrounds the gas-vapor bubble.

Overview of recent sources of research and publications

For consideration of heat exchange processes on the boundary of separation medium mathematical model of gas-vapor bubbles should contain equations describing the heat transfer of fluid in the environment. In [1] the temperature of the liquid is described by an exponential function, which is independent of the time direction of the wall of bubbles. Some authors take the temperature of the liquid constant [2, 3], and thermodynamic processes in gas-vapor environment of bubbles of adiabatic. However, these assumptions are possible only to a very limited group of tasks. In works [4, 5] the analytical solution of the problem of unsteady heat conduction in the layer of fluid that surrounds oscillating bubbles. For obtaining solutions, the author suggested the following simplifying assumptions: finite liquid layer in which there heat exchange processes are of parabolic nature of the temperature distribution in the thickness of this layer. Due to these assumptions, in the resulting solution of this problem, the heat transfer is not dependent on thermal and physical characteristics of the fluid. In work [6] process of heat transfer in the liquid is not considered, and its temperature is determined only on the basis of the combined boundary conditions. Some authors [7] consider heat transfer in such a thin layer of fluid that the curvature of the surface of the bubble can not be ignored.

Selection of not solved earlier parts of the general problem

To improve the accuracy of mathematical models of gas-vapor, bubbles must be considered in the process of heat transfer fluid surrounding the gas-vapor bubble. The feature of this problem is the movement of the walls of bubbles, the rate of which, in certain moments of time can be up to several hundred meters per second. Temperature mode of gas inside the bubbles also varies widely. Consequently, the thermophysical characteristics of fluid on the boundary of the bubble can also significantly vary.

Problem statement

The aim of this work is to create a digital mathematical model of heat transfer in the fluid around the vapor bubbles, which change its size. The liquid should have variable thermophysical characteristics.

Basic material and results

For the development of mathematical models of heat transfer fluid, the following simplifying assumptions are used:

- gas-vapor bubble has a spherical shape;
- at the surface of bubbles boundary conditions of the second kind are considered.

To determine the temperature on the inner surface of the bubbles, the process of heat transfer fluid should be considered. It is done by heat conduction and convection. For calculation of heat transfer by heat conduction, Fourier heat equation is usually used. In order to take account of convection, effective coefficient of thermal conductivity can be used.

Let us denote «*x*» coordinate, at which the radius of bubbles changes. To determine the unknown temperature on the surface, bubbles can apply nonlinear heat equation Fourier bullet considering the mobility of its walls [1]

$$\frac{\partial\left(\rho_r c_r T_{(x,\tau)}\right)}{\partial\tau}+\dot{x}\frac{\partial\left(\rho_r c_r T_{(x,\tau)}\right)}{\partial x}=\frac{1}{x^2}\frac{\partial}{\partial x}\left(\lambda_r x^2\frac{\partial T_{(x,\tau)}}{\partial x}\right), \qquad (1)$$

where $\dot{x}-$ the rate of change of the radius bubbles, m/s; λ_r – effective coefficient of thermal conductivity of fluid, W/(m°C); c_r – heat capacity of fluid, J/(kg°C); ρ_r – density, kg/m³. Considering the continuity of flow conditions when the same mass of liquid $\rho_r\dot{x}4\pi x^2=\rho_r\dot{R}4\pi R^2=const$ flows through any surface of bullet of radius ***x*** per unit time; equation (1) can be written as

$$\frac{\partial T_{(x,\tau)}}{\partial\tau}=\frac{1}{x^2}\frac{\partial}{\partial x}\left(\frac{\lambda_r}{\rho_r c_r}x^2\frac{\partial T_{(x,\tau)}}{\partial x}-\dot{R}R^2T_{(x,\tau)}\right), \qquad (2)$$

As a result of heat exchange processes in the border of bubbles liquid may change its thermophysical characteristics, so the problem will be solved as nonlinear.

Considering the fact that near the bubbles surface, specific heat flux (*q*) is known, let us write the boundary condition of the second kind

$$-\lambda_r\frac{\partial T}{\partial x}(x=R,\tau)=q \qquad (3)$$

In order to describe the thermal conductivity in the liquid around the bubbles, let us divide layer of liquid that surrounds bubble to a number of concentric shells. Let us define mass distribution of each shell

$$m_{r(2)}=2K_r m_{r(1)}$$

$$m_{r(i)}=K_r m_{r(i-1)}$$

where $m_{r(1)}-$ mass of shell of the 1st (inner) layer; $m_{r(i)}$ – mass of each one of the next shell; K_r – coefficient of proportionality. This coefficient is used to optimize its calculations and its typical values are within 1.5÷2. It is chosen so as to achieve maximum speed values for a given accuracy.

Let us determine the temperature on the inner surface of the first (inner) shell. Then, in the inner shell, which has a boundary condition differential equation will be of the form

$$m_{r(1)}c_{r(1)}\frac{dT_{(R,\tau)}}{d\tau}=-F_R q-\frac{4\pi\lambda_{r(1)}\left(T_{(R,\tau)}-T_{(R+\delta 1)}\right)}{\dfrac{1}{r_{(R)}}-\dfrac{1}{r_{(R+\delta 1)}}}. \quad (4)$$

For ease of calculation, let us denote

$$K_1=\frac{\lambda_{r(1)}}{\dfrac{1}{r_{(R)}}-\dfrac{1}{r_{(R+\delta 1)}}}=\frac{\lambda_{r(1)}}{\dfrac{1}{R}-\dfrac{1}{R+\delta 1}}. \quad (5)$$

Now the differential equation that determines the temperature on the surface of the inner layer of bubbles is of the form

$$\frac{dT_{(R,\tau)}}{d\tau}=\frac{4\pi}{m_{r(1)}c_{r(1)}}\left(-R^2 q-K_1\left(T_{(R,\tau)}-T_{(R+\delta 1)}\right)\right). \quad (6)$$

In the absence of mass transfer processes mass of 1st layer remains intact, because

$$m_{r(1)}=\frac{4}{3}\pi\rho_{r1}\left[\left(R+\delta 1\right)^3-R^3\right]=const$$

Where the outer radius of the 1st shell can be defined

$$R+\delta 1=\sqrt[3]{r_R^3+\frac{3m_{r(1)}}{4\pi\rho_{r1}}}=\sqrt[3]{R^3+\frac{3m_{r(1)}}{4\pi\rho_{r1}}}. \quad (7)$$

For all next shells, the following equation can be written

$$m_{r(i)}c_{r(i)}\frac{dT_{(x,\tau)}}{d\tau}=\frac{4\pi\lambda_r\left(T_{(i-1)}-T_{(i)}\right)}{\dfrac{1}{r_{(i-1)}}-\dfrac{1}{r_{(i)}}}-\frac{4\pi\lambda_r\left(T_{(i)}-T_{(i+1)}\right)}{\dfrac{1}{r_{(i-1)}}-\dfrac{1}{r_{(i)}}}. \quad (8)$$

In this task, let us replace the temperature of the conditioned layers by difference between the mean temperature of the layer and its edges (borders).

$$\frac{dT_{(r_i,\tau)}}{d\tau}=\frac{4\pi}{m_{r(i)}c_{r(i)}}\cdot\left(K_3\left(T_{(r_i-\delta i,\tau)}-T_{(r_i,\tau)}\right)-K_1\left(T_{(r_i,\tau)}-T_{(r_i+\delta i,\tau)}\right)\right). \quad (9)$$

The temperature at the external borders of i-th shell

$$T_{(r_i+\delta i,\tau)}=\frac{K_1T_i+K_2T_{i+1}}{K_1+K_2}. \quad (10)$$

The temperature on the inner border

$$T_{(r_i-\delta i,\tau)}=\frac{K_4T_{i-1}+K_3T_i}{K_4+K_3}. \quad (11)$$

The coefficients K_1, K_2, K_3, K_4 are determined by the following formulas:

$$K_1 = \frac{\lambda_{r(i)}}{\frac{1}{r_{(i)}} - \frac{1}{r_{(i)} + \delta_{(i)}}}, \quad (12)$$

$$K_2 = \frac{\lambda_{r(i+1)}}{\frac{1}{r_{(i)} + \delta_i} - \frac{1}{r_{(i+1)}}}, \quad (13)$$

$$K_3 = \frac{\lambda_{r(i)}}{\frac{1}{r_{(i)} - \delta_{(i)}} - \frac{1}{r_{(i)}}}, \quad (14)$$

$$K_4 = \frac{\lambda_{r(i-1)}}{\frac{1}{r_{(i-1)}} - \frac{1}{r_{(i)} - \delta_i}}. \quad (15)$$

Medium-radius of i-th shell is given by

$$r_{(i)} = \sqrt[3]{r_{(i-1)}^3 + \frac{3}{8\pi}\left(\frac{m_{r(i-1)}}{\rho_{r(i-1)}} + \frac{m_{r(i)}}{\rho_{r(i)}}\right)}. \quad (16)$$

Since the mass of the first shell is not divided in half, for the 2nd shell radius, mass is determined by the following formula

$$r_{(2)} = \sqrt[3]{R^3 + \frac{3}{4\pi}\frac{m_{r(1)}}{\rho_{r1}} + \frac{3}{8\pi}\frac{m_{r(2)}}{\rho_{r2}}}. \quad (17)$$

The outer radius of i-th shell

$$r_{(i)} + \delta_i = \sqrt[3]{r_{(i)}^3 + \frac{3m_{r(i)}}{8\pi\rho_{r(i)}}}. \quad (18)$$

The inner radius of i-th shell

$$r_{(i)} - \delta_i = \sqrt[3]{r_{(i)}^3 - \frac{3m_{r(i)}}{8\pi\rho_{r(i)}}}. \quad (19)$$

The differential equations (6) and (9) were solved by the method of Runge-Kutta 4th order. In order to assess the adequacy of the developed mathematical model a computer program was written and a series of mathematical experiments were performed.

Output data

The duration of estimated time interval is 100 ns (nanoseconds). Time step - 0,001 ns, specific heat flux - 10 MWt/m^2. The initial diameter of the bubbles - 0.1 mm, initial temperature of the water - +5 °C. 10 layers were calculated, coefficient - K_r= 1.5. Thermal conductivity, density and heat capacity of water were held constant at temperature +5°C.

Figures 1 and 2 show the results of calculation of cooling wall bubbles under constant specific heat flow conditions for increasing its radius at speeds $\dot{R} = 100$ m/s. In Fig. 3 and 4, the speed was 50 m/s. Obtained results show that during the compression of bubbles changing temperature conditions are changed just closest to the interfacial boundary of layers of fluid. “Depth” heat wave penetration is about 0.1 of the initial radius of bubbles. When expanding bubbles, temperature conditions surrounding the layer at a distance of more than 3 values of the initial radius of the bubble are changed. When reducing the size of bubbles, the total heat flow decreases, resulting in slower heat exchange processes (Figure 3).

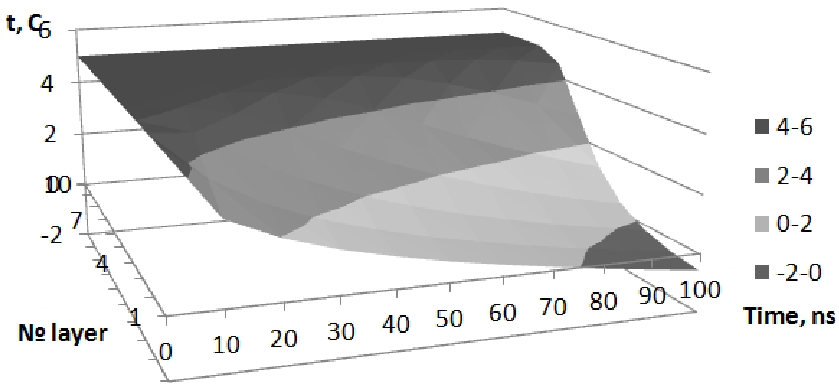


Figure.1. Diagram of temperature fields in the water that surrounds bubble (phase transition in water is not considered). The calculation results for $\dot{R} = 100$ m/s

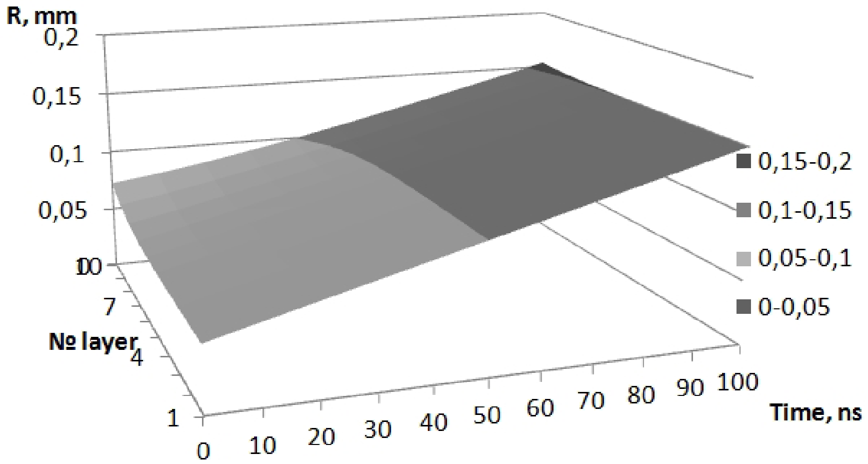


Figure 2. The diagram of radius changes in the calculation of layers at $\dot{R} = 100$ m/s

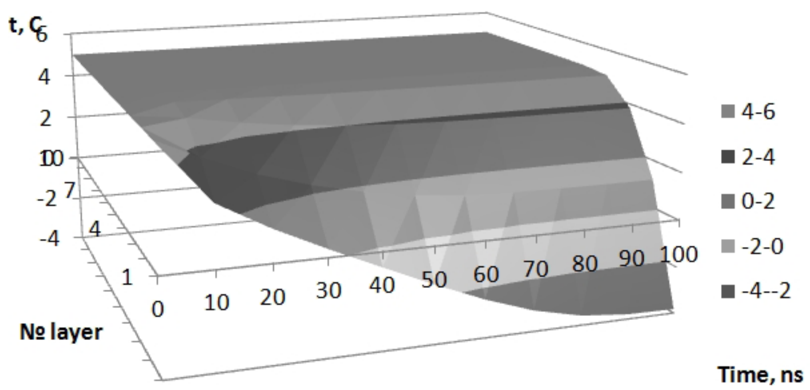


Figure 3. The diagram of temperature fields in the water that surrounds bubble (phase transition in water is not considered). The calculation results for $\dot{R} =$ -50 m/s

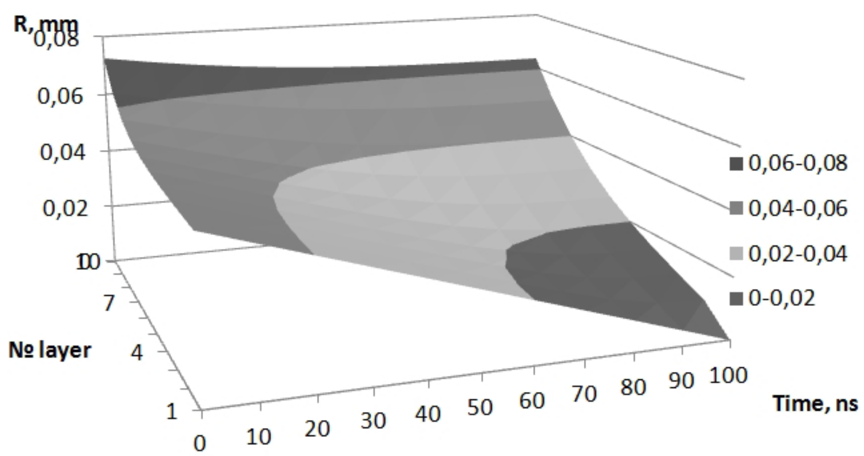


Figure 4. The diagram of radius changes in the calculation of layers at $\dot{R} =$ -50 m/s

Conclusions

The mathematical model for calculating heat transfer in the fluid that surrounds the oscillating gas-steam bubble was developed. The model takes into account the changing thermal and physical characteristics of the liquid, changing the size of bubbles, heat exchange processes at its border. Computer program for the calculation of this mathematical model was created. Distribution of temperature fields in the liquid during the transition was obtained. The proposed calculation method can be used to determine the thermal and physical characteristics of fluid and vapor in a variety of technological processes related to boiling fluid cavitation and the formation of gas hydrates.

References

1. Takeya S., Ebinuma T., Uchida T. (2002) Self-preservation effect and dissociation rates of CH4 hydrate. *Crystal Growth*. Vol. 237-239, p.p. 379-382.
2. Stem L.A., Circone S., Kirby S.H. , Durham W.B. (2003) Temperature, pressure and composition effects on anomalous or «self preservation of gas hydrates. *Can. J. Phys*. Vol. 81, p.p. 271-283.
3. Wenfeng Hao, Jinqu Wang, Shuanshi Sfan, Wenbin Hao (2008) Evaluation and analysis method for natural gas hydrate storage and transportation processes. *Energy Conversion and Management*. Vol. 49, p.p. 2546–2553.
4. Belosludov V.R., Suhbotion O.S., Krupskii D.S., Ikeshoji T., Belosludov R.V., Kawazone Y. Kudoh J. (2005) Structural and thermodynamic properties of gas hydrate phases immersed in the ice phase. *Proceed. 5-th Intern. Conf. on gas hydrates*. Trondheim, Norway, Vol. 2, p.p. 631-637.
5. Gudmundsson J., Parlaktuna M., Khokhar A. (1994) Storing natural gas as frozen hydrate. *SPE Production and Facilities, February*. p.p. 69-73.
6. Economides M.J., Sun Kai, Subero G.U. (2006) Compressed Natural Gas (CNG): An Alternative to Liquefied Natural Gas (LNG). *Journal SPE Production & Operations*. Vol. 21(2), p.p. 318 – 324.
7. Chuvilin E.M., Kozlova E.V., Makhonina N.A., Yakushev V.S. (2003) Experimental investigation of gas hydrate and ice formation in methane-saturated sediments. *Proceed. 8-th Intern. Conf on permafrost. Zurich*, Switzerland.Vol. 1, p.p. 145-150.
8. Chuvilin E.M., Makhonina N.A., Titenskaya O.A., Boldina O.M. (2002) Petrophysical investigations on frozen sediments artificially saturated by hydrate. *Proceed. 4-th Intern. Conf on gas hydrates. Yokohama, Japan*. Vol. 2, p.p. 734-739.
9. . Kim H. C. (1987) Fugacity Model of Gas Hydrate Dissociation in Three Phases. Chem. Eng. Sci. Vol. 42, p.p. 1645–1653.
10. Komai T., Sakamoto Y., Kawamura T., Yamamoto Y. (2005) Dissociation Rate of Methane Hydrates Occupied in Pore Space of Marine Sediments. *Proceeding of the Sixth (2005) ISOPE Ocean Mining Symposium Changsha*. Human, China, October 9 – 13.
11. Levik O.I. (2000) *Thermophysical and Compositional Properties of Natural Gas Hydrate. Dr.Ing. Thesis*. Department of Petroleum Engineering and Applied Geophysics, NTNU. Trondheim. 164 p.
12. Norvegian Patent No 172080. Method and for production of gas hydrates / J.S. Gudmundsson; inventor J.S.Gudmundsson. 1990. 9 p.
13. Istomin V.A. (1999) On Possibilitty of Superheating of Natural Gas Hydrate and Other Aqueous Crystalline Structures. *Russian Journal of Physical Chemistry*. Vol. 73, No 11.
14. Gudmundsson J.S., Parlaktuna M. (1991) *Gas-in-ice: Concept evaluation*. Technical report, Department of Petroleum Engineering and Applied Geophysics, Norwegian University of Science and Technology.
15. Gudmundsson J.S., Parlactuna M., Levik O.I., Andersson V. Storing Natural Gas as Frozen Hydrate. *SPE Production & Facilities*. No.1 (Feb.), p.p. 69-73.
16. Aktershev S.P., Ovchinnikov V.V. (2013) Modeling of boiling of metastable liquid in the presence of evaporation fronts. *Sovremennaja nauka: issledovanija, idei, rezultaty, tehnologii* [Modern science: studies, ideas, results, technologies]. Novosibirsk: Kutateladze Institute of Thermophysics RAS. No 1, p.p. 77–82.
17. Avramenko A.A, Sorokina T.V. (2005) *The instability of vapor bubble*. Institute of Technical Thermophysics of NASU. Kyiv: Promyshlennaja teplotehnika. Vol. 27, No 6, p.p. 12–15.
18. Pavlenko A., Usenko B., Koshlak A. (2014) Analysis of thermal peculiarities of alloying with special properties. Metallurgical and Mining Industry. No 2, p.p. 15-19.
19. Pavlenko A.M., Basok B.I. (2005) Regularities of boiling-up of emulsified liquids. *Heat Transfer Research*. No 36 (5), p.p. 419.
20. Nigmatulin R.I., Habeev N.S. (1978) The dynamics and heat and mass transfer of gas-vapor bubbles with the liquid. *Nekotorye voprosy mehaniki sploshnoj sredy*. Moscow: Institute of Mechanics, Moscow State University. P.p.229–243.

Editorial department

Technical translation:

Olga Kuyan

Page-proofs:

Lyudmila Klets

Design:

Sophia Neklesa

The journal is registered by Ministry of Justice of Ukraine. Registration Certificate No. 15475-4047P of July 13, 2009.

Publisher: "Ukrmetallurginform" STA", Ltd

e-mail: metaljournal@gmail.com

metaljournal11@gmail.com

Dnipro

Ukraine

Tel.:+38 (056) 794 36 74

Fax: +38 (056) 794 36 75

Mob: +38 (050) 320 69 72