UDC 621.91.02

THEORETICAL AND EXPERIMENTAL STUDY OF THE TEMPERATURE IN THE WORKPIECE WHEN COVERING MILLING

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A considered mathematical model for determining the temperature in a spherical workpiece, the calculation of the temperature of the spherical surface of the workpiece during processing with a rotating blade tool based on the method of point head sources, a graph of the temperature variation from the rotating angle of the workpiece.

With high-speed milling of spherical surfaces, it is important to know the temperature in the workpiece, since the temperature deformation has a significant impact on the accuracy and quality of the part [1].

For theoretical studies, known [2] mathematical formulas were used to calculate the temperature in the cilindric and spherical bodies, since the workpiece in the case under consideration has the shape of a cylinder, and the finished part - the shape of the ball.

For the cylinder:

$$\frac{\partial\theta}{\partial t} = k\left(\frac{\partial^2\theta}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial\theta}{\partial r} + \frac{1}{r}\cdot\frac{\partial^2\theta}{\partial\mu} + \frac{\partial^2\theta}{\partial z^2}\right) + \varphi\frac{\partial\theta}{\partial\mu} \quad (1)$$

For the sphere:

$$\frac{\partial\theta}{\partial t} = k\left(\frac{\partial^2\theta}{\partial r^2} + \frac{2}{r}\cdot\frac{\partial\theta}{\partial r}\right). \quad (2)$$

It is accepted that the heat source is fast-flowing, since the rotation speed of the cutter reaches 10 m / s and the Baking criterion *Pe > 10:*

$$Pe = 10\frac{\upsilon(m/s)\cdot l_n(mil)}{K(sent^2/s)}. \quad (3)$$

The schematization of the heat source by [3] is adopted, which is shown in figure 1.

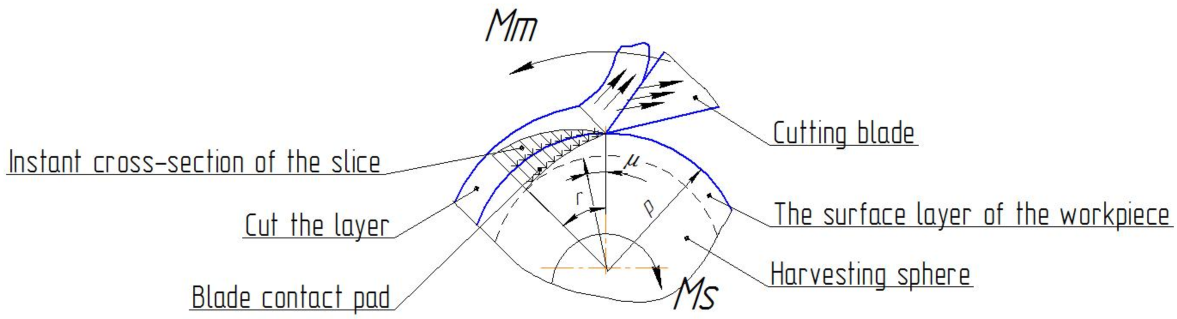

Fig. 1. Schematization of the heat source

We analyzed the results of studies on the kinematics of cutting, deformation, dynamics, thermal phenomena, surface roughness and precision, wear of cutting tools during the machining of the surfaces of the spheres cutting. Features and advantages of high-speed cutting for processing of spheres are revealed.

On the basis of the analysis of literary sources objects and directions of researches in the given dissertation are defined.

In the side Chapter describes and analyzes the possible kinematic cutting scheme obtained with the ratio of the circumferential velocity of the tool and the workpiece, and their impact on the roughness of the machined surface, the geometry of the tool blade and the cross-section of the cut layer in the cutting process.

To improve the environmental situation in the area of operation of boiler plants, it is necessary to strive not only to suppress the formed harmful substances, but also to a greater extent to the localization of their appearance [1-3]. One way to reduce the formation of harmful substances (oxides and nitrogen dioxide and carbon monoxide (II)) during the combustion of gaseous fuels is the injection of water or steam into the combustion chamber [2-5]. In prof. I.J. Sigala's opinion [2], the introduction of water or steam into the fuel-air mixture affects the combustion and formation of NO_x no less than the introduction of a similar volume of recirculating gases. Water vapour has a strong inhibitory effect on the synthesis of nitrogen oxides due to the effect of water vapour on the kinetics of NO_x formation. The prerequisite for this is the fact that water vapour affects the flame propagation velocity, and therefore the introduction of even a small amount of water vapour into the core of the combustion zone significantly affects the yield of nitrogen oxides.

However, on an industrial scale, this method is practically not used. It is due to the fact that, according to Acad. J.B. Zeldovich [3] and prof. I.J. Sigala [2], when the temperature of the flare decreases, the efficiency of the boiler decreases, which means that an additional volume of fuel is needed.

Polotsk State University is carrying out research to develop a technology for the preparation of emulsions based on oily waste [6-8]. Its use will allow enterprises to significantly reduce the capital and current costs for the separation of oily waste into petroleum products and water, since the emulsion includes water. One way to use such an emulsion is to use it as an additive to the main fuel of boiler plants [4, 5, 9].

Conclusion. Experimental studies have shown that burning emulsions based on oily waste (10-20% of water) with the main fuel with a uniform distribution of water throughout the volume of the material in the furnace of the steam boiler provides a reduction in emissions of harmful substances in the atmosphere compared to their quantity when burning dehydrated fuel. The reduction of carbon monoxide (II) by 43-59% and nitrogen oxides by 28-45% has been achieved. Using an emulsion based on OCW as an additive to fuel can reduce the consumption of the main boiler fuel by 3-5% [4, 5, 9].

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$$O + N_2 \leftrightarrow NO + N - 314{,}2 \text{ kJ/ mol}$$

$$N + O_2 \leftrightarrow NO + O + 134{,}0 \text{ kJ/ mol};$$

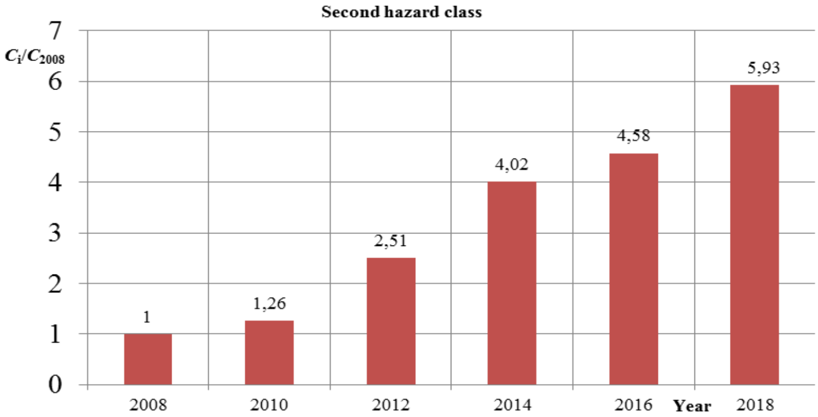

Fig. 2. Change in the ratio of the rate of environmental tax on the emission of pollutants into the air of the *i-th* year to the rate of 2008

chain termination:

$$O + O + M \leftrightarrow O_2 + M + 494{,}4 \text{ kJ/ mol}.$$

Coming with flue gases to the atmosphere, NO is oxidized to nitrogen dioxide NO_2, reacts with atmospheric moisture and falls out with precipitation as a weak solution of nitric acid HNO_3, dissolving in water bodies. The formation of NO_2 at an excess air-content ratio of 1.1 and a flue gas temperature of 200 ° C requires 35 minutes, so it is practically not formed in the gas path of the boiler. N_2O heminoxides are thermally unstable, and the proportions of the dimer of N_2O_4 dioxide and N_2O_3 trioxide are very small to take into account when studying toxic emissions of boilers [2].

The share of harmful emissions in the flue gas composition also includes nitrogen oxides formed from chemically bound nitrogen of the fuel. Fuel nitrogen through the radicals is partially oxidized to nitrogen oxides. The separation of nitrogen atoms from fuel elements consumes 1.5-4.0 times less energy than the dissociation of the nitrogen molecule from the air. The major part of the nitrogen oxides formed in the furnace of the boiler is due to the high temperature of the medium in the combustion zone and the presence of an oxidizer.

Oxides and nitrogen dioxide are formed by burning fuel in high temperature zones. Studies conducted under the supervision of Acad. J.B. Zeldovich [3] showed that reducing the burnup time of fuel droplets by two times leads to a decrease in NO_x concentration by 22% (Figure 3). Thus, the reduction in the residence time of the combustion products in the high-temperature zone of the boiler furnace leads to a decrease in the concentration of nitrogen oxides.

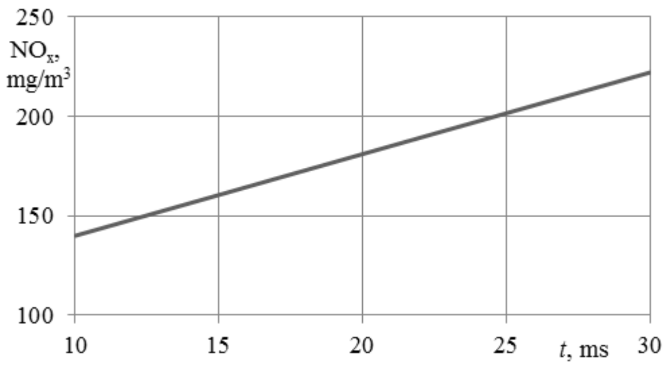

Fig. 3. Dependence of nitrogen oxides NO_x in flue gases (from burning oily emulsion) on the burnout time t in the boiler flare

same time there is a continuous pollution of the atmosphere by combustion products of gaseous fuel (mainly nitrogen dioxide) [2].

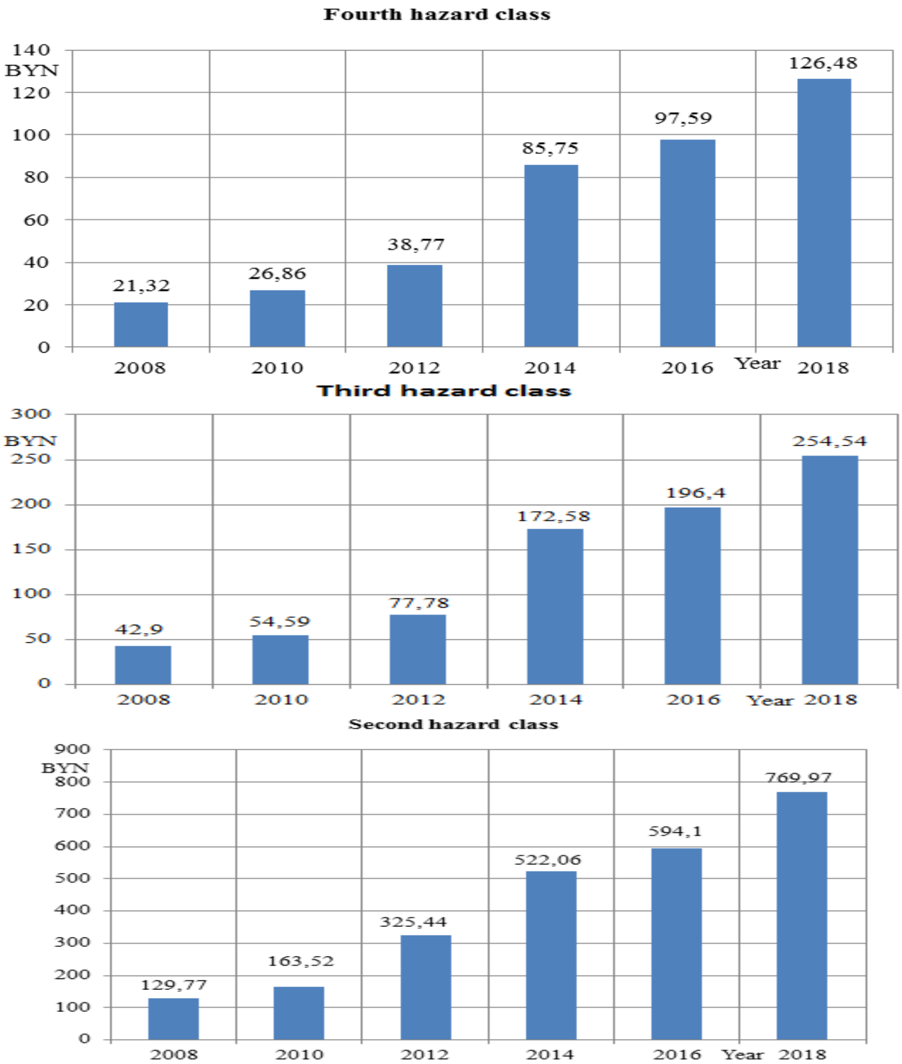

Fig. 1. Change in environmental tax on pollutant emissions
of different hazard classes in the atmospheric air annually

Formation of nitrogen oxides. Nitrogen oxides at high temperature form a number of thermodynamic stability: NO, N_2O, NO_2, N_2O_3, N_2O_4 [2]. Both nitrogen from the air and organic compounds of nitrogen with fuel take part in the formation of oxides [3]. The formation of nitrogen oxides is affected by catalysts - various compounds of mineral or mineral-organic constituents of fuel [2, 3]. Both the increase in the power of the burners and the boiler load, and the increase in the temperature of the medium in the furnace contribute to the increase of NO_x formation [2].

Nitric oxide is about 95% of the sum of all nitric oxides [2]. NO formation under high temperature oxidation of atmospheric nitrogen occurs by a radical chain mechanism with N and O atoms. The gross reaction of NO formation [3] can be expressed in the following form:

$$N_2 + O_2 \leftrightarrow 2NO - 180{,}2 \text{ kJ/ mol},$$

the complete chain diagram of this reaction is as follows:

initiation:

$$O_2 + M \leftrightarrow O + O + M - 494{,}4 \text{ kJ/ mol};$$

chains:

UDC 629.123: 665.61

A METHOD OF REDUCING EMISSIONS OF HARMFUL SUBSTANCES INTO THE ATMOSPHERE BY BOILER PLANTS

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The article deals with harmful substances which are formed during boiler operation and their influence on people. An estimation of the dynamics of the change in the environmental tax on the emission of pollutants into the atmospheric air over the last ten years is given. The mechanism of formation of nitrogen oxides is considered. Recommendations are given on possible ways to reduce emissions of nitrogen oxides to the atmosphere that form during the operation of boiler houses. It is noted that using emulsions based on oily waste as an additive to the main fuel of boiler plants will allow not only to dispose of these substances, but will reduce emissions of nitrogen oxides into the atmosphere and consumption of the main fuel.

Introduction. At present, the problem of protecting the environment from harmful emissions from the use of fossil fuels, including natural gas, attracts the attention not only of scientists but of the entire world community. Acad. M.A. Strykovich notes [1] that in recent years, the anthropogenic impact of boiler plants on the atmosphere has become especially dangerous, the number of which increases every year. The annual emissions of the main toxic substances are: 150 million tons of sulphur dioxide, 300 million tons of carbon monoxide, 50 million tons of nitrogen oxides.

According to the data of prof. I. J. Sigala [2], Table 1 shows the effects of some toxic substances on the human body, confirming the relevance of work to reduce the hazards in combustion products of fuel.

Table 1. – Characteristics of exposure to harmful substances per person

Duration and nature of human exposure	Content in air,%		
	CO	NO_x	SO_2
A few hours without noticeable action	0,01	0,0008	0,0025
Signs of easy poisoning	0,01–0,05	0,001	0,005
Serious poisoning is possible in 30 minutes	0,05–0,30	0,005	0,008–0,015
Danger of life if exposed for short periods of time	0,50–0,80	0,015	0,060

Objective – Having considered the mechanism of formation of nitrogen oxides, we propose ways to reduce emissions of nitrogen oxides into the atmosphere by boiler plants.

Results and discussion. Boiler installations, which many enterprises have, are both large consumers of fuel and energy resources and large sources of pollutant emissions [1, 2]. The pollutants formed during the operation of the boiler plants are classified in the following hazard classes: nitrogen (II) oxide (nitrogen oxide) – 3; nitrogen (IV) oxide (nitrogen dioxide) – 2; sulfur dioxide (sulfurous anhydride, sulfur (IV) oxide, sulphur gas) – 3; solid particles (undifferentiated by composition dust / aerosol) – 3; aromatic hydrocarbons – 2; aliphatic hydrocarbons C_1–C_{10} – 4; aliphatic hydrocarbons C_{11}–C_{19} – 4; carbon black (Soot) – 3; carbon oxide (carbon monoxide) – 4.

A company pays an environmental tax for these emissions. According to the Tax Code of the Republic of Belarus (Special part) of December 29, 2009 No. 71-3 (including changes and amendments, including the Law of the Republic of Belarus of January 9, 2017 No. 15-3), the environmental tax rate (rub) for emissions of pollutants into the air, in total for 1 ton substances currently constitute: the second hazard class – 769.97; third hazard class – 254.54; fourth hazard class – 126.48. Figure 1 shows the change in the environmental tax on the emission of pollutants of various hazard classes into the ambient air annually since 2008.

The dynamics of the growth of the ecological tax is vivid. Figure 2 shows the change in the ratio of the environmental tax rate for the emission of pollutants into the ambient air over the years to the rate applicable in 2008 for the second hazard class (for other hazard classes the ratio is almost the same). During 10 years the rate has increased almost 6 times. This should motivate enterprises to reduce emissions of pollutants into the air.

For many enterprises, paying an environmental tax for emissions of pollutants into the atmosphere is an important expense item and one of the reasons for switching boiler plants from fuel oil to natural gas. The use of natural gas as fuel in boiler plants excludes atmospheric pollution by sulfur dioxide and solid particles. At the shaft. With a variable turbo coupling, the filling fluid can vary to any degree between the full and empty state. Due to this, infinitely variable speed control of the working machine is possible in a wide range when working with different load characteristics.

Voith company has considerable experience [3] of equipping of pumps and compressors of main pipelines with adjustable hydrodynamic drives, offering various types of hydraulic couplings for capacities up to 35 MW. One of the largest projects implemented with the participation of Voith Turbo in the CIS countries is the equipping of the East Siberia-Pacific Ocean-2 oil pipeline with the Voith hydraulic couplings.

The choice of hydraulic couplings as an adjustable pump drive is explained by a number of significant advantages:

– saving investment costs: not yielding to the frequency-controlled drive in the accuracy and speed of automatic control of the pump's performance, the hydraulic coupling has lower cost and does not require a whole series of additional investment costs.

- compactness: the hydraulic coupling occupies an area several times smaller than the frequency converter.

– high reliability and durability with minimal maintenance costs: the operating time without failures of the hydraulic clutches supplied for the ESPO-2 is 154,000 hours, and the running costs are reduced only to the replacement of oil (if the service requirements are met - every 5 years). Working for 30-40 years, the hydraulic clutch remains maintainable, while the frequency converter, due to the rapid change in the element base, becomes almost non-repairable in 8-10 years of operation.

– high adaptive ability of the hydraulic coupling for use in various designs, different operating conditions: adjustable Voith hydraulic couplings show the same technical readiness, both in the Arabian deserts and on offshore platforms of the North Sea or the Sakhalin shelf. They are suitable for operation in both high and low temperature conditions, high humidity and dust, high salt content in the air, etc.

Damping property is an important advantage [4] of the hydraulic coupling, which protects all drive elements from impact loads, thereby increasing the resources of the pump unit.

Another example of the application of hydraulic clutches for regulating the capacity of gas-pumping units in the main gas pipeline is the compressor station Cheboksarskaya (Russia) where hydraulic clutches were installed in 2005.

Nevertheless, hydraulic couplings have one drawback - it has a lower efficiency than the VFC.

Comparative characteristics of devices for regulating the speed of the VFD and the hydraulic coupling show that the first version (VFR) has large mass, several times larger than the size. This method has strict requirements at the installation site, and the time between failures is one fourth (40,000 h) of the operating time of the hydraulic clutches (160,000 h).

On the basis of the foregoing, it is obvious that the use of VFC is more effective, but is also more difficult to operate and maintain and less fault-tolerant.

Due to the high cost of the VDC equipment (about 3 times more than the cost of the hydraulic coupling) and the high cost of operating costs, the payback of the VFC relative to the hydraulic coupling during the operation period (40 years) is possible only if the oil is pumped constantly. Based on the presented criteria, it can be concluded that the hydraulic coupling is cheaper to maintain, more reliable and durable in operation.

Thus comparable analysis of equipment used for regulation of working parameters of the main pumps on oil pipelines showed that application of the hydraulic coupling is more preferable according to its operational capabilities and cost effectiveness.

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UDC 629.18.064

COMPARISON OF EQUIPMENT USED FOR REGULATION OF WORKING CHARACTERISTICS OF THE MAIN PUMPS ON OIL PIPELINES

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The main goal of this article is to determine the most effective and reliable method for changing the characteristics of pumping units. Since during the operation of pumping units the consumption of hydrocarbon energy carriers by consumers is unstable, the question arises of reducing the energy costs for the the electric motors input at pumping units. There are a number of methods for solving this problem. Here we will consider two basic and effective methods of regulating the performance that are currently used at the constructed pumping stations: the use of a frequency-controlled drive and a hydraulic coupling. A number of advantages and disadvantages of these methods are given and a conclusion is made as to which is more suitable both in terms of efficiency and reliability.

The condition for effective operation of pumping and compressor stations of main pipelines is continuous control of their performance. The performance control reduces energy costs and adapts the pressure and flow to the operating conditions of the transport system. So, with regard to the operating conditions of the oil transportation system seasonal fluctuations of oil consumption are unavoidable due to start-ups and stops of pump units and changes in oil flows through separate pipelines.

No pipeline works with the same capacity during the year. The reasons for work that differs from initially scheduled can be the following: insufficient amount of pumped liquid in the reservoirs, repairing works on the pipeline route without stopping pumping, organization of ground discharges, stop of the intermediate pumping stations or change in viscosity of the pumped liquid [1].

Regulation of the pump supply [2] and ensuring its operation at the required point is possible both by changing the resistance of the pipeline and by changing the characteristics of the pump. The pump speed can be changed in the following ways: either using variable speed motors or at a constant speed of the electric motor with an adjustable hydraulic clutch or a high-voltage variable-frequency drive.

The variable frequency converter (VFC) provides the ability to operate equipment at various speeds, which is realized by converting a general-purpose supply with a constant frequency and a constant voltage to a current with variable frequency and alternating voltage. Transformation is carried out electronically without moving parts and without side effects that are undesirable to the user. The efficiency of modern frequency converters ranged from 96.5% to 98.5%. One of the producers of this type of units is Danfoss which sells its production all over the world.

This method has the following advantages:

1) VFC allows regulating both minimum and maximum operating pressure at the inlet of the main pumping unit.

2) When using the VFC, no additional soft starter is required.

3) Frequency control reduces the number of replaceable pump rotors.

4) VFC can be used to redistribute oil streams when it is necessary to drop some of the oil to other directions, with the discharge being either permanent or variable.

5) Advantages of using VFC to maintain pumping modes are evident, associated with a sharp change in the rheological properties of the pumped medium (density, viscosity). For example, if one of the sections of the pipeline starts pumping oil with a higher density or viscosity, and this requires pressure increase - this is easily done by changing the speed of the pumping unit.

Above, the advantages of using VFC were compared with other frequency control methods. However, when installing an inverter, the following important aspects of its operation must be considered: significant increase in value and investment costs during operation. This type of device is also the source of electromagnetic interference.

A hydraulic drive is a set of devices designed to drive machines by means of a pressurized working fluid while performing control functions.

The adjustable turbine coupling produced by Voith is a hydrodynamic coupling. It transfers the energy coming from the engine due to the dynamic forces of the fluid flow circulating in the closed working cavity between the pump wheel on the leading (primary) shaft and a similar turbine wheel on the driven (secondary) between processes is mainly sequential. The applied approach allowed to determine that at the given stage of the life cycle the following types of hazards can arise: mechanical, industrial, fire, explosion, thermal, electric.

Reconstruction of the main pipeline is a complex of measures for the reorganization or technical re-equipment of the main pipeline. In terms of the content of the works performed and the application of technical basic legal acts this stage of the life cycle is similar to construction. At this stage of the life cycle the following types of hazards can occur: mechanical, industrial, fire, explosion, thermal, electrical. Interaction between processes is mainly sequential.

Conservation of the main pipeline is a set of measures to protect the main pipeline facilities from adverse environmental impacts and other factors after the main pipeline is taken out of service. At this stage of the life cycle there may be such hazards as mechanical, fire, explosion, thermal, electrical. Interaction between processes is mainly sequential.

The liquidation of the main pipeline is the actions for dismantling, demolition or re-profiling of the main pipeline facilities and bringing the environment into a condition that is safe for life and health of citizens and suitable for further use. At this stage of the life cycle there may be such hazards as mechanical, fire, explosion, thermal, electrical. Interaction between processes is mainly sequential.

The presentation of the stages of the main pipeline transport life cycle at the second level of decomposition with the help of the process approach made it possible to compare the types of hazards to the stages of the life cycle.

Dangers in the main pipeline transport can originate at any stage of the life cycle. Among them the most important are designing and construction. The manifestation of hazards can occur at all stages of the life cycle with the exception of design. During the construction of the main pipeline, 4 types of hazards can occur, during operation – 7, during major repairs – 6, during reconstruction – 6, at liquidation – 5. Operation as the life cycle stage of the main pipeline transport is the most dangerous and responsible both in quantity of dangers and the scale of their manifestation.

Thus, from all stages of the life cycle operation requires the most thorough systematic assessment of hazards. Performing an assessment of the dangers must be carried out by focusing on the process approach because both quality assurance and loss of security are observed in the processes. The display of processes and the interrelationships between them in a graphic form facilitates the process of assessing hazards since such a graphical representation is concise, intuitive, well perceived and at the same time informative.

The proposed approach of mapping processes in graphic form is expedient for applying in the development of technical normative legal acts in the main pipeline transport. Currently the most of the technical regulatory legal acts are presented in text form. This is not always convenient for understanding because the text can poorly trace the sequence of processes and doesn't describe the inputs to processes and outputs from processes. Graphical display of processes with inputs, outputs, control actions will eliminate this disadvantage. Along with that this approach allows to take into account the maximum possible list of hazards arising in processes at various stages of the life cycle when developing technical regulatory legal acts. This feature is realized by decomposing the processes of the highest level to simple operations.

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