UDC 693.6.002.5
DOI: 10.15587/1729-4061.2016.80626

THE WORKING PRESSURE RESEARCH OF PISTON PUMP RN-3.8

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Досліджено вплив кута повороту кривошипа та рівня початкового тиску в комбінованому компенсаторі на величину тиску подачі розчинної суміші та пульсації її подачі протягом робочого циклу однопоршневого розчинонасоса. Розроблено конструкцію поршневого розчинонасоса, який забезпечить стабільний тиск подачі, помірний рівень пульсації під час перекачування. Подано рекомендації стосовно його налаштувань для високоефективної експлуатації у різних галузях промисловості

Ключові слова: ступінь пульсації тиску, комбінований компенсатор, тиск подачі, кривошип, такт нагнітання, такт всмоктування, стиснуте повітря, хід поршня

Исследовано влияние угла поворота кривошипа и величины начального давления в комбинированном компенсаторе на величину давления подачи растворной смеси и пульсации ее подачи на протяжении рабочего цикла однопоршневого растворонасоса. Разработана конструкция поршневого растворонасоса, который обеспечит стабильное давление подачи, умеренный уровень пульсации при перекачивании. Приведены рекомендации относительно его настроек для высокоэффективной эксплуатации в разных отраслях промышленности

Ключевые слова: степень пульсации давления, комбинированный компенсатор, давление подачи, кривошип, такт нагнетания, такт всасывания, сжатый воздух, ход поршня

1. Introduction

The mortar pumps were used for transportation of building mortar mixes directly to jobs in the initial phase of implementation. The surface treatments of buildings and structures were performed manually in the next step. The mortar solutions have been of large mobility at the same time. They were fed with significant pulsation (pressure fluctuations), which had no impact on the technology, because there was only filling in the working tanks. There is a gradual transition from manual application of mortar solutions on the buildings and structures working surfaces to mechanized. Labour productivity increased several times. The nozzles are used in mechanized application. They have mouth pieces that are located at the end of the pressure pipeline. Pulsation affects the quality of performed work. Its impact has become the dominant factor that hindered the development of treatment processes by a nozzle.

Methods of finishing external and internal surfaces of buildings and structures with panels of different materials are in widespread use nowadays. But the process of plastering is still relevant until now. It has a relatively low cost and satisfactory quality.

Also, the mortar pumps can be used for the feed and laying of cement-sand mixtures when performing a self-levelling floor screed, filling under pressure a hard mortar for joints and seams between concrete structures for grouting and also for pumping of whitewashing compounds with a large scope of work.

Piston pumps have found application not only in construction but also in mining, oil, gas, petrochemical and other industries where all the main processes are connected with pumping of sand-clay mortar, oil, petroleum products, liquefied gases, water, chemicals, construction-soluble compounds, etc. by pipelines [1–3]. They are simple and reliable.

The problem of ways searching to reduce the feed pulsation magnitude of mortar pumps is still relevant.

2. Literature review and problem statement

Piston pumps remain the most common currently. They have a direct impact of the working body (piston) on the working environment.

The authors [4] made a review of modern equipment designs. It is used for transportation and preparation of building mortars on the basis of pumping equipment of various designs. The piston pump is characterized by simplicity of design, ease of maintenance and repair even in field conditions.

The complex of requirements for mortar pumps design for the modern mechanized technology of surface plastering is noted in [5]. Properties of the pumped mortar have been summarized. Attention is paid to the issue of equipment reliability. The requirements were written for pumps modern designs generally. Their advantages and disadvantages are noted. The essence of the

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problem of the feed pressure pulsation is disclosed. One of the problems is its stability when piston pumps are used. But ways of its reduction or elimination are not proposed.

The author of the work [6] writes, that the mortar feed pressure pulsation in the pressure pipe is certainly a harmful factor. This factor degrades the technical-economic indicators of the work of the grouting pump by increasing resistance to movement of mixtures through pipelines, and increases back bounces off the surfaces that are processed if you perform nozzle processing. The registration method of indicators of mortar mixture pressure and displacement of the working mortar body on a PC at the same time has been described in the work. It will give the opportunity to compare the pressure recorded on different sections of the pressure line or pump chambers at a specific point in the operating cycle. Unfortunately, the specific ways of pulsation reducing are also not suggested.

The pumping workflows have been investigated in [7]. The authors suggested laboratory load test. It is designed to test pumps. Its advantages and disadvantages were described. The feed uniformity is one of important characteristics during the working cycle. The main theme of this publication is to study the issue of energy consumption, volumetric efficiency and reverse leakage of mortar mix through the valve nodes. The work has not paid enough attention to the problem of feed pulsation.

Study of pumping equipment progressive structure is given in [8]. Its effectiveness is proven. But the design complexity plays a main role during decision making about the use of equipment of this type in the field conditions.

Study of a new, progressive pump with elastic pipeline was performed in the publication [9]. The pump has no valves and seals. The design is complex. Its scope is severely limited.

The designs of one-piston mortar pump RN-3.8 with a combined pressure pulsations compensator are presented in [10]. It is a partial solution to the problem of ensuring feed stability. Piston pump RN-3.8 with a combined pressure pulsations compensator (Fig. 1) has undergone a long production test. It was used both separately and as part of the universal mobile mortar-mixer URZ-3.8 (Fig. 2, 3) [10].

Graphic dependence has been obtained during a series of theoretical and experimental studies. They show the influence of feed pressure of the sandy-clay solution on the degree of pressure pulsation of one-piston pump when pre-pressure of comressed air in a closed chamber 0.5; 0.7 and 1.0 MPa. They describe only its maximum deviation from the average [10] and don't allow seeing how pressure will change during the working cycle of one-piston pump.

So, the piston pumps are simple and reliable. The stable feed high-pressure of the pumped medium with a low level of pulsation is an actual problem.

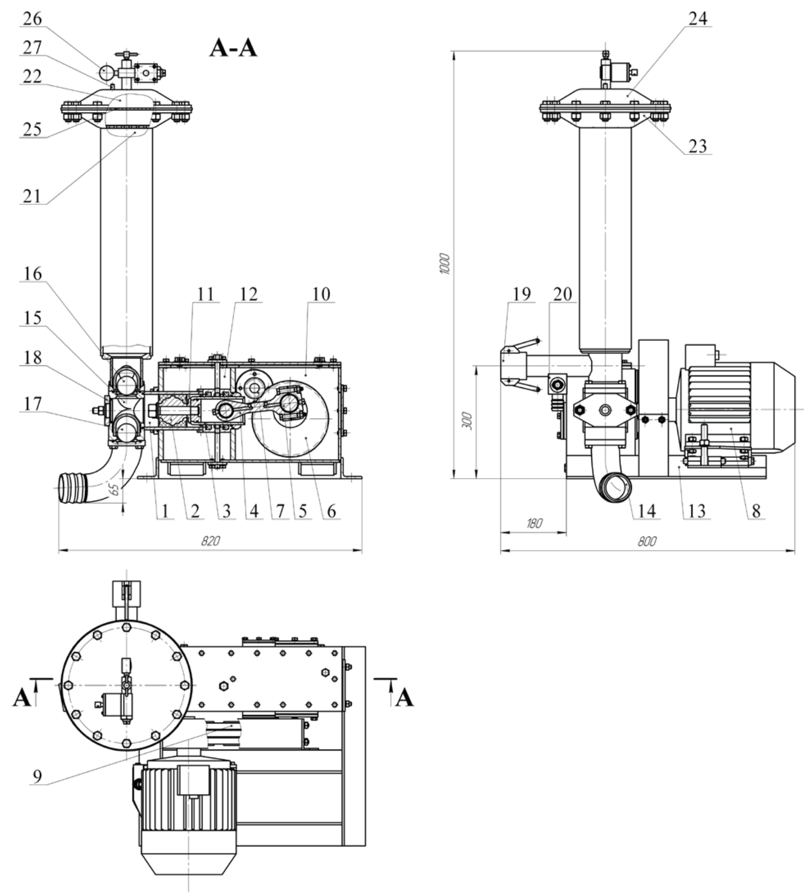

Fig. 1. One-piston pump with a combined pressure compensator type RN-3.8: 1 — slave cylinder; 2 — piston; 3 — slide; 4 — rod; 5 — crankshaft axis; 6 — gear; 7 — gear shaft; 8 — motor; 9 — belt drive; 10, 12 — locked chamber; 11 — rod cavity; 13 — frame; 14 — suction nozzle; 15 — working chamber; 16, 17 — ball valves; 18 — cover; 19 — discharge pipe; 20 — pressure reducing valve; 21, 22 — closed compensator chamber; 23, 24 — disc-shaped parts; 25 — rubber diaphragm; 26 — pressure gauge; 27 — nipple

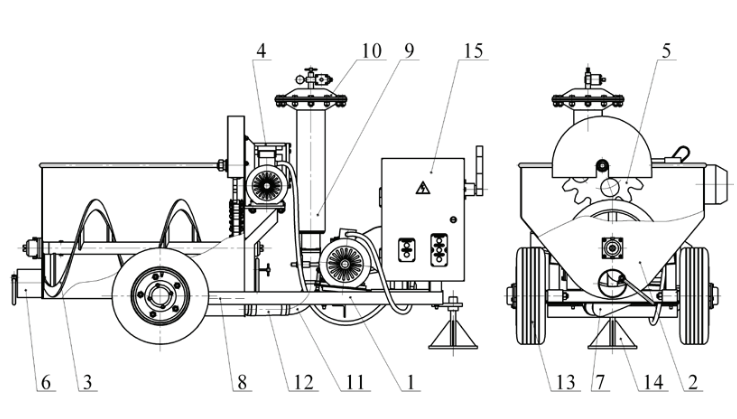

Fig. 2. Mortar mixer URZ-3.8: 1 — frame; 2 — case; 3 — mixer; 4 — worm gearbox; 5 — cycloid gear; 6 — shutter; 7 — feeder chamber; 8 — grille; 9 — mortar pump; 10 — combined pressure compensator; 11 — suction pipe; 12 — rubber sleeve; 13 — pneumatic tires; 14 — support; 15 — electrical cabinet

Fig. 3. Production testing of one-piston mortar pump RN-3.8 with universal mortar mixer URZ-3.8 (building site of company «Poltavtransbud»: Alexander Bedniy Street, 3a, Poltava, Ukraine)

3. Setting of the task

The goal of this work is to provide a stable high-pressure feed of the pumped medium (solution), with a reduced level of pulsation. This is to determine a minimum value of a given volume of air in the pump combined compensator.

The tasks were set to achieve the goal:

– the motion law of the piston (installed with an offset) for mortar pump with a combined compensator of pressure pulsations must be written;

– the compressed air volume change in the compensator while changing the crank rotation angle φ must be determined;

– the dependence of feed pulsation on the pressure initial value must be determined;

– on the basis of obtained theoretical dependences of the compressed air volume change in the compensator and the feed pressure depending on the angle φ of crank rotation to carry out the calculations for pump RN-3.8. The recommendations regarding the modes of its practical use on the base of calculations results must be given.

4. Materials and methods of the study of changes in pressure of solution feed

The calculations of changes in the solution feed pressure during the cycle with piston motion law and combined pressure pulsations compensator action need to be done (Fig. 1).

The piston pump is driven by the crank mechanism. In this mechanism, the axis of the crank shaft is offset downward relative to the piston axis, by the magnitude of e (Fig. 4). It is calculation condition.

The law of motion of the piston (point B) will be determined. First, let's write x and y coordinates of the point A when φ is an angle of rotation of the crank shaft:

$$\begin{cases} x_A = R\cdot(1-\cos\varphi), \\ y_A = R\cdot\sin\varphi. \end{cases} \quad (1)$$

Connecting rod AB will change the angle of its inclination to the horizontal when you rotate the crank. Its horizontal projection will be shorter than the length of the connecting rod by a certain value. It is equal to

$$l-\sqrt{l^2-(R\cdot\sin\varphi-e)^2}.$$

Then x-coordinate of the piston point B (coordinate measured from the position of the point B, φ=0) is equal to

$$x_B = R\cdot(1-\cos\varphi)-\left[l-\sqrt{l^2-(R\cdot\sin\varphi-e)^2}\right], \quad (2)$$

where R – crank radius; l – connecting rod length; e – displacement of crank axis by height relative to the piston axis.

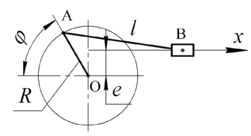

Fig. 4. Piston drive scheme: OA — crank, radius R; AB — connecting rod, length l; φ — angle of the crank rotation; B — piston; e — displacement of the piston axis

The piston stroke (point B, Fig. 4) will be (solution injection during the entire pump work cycle, φ=0...2π):

$$0\le\varphi\le\pi:$$
$$x_1 = R\cdot(1-\cos\varphi)-\left[l-\sqrt{l^2-(R\cdot\sin\varphi-e)^2}\right];$$
$$\pi\le\varphi\le 2\pi:$$
$$x_2 = 0, \quad (3)$$

one part of solution will be squeezed in the pipeline to the stroke of injection, another part will fill the compensator air chamber and reduce the volume of this chamber.

The pressure changes in injection strokes and intake strokes occur in the same range. The jet of solution during pump operation with a pressure combined compensator is almost uniform at the exit of the injection pipeline. We accept the following. The feed of mortar does not change during the cycle. Then, the volume change of compressed air in the compensator will be when changing the angle φ:

$$0\le\varphi\le\pi:$$
$$\Delta V_1 = F_p\cdot\left(x_1-\frac{h_p}{2\pi}\cdot\varphi\right);$$
$$\pi\le\varphi\le 2\pi:$$
$$\Delta V_2 = F_p\cdot\left[\left(x_\pi-\frac{h_p}{2}\right)-\frac{h_p}{2\pi}(\varphi-\pi)\right], \quad (4)$$

ΔV_1 – volume change of compressed air in the compensator during the piston injection stroke relative to the volume of compressed air, φ=0...π; ΔV_2 – the same in the intake stroke of the piston, φ=0...2π; F_p – piston area, $F_p=\frac{\pi D_p^2}{4}$, D_p – piston diameter; x_1 – law of piston motion, determined by the equation (3), in the stroke of injection (φ=0...π) depending on the angle φ; h_p – full piston stroke, $h_p = x_1^{max} - x_1$, determined by the equation (3), this value will be slightly different from 2R due to the crank shaft axis displacement relative to the piston axis; x_π – x_1 value when φ=π.

According to the Boyle-Marriott law,

$$V_\varphi = \frac{V_g}{10 p_\varphi}. \tag{5}$$

Where we have

$$p_\varphi = 0{,}1\frac{V_g}{V_\varphi}, \tag{6}$$

where V_φ – current volume of compressed air in the compensator at an angle φ; V_g – given to normal conditions (p=0.1 MPa) volume of air in the compensator; p_φ – compressed air pressure (and solution) at an angle φ, MPa.

As you know, $V_\varphi=V_0-\Delta V$. So, according to the equation (4), we have:

$$0 \le \varphi \le \pi:$$
$$p_{\varphi_1} = \frac{0.1\cdot V_g}{V_0 - F_p\cdot\left(E_1 - \frac{h_p}{2\pi}\cdot\varphi\right)};$$
$$\pi \le \varphi \le 2\pi:$$
$$p_{\varphi_2} = \frac{0.1\cdot V_g}{V_0 - F_p\cdot\left[\left(E_\pi - \frac{h_p}{2}\right) - \frac{h_p}{2\pi}\cdot(\varphi-\pi)\right]}, \tag{7}$$

where V_0 – volume of compressed air in the compensator if

$$\varphi = 0,\ \ V_0 = V_g / (10\cdot p_0),$$

where p_0 – compressed air pressure at the beginning of the pump cycle, MPa; x_1 – piston stroke in the stroke of injection, determined by the equation (3).

After inserting x_1 value according to the equation (3):

$$0 \le \varphi \le \pi:$$
$$p_{\varphi_1} = \frac{0.1\cdot V_g}{V_0 - F_p\cdot\left(R\cdot(1-\cos\varphi) - \left[l - \sqrt{l^2 - (R\cdot\sin\varphi - e)^2}\right] - \frac{h_p}{2\pi}\cdot\varphi\right)},$$
$$\pi \le \varphi \le 2\pi:$$
$$p_{\varphi_2} = \frac{0.1\cdot V_g}{V_0 - F_p\cdot\left[\left(E_\pi - \frac{h_p}{2}\right) - \frac{h_p}{2\pi}\cdot(\varphi-\pi)\right]}. \tag{8}$$

So, the dependence is obtained. It will determine the pump working pressure during the operating cycle (stroke of injection, intake stroke).

5. The results of studies of changes in pressure of solution feed

The change in pressure of the solution feed can be determined by the equations (8) during the pump operation cycle. The R, l, e, F_p, V_g, p_0 parameters are known.

The pump (Fig. 1) has the following design parameters: crank radius R=0.04 m; length of connecting rod l=5R=0.2 m; offset value e=0.5R=0.02 m; piston area (it has a diameter of 0.09 m) $F_p=(\pi\cdot 0.092)/4=0.006$ m²; given air volume in both chambers of combined pressure compensator

$$V_g = V_f + V_c \cdot p_c = 0.026\ \text{m}^3,$$

where V_f – free air volume in the first compensator chamber, V_f=0.005 м³; V_c – closed chamber volume filled with compressed air, V_c=0.003 м³; p_c – air pressure in a closed chamber before the pump operation. It is taken for calculations p_c=0.7 MPa.

The volume of solution and compressed air will vary in combined compensator chambers during the pump full cycle. Consider this.

This process is shown in Fig. 5 clearly.

Curve 1 shows feed of solution in the first compensator chamber from the piston in the stroke of injection. This feed is determined by the equation $F_p\cdot x_1$.

The second curve characterizes the change of solution volume in the first chamber from the solution feed in the injection pipeline. It is determined by the equation

$$q = \frac{V_{r.w.}}{2\pi}\cdot\varphi, \tag{9}$$

where $V_{r.w.}$ – real working piston volume.

The third curve shows the real change of the solution volume. The change occurs in the compensator chamber during the pump operation cycle. It causes changes in the compressed air pressure and the solution feed pressure in the compensator.

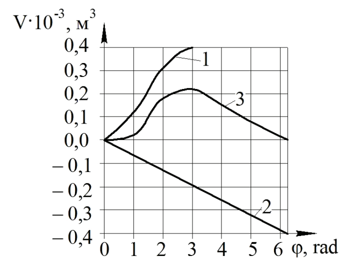

Fig. 5. Changing of solution volume in compensator: 1 — piston movement; 2 — feed in pipeline; 3 — valid change

Fig. 6 shows graphs of pressure of the solution, which is pumped. It takes place during the full operation cycle. Graphics were obtained with PC help. Also, the equations (8) are used. Initial pressure p_0=1; 2; 3 and 4 MPa. Numerical values of these calculations are presented in the table 1.

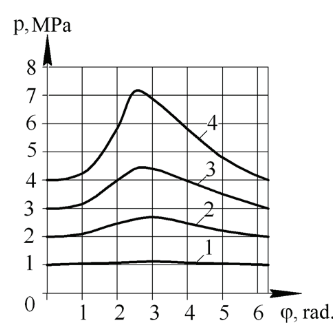

Fig. 6. Dependence of solution pressure (solution is pumped) on the angle of shaft crank rotation: 1 — p_0=1 MPa; 2 — p_0=2 MPa; 3 — p_0=3 MPa; 4 — p_0=4 MPa

Fig. 7 shows variation graphs of air pressure in the compensator during the cycle. It depends on the total given volume of air contained in the combined compensator. These graphs are constructed by the equation (8) for given total air volume V_g=0.01; 0.02; 0.03 м^3 at an initial pressure p_0=2 MPa. This initial pressure level was chosen due to the fact that the feed pressure of 2.0...2.5 MPa is the most common.

Table 1

Dependence of pump feed pulsation on the initial pressure level

p_0, MPa	p_{max}, MPa	Δp, MPa	p_{av}, MPa	ε, %
1.0	1.145	0.145	1.073	13.5
2.0	2.600	0.600	2.300	26.0
3.0	4.500	1.500	3.750	40.0
4.0	7.200	3.200	5.600	57.0

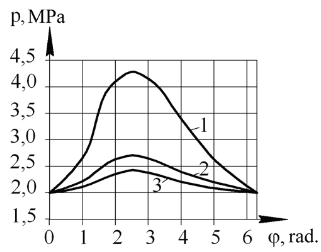

Fig. 7. Dependence of feed pressure during the cycle on the total given volume of air: 1 — 0.01 m^3; 2 — 0.02 m^3; 3 — 0.03 m^3

So, specific values of pressure and feed pulsations were obtained during the working cycle of the piston pump RN-3.8 with combined compensator. The real pump design parameters and the above-obtained theoretical dependence were taken.

6. Discussion of results of researches of change of pressure of the solution feed

The benefits of research are to monitor pressure changes of the combined compensator and pressure during the working cycle of one-piston mortar pump.

The air pressure (and solution) in the compensator starts to grow during the stroke of injection (φ=0...π). It reaches the maximum level even for some time before the end of the stroke of injection. The pressure then begins to decline.

The air pressure in the compensator only gradually decreases during the intake stroke (φ=π...2π). The degree of pressure increase in the stroke of injection depends on the level of initial pressure. So, at the initial pressure of 1 MPa pressure pulsation is 13.5 %, but if p_0=2 MPa is already 26 %, i. e. almost twice as much.

The shift of maximum in the curves of pressure change to the left of the angle φ=π is explained as follows. The piston speed is reduced substantially in the stroke of injection at the end of its stroke. It does not provide the level of average feed per cycle after some time. The solution feed in the injection pipeline is not only due to injection from the piston, starting now. The compressed air in the compensator expands and is affected also. This leads to a reduction of air pressure. The same phenomenon is observed in the initial moment of the stroke of injection, when the piston stroke speed is low and it does not provide the desired level of the solution feed. The areas of some reductions in pressures appear on the curves of pressure change in the initial period of the stroke of injection in this regard. They are especially noticeable on curves with a high initial pressure (p_0=3...4 MPa).

The researches are especial. The calculations are not only theoretical but have practical implementation. They complete the studies cycle of one-piston mortar pump RN-3.8 with the combined compensator. It has a stable performance. The results can be used to develop a parametric series of similar pumps.

7. Summary

1. Functional dependence in the form of a trigonometric equation is obtained. It describes the law of pump piston motion according to constructional features of the drive link and crank rotation angle depending on the operation stroke of one-piston mortar pump.

2. The given air volume in the compensator should be less than 0.02 m^3. This will provide a moderate level of solution feed pulsation.

3. The feed pulsation depends on the pressure initial level in the compensator. It can range from 13.5 % to 57 % at p_0 from 1 to 4 MPa, respectively.

4. The design of the mortar pump RN-3.8 was proposed according to studies results with the following design parameters: crank radius R=0.04 m; connecting rod length l=0.2 m; offset amount e=0.02 m; piston diameter 0.09 m; given air volume in both chambers of combined compensator 0.026 m^3.

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UDC 004.09
DOI: 10.15587/1729-4061.2016.76928

DEVELOPMENT OF THE SYSTEM ARCHITECTURE FOR DESIGN WORKS AUTOMATION

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Представлено опис компонентів інформаційної системи для автоматизації застосування елементів САПР. Проведено системний аналіз процесу проектування як предмету автоматизації. Визначено необхідні інформаційні потоки для організації процесу проектування технічних об'єктів. Наведено діаграми взаємодії проектантів із системою проектування та елементів самої системи між собою у процесі виконання проектних робіт. Запропоновано концептуальний устрій системи для комп'ютеризації процесів проектування та управління ними

Ключові слова: система автоматизації проектних робіт, інформаційна модель, архітектура системи

Представлено описание компонентов информационной системы для автоматизации применения элементов САПР. Проведен системный анализ процесса проектирования как предмета автоматизации. Определены необходимые информационные потоки для организации процесса проектирования технических объектов. Приведены диаграммы взаимодействия проектировщиков с системой проектирования и элементов самой системы между собой в процессе выполнения проектных работ. Предложено концептуальное устройство системы для компьютеризации процессов проектирования и управления ими

Ключевые слова: система автоматизации проектных работ, информационная модель, архитектура системы

1. Introduction

Today design automation of technical objects is an important factor for the increase of the designers' labor productivity. However, it isn't developed enough. Nowadays achievements in this area are rather insignificant in comparison with achievements in mechanical engineering in general. In the work [1] Petrenko observed that in the twentieth century the labor productivity in mechanical engineering increased much more, than the labor productivity of developers, who designed new equipment.

It is noted that complexity and volumes of projects tend to double every 10 years. Developers use rather old and well-known design methods for the automation of only separate design operations, which doesn't significantly contribute to the increase of their labor productivity. The latter depends on the use of traditional design methods, which aren't optimized, and the job management, which isn't controlled enough and doesn't provide the optimization of non-manufacturing actions. All these are reasons of the designers' lagging behind the general increase of the industrial manufacturing.

Therefore, there is an urgent need to solve this complex problem and to develop the full-function system for design works automation. Further, under the system for design works automation (CAD system) we will consider the set of programming and information means, which help to exclude the expert from a contour of the design process management. According to requirements of an integrated approach, not only separate components of the system, but also their interaction have to be the subject of improvement. Based on this provision it is necessary to automate the whole design process from the development of Terms of Reference to the formation of the completed project and its transferring to the client, but not only separate design operations, as it takes place nowadays. Such full-function CAD system would provide both the design automation of technical objects and the job management of the whole design process. In consequence, it will increase the designers' labor productivity. This determines the topicality of the CAD system development for the management of the performance of all kinds of works at design organizations and design subdivisions of industrial enterprises.

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